Deep Space Network to Viking Orbiter Telecommunications Performance During the Viking Extended Mission, November 1976 Through February 1978

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This article discusses the telecommunications performance during the Viking extended mission, starting with the completion of the first superior conjunction in November 1976 and ending with the jettison of the VO-2 aft bioshield early in March 1978. Continued Viking operations are planned through February 1979, concluding with the second superior conjunction. Included in this article are Viking Orbiter activities and problems, the ground system activities and problems, radio science activities, and communication link performance. The substantial involvement of the Deep Space Network and the coordination of their telecommunications planners with Viking Project telecommunications analysts in the planning and execution of complex Viking Orbiter sequences are discussed.

I. Introduction

Viking 1 was launched on Aug. 20, 1975; Viking 2 on Sept. 9, 1975. The Mars Orbit Insertions were on June 19, 1976 for VO-1 and on Aug. 7, 1976 for VO-2. Lander 1 touchdown on Mars was July 20, 1976, and Lander 2 touchdown was September 3, 1976. The end of the primary mission was defined as Nov. 15, 1976, ten days before the first Viking superior conjunction. Viking activities involving the Deep Space Network, starting with prelaunch compatibility testing and mission and operations planning and ending with the primary mission, are discussed in the three volumes of Ref. 2. The superior conjunction telecommunication link effects are discussed in Ref. 1. Deep Space Network and Orbiter telecommunications configuration and parameters are contained in Ref. 3.

This article begins with a description of a number of Viking Orbiter extended mission activities in which the telecommunications links were heavily involved. Following that is a section describing various problems, failures, and anomalies in the Orbiters that affected the links or in which the links were used to resolve the problems. Ground system activities and ground system problems comprise the next sections, following which a number of representative radio science experiments are discussed from a communication link viewpoint. The article ends with a quantitative and graphical evaluation of S-band and X-band Orbiter-Deep Space Network link performance.

II. Viking Orbiter Spacecraft Activities

A. Viking Orbiter High-Gain Antenna Calibrations

Four times during 1977 high-gain antenna calibration sequences were programmed into the Orbiter on-board computer. The sequences each caused the high-gain antenna to execute a series of steps in azimuth and elevation, tracing a square approximately 1 deg on each side. A 64-m station was allocated to track the X-band downlink and to send the resulting signal level data to the Mission Test Computer in the MCCC. The X-band signal level data was used, together with the telemetered azimuth and elevation position data, to ascertain the actual pointing of the Orbiter antenna relative to the predicted directions. Orbiter attitude control limit cycle motion, also telemetered, was removed from the data.

The four extended-mission calibrations include:

Date, 1977	VO	Reference star	Station
May 23	2	Jupiter	DSS 43
July 15	1	Procyon	DSS 43
September 30	1	Alkaid	DSS 63
December 2	2	Arcturus	DSS 14

Generally a high-gain antenna calibration was requested for each new attitude control system reference star used, as the antenna operated in a different portion of the azimuth/elevation angle range for each star.

The Deep Space Station activity was similar for each calibration. The X-band CONSCAN was used prior to the first calibration point and following the last calibration point. CONSCAN was otherwise turned off during the sequence to minimize signal level variations, except for a 4-min period during the fifth of the 10 points. The high-gain antenna remained at each point for 10 min, approximately, to permit an adequately long sample of X-band signal level points. Generally the station antenna control was very good, with the antenna computer controlled. For example, during the May 23 DSS 43 sequence, the X-band signal level showed less than a 0.3 dB change when CONSCAN was turned on during the fifth point. These calibrations are made with the station receiver AGC bandwidth set at medium to assure that the station receiver will not go out of lock when the Orbiter antenna changes position. Signal level changes of as much as 7 dB occur from one position to the next.

The Sept. 30 sequence was the first one in which a portion of the sequence was tracked simultaneously by DSS 63 and DSS 43. In this way, a comparison could be made of the X-band signal level variations attributable to station effects only. The results of this comparison appear in Fig. 1. That figure shows that the absolute level of the received signals varied, with DSS 14 being 2.5 dB higher than DSS 63 at any given time. This is attributed to calibration differences. The DSS 63 CONSCAN caused approximately 0.5-dB peak-to-peak variations in the signal while it was on.

B. Mars Orbit Trims (MOT)

The Mars Orbit Trims accomplished during the extended mission are summarized in the next several paragraphs.

1. **January 20, 1977: VO-1 MOT-10, DSS 63.** The Orbiter high-gain antenna was used in the flipped position to enable reception of 2-kbps high-rate telemetry data during the motor burn. A GO command for motor burn was transmitted by DSS 63.

2. **February 4, 1977: VO-1 MOT-11, DSS 42.** This maneuver also required a GO command, which was transmitted from DSS 42. Unlike MOT-10, however, no downlink signal could be received during the portion of the maneuver when the Orbiter low-gain antenna was in use and the Orbiter yawed away from the Earth to motor burn attitude.

3. **February 11, 1977: VO-1 MOT-12, DSS 42 and DSS 43.** This sunline maneuver was the third in the triad of maneuvers to obtain a close flyby of the Martian moon Phobos. DSS 42 had the uplink and DSS 43 received the downlink from VO-1.

4. **March 2, 1977: VO-2 MOT-9, DSS 14 and DSS 42.** MOT-9 occurred near the VO-2 orbit periapsis, when tracking doppler rates were high. DSS 14 lost downlink receiver lock upon selection of the Orbiter low-gain antenna, as a result of the 20-dB decrease in signal level. It was later determined that the DSS 42 uplink tuning following earth occultation increased the already high doppler rate present on the downlink, further hampering the attempts of DSS 14 to reacquire. DSS 14 was also busy with direct links from the Viking Lander.

5. **March 11, 1977: VO-1 MOT-13, DSS 63, DSS 14.** The maneuver went well. DSS 63 and DSS 14 performed all actions involving their transmitters and command modulation exactly per plan, and all expected uplink capability was available. Downlink data was also received as expected, with the minor exception that DSS 63 had had a failure of their primary S-band maser and had to use the backup maser. The 2-kbps engineering data was well above threshold for the motor burn, and good S-band and X-band doppler.

6. **March 24, 1977: VO-1 MOT-14, DSS 42.** With a roll and yaw turn before motor burn, and no plans to select the Orbiter high-gain antenna, DSS 42 had no chance to receive downlink data at motor burn. The maneuver was therefore planned to occur "in the blind," but with the telemetry data to be played back about ten hours later over DSS 63. All went according to plan.

7. **April 18, 1977: VO-2 MOT-10, DSS 43.** As with MOT-9, there was also an Earth occultation during MOT-10, further complicating the sequence. No uplink station would be available for MOT-10, as DSS 43 uplink was devoted to VO-1 for orbit determination. For MOT-10, the Project requested the

use of an X-band downlink receiver to confirm proper high-gain antenna pointing and thus correct attitude at motor burn. In addition, plans were made for possible use of the DSS 43 uplink for VO-2 if problems should occur during the maneuver sequence. The careful planning and coordination paid off: the switching of Receiver No. 4 back and forth between VO-1 and VO-2 allowed both observation of the VO-2 motor burn and a nearly continuous tracking of VO-1 doppler for orbit determination.

8. May 15, 1977, VO-1 MOT-15, DSS 43. The Project navigation team checked the orbit determination solutions carefully for the May 27 near encounter with Phobos. The orbit of Phobos had been determined with considerable precision from Mariner '71 photographs and more recent Viking Orbiter photos. However, the VO-1 periapsis was occurring over the Tharsis region of Mars, which is one of the major regions of gravity anomaly on Mars. The orbit of the Orbiter was affected each time it passed over the region; it was difficult to project distantly into the future the exact orbit. At the time the planning for a possible maneuver would have to begin the expected miss distance to Phobos was less than 12 km. This maneuver absolutely eliminated any possibility of collision with Phobos, yet left the orbit close enough to Phobos for the desired high-resolution photography.

9. July 1, 1977, VO-1 MOT-16, DSS 14 and DSS 43. Following the successful Phobos flybys, the Viking Project wished to place VO-1 into a 24-h orbit for radio science activities, with the periapsis centered over the DSS 14 and DSS 43 view period overlap. A motor burn of just 3 s would accomplish this, following a roll-yaw-roll turn set. The Earth occultation occurred just after the motor burn, with downlink data being lost until the end of the occultation just before the end of the yaw unwind. DSS 43 acquired the uplink at motor burn attitude, During the maneuver, DSS 43 was not able to lock up promptly on the 2-kbps data prior to the turns. The problem was caused by difficulty with the ground antenna polarizer, and they were unable to switch from linear polarization (used for the previous spacecraft track) to circular polarization (for Viking).

10. September 26, 1977, VO-2 MOT-11, DSS 63. MOT-11 was the first of three VO-2 maneuvers which together (a) phased the VO-2 orbit for a near-Deimos encounter to occur on October 15; (b) lowered the periapsis altitude to 300 km; and (c) changed the orbit period to 24 h. In a sense, these maneuvers were parallel in purpose to MOT-10, -11, and -12 for VO-1. DSS 63 was the uplink and downlink station for VO-2 MOT-11. However, DSS 63 inexplicably failed to lock the downlink receiver to the S-band signal after the yaw turn. Worse, the station still could not lock the S-band downlink during the subsequent 16-min period when the Orbiter was on the high-gain antenna. DSS 63 was unable to lock the X-band receiver during motor burn also, probably because their major concentration was on the S-band problem. The maneuver telemetry data was played back later, and this showed that uplink lock was maintained throughout the maneuver, and uplink events were executed properly. An investigation into the S-band problem showed that had the station used the automatic Block IV receiver sweep system, downlink lock probably could have been achieved. The navigation team report was that the accuracy of MOT-11 was excellent, with a resulting orbit period just 5 s longer than planned, and a periapsis altitude just 0.1 km different from that planned.

11. October 9, 1977, VO-2 MOT-12, DSS-14. MOT-12 was planned to occur far from periapsis, so the doppler rate should not be a problem. Downlink data during the motor burn period was essential, because a NO GO command would be transmitted if the spacecraft performance was not normal. The Viking Project Manager briefed the DSS 14 crew who would be participating in this maneuver as to the purpose and the importance of the maneuver. Proper execution would result in a near-approach to Deimos on October 15. The advance planning and coordination again paid off. All uplink and all downlink activities were accomplished properly and on time. The trajectory following the maneuver was nearly as planned, with a predicted mean miss distance to Deimos of about 24 km. A contingency Deimos avoidance maneuver which would have occurred on October 14 was not needed.

12. October 23, 1977, VO-2 MOT-13, DSS 14 and DSS 43. MOT-13 was the last propulsive maneuver to be done on either Viking Orbiter. The 13-2/3 s motor burn caused a change in doppler frequency of 150 Hz, as had been predicted. This maneuver was particularly critical in that a severe overburn would have caused the Orbiter to impact Mars. DSS 14 transmitted a GO command when the Project analysts had determined that all subsystems were operating normally. The maneuver lowered the orbit periapsis to 300 km.

Figure 2 is a plot showing how the uplink and downlink signal quantities for VO-2 MOT-13 change during a typical maneuver. The five link quantities are plotted on a common time base. They are: uplink signal level, S-band downlink level, X-band downlink level, low-rate channel signal-to-noise ratio, and high-rate channel signal-to-noise ratio. The signal levels are in decibels below 1 mW (dBm); the signal-to-noise ratios are in decibels. Six key events are noted on the plot; these are (1) roll turn start, when the Orbiter is already on the low-gain antenna; (2) yaw turn start, when the signal levels decrease as the Orbiter low-gain antenna boresight moves farther from Earth; (3) yaw turn end, and the selection of the high-gain antenna, when a 20-dB increase occurs in the S-band signal levels and the X-band signal can be received; (4) yaw unwind start after motor burn, when the low-gain antenna is again selected, and the X-band signal disappears as the high-gain antenna boresight moves from Earth; (5) yaw unwind end, when the S-band levels are again at the same value as they were at the yaw turn start; (6) roll unwind end, which is the end of the maneuver sequence, and the high-gain antenna is again selected.

C. VO-2 Aft-Bioshield Jettison

The VO-1 aft-bioshield was separated shortly after Lander separation in 1976. The shock impact on the VO-1 radio subsystem was a momentary change in the uplink signal level, indicating a momentary out-of-lock even with an uplink present. Also, a transient occurred in the traveling wave tube helix current, which required a half hour to recover. Because of these effects, and a failure in a gyro power supply on VO-2 at Lander separation, the VO-2 aft bioshield was not separated during the Viking primary mission.

The decision was made to separate the bioshield on March 3, 1978. DSS 63 was the primary tracking station, but with DSS 61 also assigned as a backup if needed for the GO command for the sequence. The data was returned in real-time, using the 2-kbps high-rate channel, and the data was also recorded for later playback. The separation sequence went entirely without problems. The first indication of a successful separation was an abrupt change in the spacecraft two-way doppler from DSS 63. Prior to the separation, the X-band signal level had been steady at −141.4 dBm at DSS 63; the first sample after separation was at a value 7.5 dB lower, indicative that the X-band boresight had moved about 1.2 deg from Earth. Pointing was restored by the attitude control system within 45 s of separation, as indicated by restoration of the X-band signal level to its previous value.

The VO-2 aft bioshield separation is the last major spacecraft event planned on either Orbiter. With the bioshield off, the Orbiter will use slightly less gas in maintenance of its normal attitude and in maneuvers; also the science instruments will enjoy a greater field of view.

D. Viking Extended Mission and Viking Continuation Missions

The operations associated with the extended mission are planned to end June 1, 1978; the continuation mission will commence then and continue until Feb. 28, 1978. This latter date will allow observation of the second Viking Superior Conjunction, which is of great interest to the radio science experiment.

The extended and continuation missions required a strict limit on Orbiter attitude-control gas usage per week, in order to stretch the supply to the end of the continuation mission. Both Orbiters were in 24-h orbits, and both Orbiters had periapsis altitudes of 300 km by the end of 1977.

The number of Deep Space Network station passes was reduced somewhat during the extended mission and was planned to be reduced further for the continuation mission. One 64-m station pass per day and twelve 26-m passes per week for metric tracking would be provided. Large amounts of science playback, particularly the visual imaging subsystem (television) data at 16 kbps was accomplished late in 1977 and early in 1978 when communication distances were smaller, thus partially compensating for the reduced station allocation. In the continuation mission, communication ranges will again become large as during the primary mission, the 16-kbps rate will not be possible, and the television data will be limited to 15 frames per orbit.

E. Orbiter Equipment Operating Times and Operating Cycles

As of March 3, 1978, all Orbiter radio equipment is in fine working condition, and none of the redundant subsystem elements have had to be used. The radio equipment includes redundant receivers, exciters, traveling wave tubes, telemetry modulation units and command detectors.

Through March 3, 1978, the telecommunications subsystems had accumulated the following number of hours of operation:

Subsystem	VO-1 hours	VO-2 hours
X-band transmitter	20,000	20,000
Relay radio and telemetry	13,500	12,500
Radio frequency subsystem	22,000	22,000

As of March 3, 1978, there have been 927 days since the launch of VO-1 and 907 days since the launch of VO-2.

III. Viking Orbiter Telecommunication-Related Problems

A. Ranging Modulation Interference to One-Way Orbiter

This effect is caused by uplink ranging modulation intended for one of the two Viking Orbiters reaching the receiver of the second Orbiter. It is, of course, only possible when both Orbiters are within the beamwidth of the Deep Space Station transmitting antenna, as was the case throughout the extended mission with both Orbiters in orbit around Mars. The relative channel spacings and power levels for the DSN-Orbiter link also caused the effect to be present only when the interfered-with Orbiter was one-way, when the relative doppler offset between the two Orbiters corresponded to a sufficiently strong ranging sideband, and when the particular ranging sequence being transmitted produced a sufficiently strong sideband. Since all of these factors had to be present at the same time, ranging modulation interference was a relatively rare occurrence, happening perhaps a dozen or so times during 1977, each time the interference causing one or several momentary disruptions in tracking each lasting less than one minute. The stronger the uplink, the more probable the occurrence. Therefore, ranging interference occurred only when a 64-m station was transmitting the ranging modulation, and it happened more frequently as the Earth-Mars communications range decreased during 1977. A reduction in station transmitter power or in ranging modulation index could often eliminate the interference on a given occasion. To put things into perspective, VO-1 is on channel 9, with an uplink carrier frequency of 2111.6 MHz; VO-2 is on channel 20, with a frequency of 2115.4 MHz.

The first instance of ranging interference during the extended mission occurred on December 9, 1976. DSS 43 was two-way with VO-1 at a transmitter power of 50 kW. When ranging acquisitions occurred, each acquisition caused the VO-2 downlink to switch from the auxiliary oscillator frequency source to the voltage-controlled oscillator source, as the VO-2 radio was "fooled" into going two-way momentarily and then dropping back to the normal one-way mode. These transitions in downlink frequency then caused the DSS-43 downlink receivers to drop lock momentarily. Later in December, this problem also occurred over DSS 14 and DSS 63 but seemed associated only with the use of the high-power transmitters. Once, during a DSS 43 ranging pass, dropping the transmitter power from 50 to 25 kW stopped the effect.

On Jan. 18, 1977, when VO-1 was one-way, and DSS 43 was ranging with VO-2, the VO-1 downlink glitched a total of eight times over about a half-hour interval. The ranging was a special test for the benefit of the Voyager spacecraft, and the interference stopped when DSS 43 handed over to the 26-m DSS 42 for another portion of the test. All VO-1 radio subsystem telemetry parameters were normal.

Figure 3 shows that both S-band downlink receivers tracking VO-1 at DSS 63 suffered short out-of-locks at the same time, as denoted by the vertical glitches occurring during the relatively stable downlink signal level plot. These downlink receiver out-of-locks, in turn, caused equipment downstream of the receivers also to go out of lock, resulting in disturbances in the signal-to-noise ratio of both the 33-1/3 bps low-rate and the 16 kbps high-rate data. In one case, an outage of low-rate engineering data caused a bit error on the telemetered uplink signal level, shown as the vertical spike in the top plot.

B. Loss of Orbiter Roll-Reference

When the Orbiter attitude-control system roll-reference is lost, the spacecraft enters a safing routine which, among other things, switches the telecommunications links from the high-gain antenna to the low-gain antenna. The tracking station, of course, observes the unplanned decrease in downlink received signal level which is about 20 dB in magnitude. In addition, if the Orbiter is in a dual-subcarrier mode, the high-rate and low-rate telemetry channels most likely will be below their thresholds when the switch to the low-gain antenna occurs.

As part of the process of restoring the Orbiter to normal operation, it is very important to determine the amount that it has rolled from the reference star. During some roll-reference losses in December 1976 and January 1977, the X-band telecommunication link was used for this purpose. The beamwidth of the Orbiter's high-gain antenna is such that the X-band level is down 10 dB at a distance of 1.3 deg from the boresight. Therefore, the X-band level received at a tracking station can be a valuable indicator of the pointing error.

C. VO-1 Uplink Signal Level Anomaly

Shortly after the August 20, 1975 launch of Viking Orbiter 1, the telemetered uplink received signal level was as much as 3.5 dB lower than predicted by the Project. The difference between the observed value and the predicted value is called a residual. The uplink signal level anomaly has continued since launch, varying in size from time to time. Figure 4 is an overview of the variation in the residual. The discrepancy between observed and predicted values decreased within about a month after launch as the Orbiter low-gain antenna operated at smaller and smaller Earth cone angles. Thus, it seems that a part of the discrepancy was due to low-gain antenna pattern uncertainties at large angles from boresight. When the switch to Orbiter high-gain antenna occurred about 100 days after launch, there was no noticeable change in the residual, suggesting that our knowledge of the gain of both the low-gain and the high-gain antenna was good and that any hardware cause of the discrepancy did not lie in the antennas or their separate cabling.

To isolate the cause of the VO-1 uplink variations, a number of special tests involving the Deep Space Network were scheduled. These include (a) a Radio Frequency Subsystem (RFS) Threshold Test, (b) several Command Detector Unit (CDU) Signal-to-Noise Ratio Estimator (SNORE) tests, and (c) a series of routine CDU SNORE "checks." These will be discussed subsequently.

1. VO-1 RFS threshold test. The test was accomplished on Aug. 3, 1977, over DSS 14 for the downlink and DSS 12 for the uplink. The test was preceded by a Project and Deep Space Network coordination meeting, at which the sequence of events for the test was made final. It was later sent to the stations involved for their information. The test was planned such that the received carrier power at the Orbiter would be decreased in 1-dB steps, by use of increasing amounts of ranging modulation carrier suppression from the DSS 12 Planetary Ranging Assembly. Three separate runs were included in the overall sequence. The one successful run of this test proved that there has been little, if any, shift in the radio's threshold during flight; neither has there been a change in the threshold of the command detector unit. However, the threshold test is not a sensitive indicator of normal operating range measurements, which are at levels of 20 to 50 dB higher than "threshold" for Viking. The difficulties in executing this test, given the planning and coordination that went before it, make it difficult to see how "valid" RFS threshold tests can be made in-flight without using special Deep Space Station configurations which make correlation with the normal station configurations difficult.

2. VO-1 CDU SNORE tests. The first formal command detector unit signal-to-noise ratio estimator (CDU SNORE) tests were approved for VO-1 for September 15 and for VO-2 for September 16, both over DSS-61. After these tests were completed, it did not seem that the settability or accuracy of carrier suppression with the station's auxiliary modulation source could be made good enough for the very precise results needed.

The CDU SNORE results for both Orbiters suggest residuals in the −2 dB range, compared with predictions made on the basis of prelaunch tests.

3. CDU SNORE "checks." The checks are accomplished by the uplink station leaving the command system in the IDLE 2 state for one hour following normal Orbiter command loads, with the transmitter power reduced to a predetermined level of less than 1 kW. The checks were instituted about Aug. 1, 1977, because it was desired to have a continuing check on the performance of the Orbiter command systems. Throughout the period the CDU SNORE checks were conducted routinely, a considerable amount of scatter appeared from test to test for no known cause. Observation of the uplink signal level change from 20 kW down to the power level for the test suggests that the stations cannot set a desired 500 or 100 W level accurately, at least without a calibration.

D. Attitude Control Gas Leaks

Both VO-1 and VO-2 have had "gas leaks" involving the dry nitrogen attitude-control gas. Once stopped, the leaks were further controlled by switching to the alternate half-gas system on each Orbiter, involving a different set of valves. More recently, VO-2 had a major gas leak, at rates of up to 6.7 kg (1.5 lb) of gas per day. This leak was eventually controlled but no redundant half-gas systems remained. Careful management of the amount of gas intentionally used for normal operation and science experiments is necessary during the extended and continuation missions.

The Viking Project declared a spacecraft emergency on November 1, 1977 in order to obtain use of DSS 62. A gas jet leak had been detected on VO-2, in the yaw axis, and the station was needed in order for the Project to watch the Orbiter's behavior closely and to send commands to characterize the leak and possibly to eliminate it. The leak rate was low, but variable. Commands were transmitted to perform 0.72-deg yaw turns to clear the leak in the valve. With this satisfactorily accomplished, the reaction control assembly No. 2 was turned OFF.

A small gas leak occurred in VO-1, roll axis, on Nov. 18. Voyager Project was willing to release DSS 62 without Viking Project's having to declare a spacecraft emergency, and the station was quickly made available to Viking. The gas leak had cleared itself by the time Viking data came on line from DSS 62. This gas leak was believed to be caused by a particle that cleared itself. By far the most serious gas leak of the extended mission occurred on VO-2 beginning February 8, 1978. The leak continued for more than 2 days after that, with a total loss of 1.18 kg (2.6 lb) of gas. Based on previous experience with the VO-1 solar occultations and gas leaks, it is believed by the Orbiter guidance and control analysts that the large VO-2 leak was probably induced by the temperature variations and that the relative impurity of the helium supply compared to the nitrogen may have contributed. Several VO-2 nonpropulsive maneuvers were canceled after the gas leak to allow the Orbiter to get through the solar occultation season without additional strain. The solar occultations ended late in February 1978.

E. VO-2 Central Computer and Sequencer Timing Problem

Each Orbiter computer contains two processors. Certain tandem events require that the relative timing between the two processors not exceed a preset value, normally 160 ms. One such tandem event is the "flip", in which the master/slave relationship between the processors changes. Flips are used when the Orbiter sequence contains so many events that they cannot all be executed by a single processor.

On Sept. 19, 1977, at the time scheduled for a flip from Processor B to Processor A on VO-2, the ongoing sequence abruptly halted and the spacecraft was put into a safe state, transmitting 8-1/3 bps single-subcarrier via the low-gain antenna. The immediate indication of trouble was lack of downlink data from the tracking station DSS 44. This 26-m station could barely hold receiver lock at an indicated downlink carrier level of −167 dBm, and the 8-1/3 bps signal-to-noise ratio was about 1 dB. Viking Project declared a spacecraft emergency, in order to obtain use of DSS 43 in Canberra and then DSS 63 in Madrid. DSS 43, in fact, was still in final Deep Space Network system tests after conversion to the Mark III Data System, and DSS 63 was allocated to Helios.

DSS 43 was brought on-line in a little more than one hour after the spacecraft emergency declaration. After Orbiter analysts assessed the telemetry data, they transmitted commands from DSS 44 which still had the VO-2 uplink. These commands restored downlink transmission on the high-gain antenna, and put the Orbiter into the 33-1/3 bps data mode. The Orbiter remained in this condition, with the remainder of that week's onboard science sequence canceled while testing of the central computer and sequencer subsystem continued. VO-2 returned to its science mission on Sept. 22. The spacecraft emergency was lifted on Sept. 20.

IV. Ground System Activities

A. Upgrade of Deep Space Stations for Post-Viking Era

During the Viking Extended Mission, the Deep Space Stations were taken out of service for approximately three months each to install Mark III Data System hardware and software. The conversion was accomplished first at Goldstone (DSS 12 and DSS 14), then at Canberra (DSS 42 and DSS 43), and then at Madrid (DSS 61 and DSS 63). The remaining 26-m stations were also included, but Viking operations were primarily affected by loss of the 64-m stations, over which the majority of the science data playback occurred.

1. DSS 14. This Goldstone 64-m station tracked Viking informally on June 23, 1977, as a checkout of Mark III equipment. Demonstration tests took place in July, including reception and processing of 8-kbps and 16-kbps high-rate block-coded data. The Mark III Data System 64-m stations have capability for only four telemetry streams simultaneously, instead of the six that Viking was used to previously. As a result, during one of the demonstration tests when both Orbiters were in the dual-subcarrier mode, and there was a simultaneous Lander direct link, it was necessary to have DSS 14 track VL-1 and VO-1 and to have the simultaneously available DSS 63 track VO-2. DSS 14 was also used for the VO-1 RFS Threshold Test during its checkout period.

2. DSS 43. The last Viking pass by either of the conjoint Madrid stations, DSS 61 and DSS 63, took place during the VO-2 Deimos near-flyby on Oct. 15. The stations were then taken down for three months. About this same time the conjoint Canberra stations, DSS 42 and DSS 43, completed their requalification tests with no problems, and were again made available for Viking. Competition for the available stations became severe in July and August, considering operational readiness tests for the upcoming Voyager launches as well as routine Helios and Pioneer tracking. By this time, both VO-1 and VO-2 could play back data at 16 kbps over a 64-m station. The high-rate capability was limited for transmission of this data from the overseas stations to the space flight operations facility because of the 27.8 kbps capacity of the wideband data lines. Operationally, the 16 kbps from one of the Orbiters would be transmitted over the wideband line in real time, while the 16 kbps from the other would be recorded on a digital original data record, and then replayed from the station post-pass.

The first use by Viking of DSS 43 was under the spacecraft emergency requirement on Sept. 19, when the VO-2 central computer and sequencer developed its timing problem. The station performed admirably under these circumstances, obtaining for Viking telemetry data when it was really needed. The more formal demonstration passes, ground data system tests, began the second week in October. The Project telecommunications analyst noted several times during these tests that the ranging carrier suppression was set to an erroneous value. The station was checking out a new ranging module. The stations were scheduled to be available formally to Viking on Oct. 15, the same date that the Madrid stations would be taken down.

3. DSS 63. The first systems integration test for DSS 61 and DSS 63 was scheduled for Jan. 5, 1978. However, as in the case of the first use of DSS 43 in September, the first Viking track by DSS 63 was on a semi-emergency basis on Jan. 3. The situation arose because earlier on that same date, DSS 43 had not been able to bring their antenna to point at the scheduled start of track. The playback of Lander relay data from VO-2 was lost as a result. DSS 63 was made available, and a command load transmitted to VO-2 to play back the missed data again during the DSS 63 pass. DSS 63 not only received the 8-kbps data with a good signal-to-noise ratio, but they also transmitted the 25 commands that were necessary to position the Orbiter recorder and to initiate the playback.

B. Improvement in Analog Original Data Record System

By mid-November 1977 the 64-m stations had obtained and installed the FR 2000 analog recorders intended as replacements to the old FR 1400's. The first demonstration pass for the new equipment was at DSS 14 on Nov. 18. A similar demonstration pass took place at DSS 43 on Nov. 25. The tests were successful, and the stations were then authorized to use the FR 2000's for all future Viking analog recording and playback. Each station has a single FR 2000. Therefore, for long periods of analog recording, there yet remain unavoidable gaps in the data; these occur during the times the operators are changing the tapes. For particularly critical sequences, the times that the tapes are changed may be coordinated by the Viking real-time Flight Control Chief.

C. Uplink Transmitter Power

For the superior conjunction period, November 1976 through January 1977, the 64-m stations overseas used 50-kW uplink power and DSS-14 at Goldstone used 100 kW. The higher powers were necessary for the radio science relativity experiment, considering the increased noise from the Sun and the maximum Earth-Mars distance at the time. After superior conjunction, the 20-kW power level was again used throughout 1977. On Feb. 8, 1978, the Viking Mission Director authorized the Deep Space Network to use 10 kW for all Viking uplinks for the remainder of the extended mission.

D. Planning for Orbiter Playback Bit Rates

Throughout the Viking primary mission, the playback bit rate profile for each Orbiter was generated manually by Project telecommunications people.

During the last three months of 1976, Orbiter telecommunications people were developing a program, the "Telecommunications Playback Opportunities Profile," (TPBOP) which would specify the bit rate change times automatically. The program was in the demonstration phase during January 1977, and put on-line for production in February 1977. The Viking Extended Mission sequences were, in fact, more complex than those of the primary mission in terms of the data playback. This was because there were fewer Deep Space Stations allocated, meaning: (a) the 64-m station coverage was no longer continuous, so many more bit rate changes occurred each day; and (b) uplinks were no longer continuous, so there were more one-way to two-way transitions to contend with. As a result of the reduced DSN allocations, those allocations remaining were used to the maximum, with the result for less margin for error in planning. Earth occultations also occurred during the extended mission on both Orbiters, and these further complicated the tape management process. However, with the direct computer file interface between the TPBOP software and the tape management software, sequence planning was generally smooth throughout the extended mission. Most errors occurred as the result of station allocation changes made after the original tape management had already been completed.

E. Use of 26-m Stations for Orbiter High-Rate Data Return

As competition from other Projects for the 64-m stations increased in mid-1977, the Viking Project became interested in the predicted capability of the 26-m stations to receive 2-kbps high-rate data. The Project telecommunications assessment was that the communications range would become small enough by August 1977 for the 26-m stations to support 2-kbps visual imaging data. The Telecommunications Playback Opportunities Profile was upgraded to include data transition times for 26-m stations. The first such playback was to be Aug. 16, 1977.

There are station limitations which preclude the reception of more than one simultaneous 2-kbps data stream at some of the stations. DSS 11, for example, had a single symbol synchronizer because the second one was being used for support of Voyager launch activities at Cape Canaveral. In addition, the 26-m stations could support only two data streams (high rate or low rate) simultaneously. In this case, if an Orbiter were in the dual-subcarrier mode (2 kbps and 8-1/3 bps, for example) and the second Orbiter were in the single-subcarrier mode (33-1/3 bps, for example), the on-duty Flight Control Chief would have to decide which of the three streams to sacrifice. Eventually, all data streams were given priorities so that such decisions did not have to be made under pressure in most cases. Selection of the data stream to be dropped would be made on the basis of which Orbiter was busier at the time; the busier Orbiter's low-rate engineering stream would be returned together with the 2-kbps high-rate playback stream.

V. Ground System Problems

A. Interference to Orbiter Low-Rate Channel by High-Rate Data Content

The Orbiter high-rate subcarrier frequency is 240 kHz; the low-rate subcarrier frequency is 24 kHz. It was noted during prelaunch testing and during interplanetary cruise that certain high-rate data patterns would cause a decrease in the low-rate channel signal-to-noise ratio. The cause of the problem is sidebands of the data spectrum around the 240-kHz subcarrier falling on top of the 24-kHz subcarrier. This causes difficulty with the station's subcarrier demodulator assembly, and was verified by tests at Compatibility Test Area 21 (CTA 21). These tests showed that 16-kbps uncoded data (present during the Viking Lander Capsule checkout in interplanetary cruise) could create enough energy near 24 kHz to knock the subcarrier demodulator assembly out of lock. Some data patterns, such as "all zeroes," of 8 kbps or 16 kbps block-coded data could cause lesser degradation.

Figure 5 shows that the 8-kbps and 16-kbps block-coded data did cause such degradation during the Viking Extended Mission. With downlink carrier signal levels in the −140 dBm range, certain data patterns caused degradation of between 2 and 6 dB in the 33-1/3 bps low-rate telemetry signal-to-noise. Considering that the average signal-to-noise ratio of 16 to 17 dB was well above the threshold signal-to-noise ratio of 5.2 dB, these degradations did not cause any difficulty in reception of the data.

The maximum interference occurred at the maximum signal level. In several specific cases, such as in Fig. 5, the interference was associated with specific events such as Orbiter tape recorder reversals, or periods of "all data zeroes" during the time the tape recorder was not running but the dual-subcarrier mode was on. The condition of "all data zeroes" refers to the input to the spacecraft block coder, and not to the symbol stream from the block coder to the high-rate modulator.

B. High Doppler Rate Near VO-2 Orbit Periapsis

Late in November 1977, several passes occurred in which 26-m stations could not maintain lock on the (two-way) downlink carrier when the Orbiter was on the low-gain antenna. This condition would persist for about one hour total, the time centered on the periapsis. The downlink signal level was about −157 dBm, predicted, at this time, and the Orbiter was in the single-subcarrier mode. The highest two-way doppler rate on Nov. 21, 1977 was 19 Hz/s. That day, DSS 11 downlink receiver went out of lock at 08:24 GMT, and did not regain lock until 08:41 GMT, with periapsis at 08:34 GMT.

C. Missed Uplink Acquisitions After VO-1 Earth Occultation

The most difficult uplink acquisitions of the extended mission were those to VO-1 just after exit from Earth occultation. Prior to enter occultation, the outgoing station was, by procedure, to have the uplink tuned so that the Orbiter radio would be at best-lock frequency. The Orbiter would enter Earth occultation two-way, and would exit one-way. Orbital doppler rates were high near-Earth occultations, which occurred near periapsis on VO-1.

Difficult uplink acquisitions are not limited to any one station or site, nor to any one of the Viking vehicles. Figure 6 shows the variation of the Orbiter receiver static phase error during two different types of acquisitions. In the normal track, the track synthesizer frequency (TSF) is set so that the static phase error goes equally in both directions from a telemetry data number of 64 (receiver best lock) during the station pass. Part (a) of the Fig. 6 shows a one-way to two-way acquisition by DSS 11, when the orbit periapsis occurred well after start of track. Part (b) shows a DSS 61 to DSS 14 handover, in which the handover was required to occur near-orbit periapsis. Both these acquisitions happened to be with VO-2.

D. High-Rate Data Losses

The only time during the extended mission playback data losses became a concern to the Project was early in September 1977. At that time, a significant fraction of the total infrared science played back from the Orbiters was lost because of station problems.

Most of the data losses had occurred over DSS 63, which happened to be the only 64-m station tracking Viking at the time. Most of the data outages were of 4-kbps playback data near the start of the station pass. The root cause of the outages was the station crew had too many things to do all at the same time. The conjoint stations DSS 61 and DSS 63 were operated with a single four-person crew normally, and the crew was shorthanded at the time. The station operators were required to establish an up-link to an Orbiter and to get two low-rate and two high-rate data streams started within about 15 min of the start of track.

Participants at the meeting agreed that the most immediate relief could be obtained by having the high-rate playbacks at the beginning of the pass start at different times rather than simultaneously for the two Orbiters. In the Playback Opportunities Profile, the VO-1 playback would continue to be allocated to begin 10 min after the station start of track. The VO-2 playback would not be allowed to start until 20 min after station start of track. This expedient worked and no further losses were experienced.

There were no significant problems associated with imaging playbacks during the extended mission, other than when hardware failures prevented the reception of the data.

E. Degradation to Orbiter 16-kbps Signal-to-Noise Ratio on Back-up S-band Maser

During the Viking primary mission, a "pad" of 1.2 dB was added to the required threshold for science data playback to account for the more likely degradation factors. Among these factors was the occasional use of a 64-m station's backup S-band maser when the primary maser would fail. The backup maser has a slightly higher system noise temperature and, on average, one can expect a 1 to 1.5 dB degradation in signal-to-noise ratio when the backup maser is used.

During the week of May 15, DSS 43 operated several days on its backup maser. During these passes, the system noise temperature at S-band was about 34 K instead of the 22 deg that is expected for the primary maser. Even with the Orbiter ranging channel OFF, the VO-1 16-kbps signal-to-noise ratio averaged 0.5 dB and the VO-2 16-kbps signal-to-noise ratio averaged 1.0 dB. The station's performance was degraded by between 2 dB and 3 dB, compared with the expected 1 to 1.5 dB. Prior to Viking launch, during the systems integration tests, the DSS 43 backup maser system noise temperature had been 27 K, and it had gone to 34 K some time after those tests. The primary maser was back in operation on May 22, and the 16-kbps performance was normal after that. (The threshold for 16-kbps visual imaging data, without the 1.2 dB pad is 1.8 dB; therefore, the observed values while on the backup maser were well below the required threshold.)

F. "Catastrophic" Increases in Station System Operating Temperature

On Jan. 7, 1977, it snowed heavily at DSS 14 and DSS 11 at Goldstone DSCC. The DSS 14 system noise temperature went to 450 K, compared to a normal of about 20 K at S-band. The resulting 14-dB degradation caused the loss of high-rate playback from both VO-1 and VO-2. Nothing could be done about the loss, except to wait for the next 64-m station, DSS 43, to rise. DSS 11 system noise temperature increased to 125 K, from a normal of about 33 deg K, due to the same snowstorm.

Another weather-related type of data loss is excessive wind which requires stowage of the ground antenna. During one Viking Extended Mission pass, DSS 63 was required to stow the antenna for three hours, causing the loss of 16-kbps data from both Orbiters.

G. Radio Frequency Interference from External Sources

Radio frequency interference was predicted during the extended mission from the Earth-orbiting GEOS satellite and (at Goldstone DSCC) from military exercises in the area. A large amount of Viking and Deep Space Network analysis had gone into potential interference to Viking by GEOS, which has a transmitter in the deep space downlink band; the GEOS frequency is 2299.5 MHz, compared to 2293.2 MHz for VO-1 and 2297.2 MHz for VO-2. GEOS was planned to be launched into geosynchronous orbit, very much closer to the Deep Space Stations than is Mars; its omnidirectional antenna has a beamwidth that covers the Earth. Thus, anytime GEOS appeared in the same angular direction from a Deep Space Station as Mars, interference could be expected. The Deep Space Network generated a computer program to calculate the times and severity of the interference.

This interference was predicted starting the last week in May 1977 and continuing through the end of June. The observed GEOS signal level at DSS 43 was a carrier at about -130 dBm. The first interference was noted during VO-2 playback of 16-kbps imaging data on May 29 and 30. The signature of the problem was that the 16-kbps data would go out of sync in the station's subcarrier demodulator assembly. The telemetry and command processor channel would then be reinitialized by the station operator after the subcarrier demodulator assembly lock was regained, several minutes later, and the signal-to-noise ratio would then be back at predicted levels. The degradation was not smooth in time, as a result, but rather was discontinuous due to subcarrier demodulator assembly drop-lock.

The Deep Space Network analysis suggested:

(1) Severe telemetry bit signal-to-noise ratio and bit error rate degradation when the carrier interfering signal is near or on the subcarrier's first and third harmonic spectrum of the desired signal;

(2) No noticeable degradation when the interfering carrier is near the even harmonics of the subcarrier of the desired signal;

(3) Severe tracking doppler phase jitter degradation effects, as well as telemetry bit signal-to-noise ratio and bit error rate degradation, when the interfering carrier is within 1 kHz of the desired downlink carrier signal.

In comparison with the -130 dBm level of the GEOS signal late in May 1977, the Viking Orbiter signal level was -141 dBm for single-subcarrier and -146 dBm for dual-subcarrier.

H. Scheduling Problems

Viking Project scheduling is carried out in coordination with the Deep Space Network scheduling office. About mid-1977, several instances of lost data were traced to last-minute changes in station allocation which had not been made known to the Orbiter people involved in management of Orbiter tape recorder playback. Typically, the loss would be of a few minutes' duration and would be caused by the change in time for the uplink station allocation.

On Sept. 13, 1977, one minute of 8-kbps data from the playback of a Lander-to-Orbiter relay pass was lost. The Lander analysts were bothered by this seemingly short outage because that minute of data contained engineering data spanning 24 h for some instruments. Analysis of the problem indicated that it started with the loss of a DSS 14 allocation for Voyager, and the reassignment of DSS 63 to Viking. In addition, the uplink allocation of DSS 61 was moved from the originally scheduled time. So, the playback of the relay data was moved into the DSS 63 view period and then was disrupted by the DSS 61 transmitter coming on at a time different than planned.

In October 1977 the stations continued to be squeezed in terms of time required for precalibration, compared with the start of track time scheduled. The Viking Project flight plan summaries began to show priority of data, so that the real-time Flight Control Chief could determine which things could be neglected during a particular precalibration, if required.

In November 1977 numerous late changes in scheduled tracking time occurred. Some data outages occurred because tape management had placed playback where no station allocation still existed. To alleviate this problem, Viking Project scheduling produced weekly handwritten memos indicating changed allocations. Also, DSN scheduling began to put revisions to the 7-day schedule on the Project teletype machine for use in realtime. The Viking Radio-Science Team also published periodic memos detailing the timing for their upcoming experiments, including the VO-1 and VO-2 Earth occultations, the gravity field coverage, the near-simultaneous Lander/Orbiter ranging, and bistatic radar. The scheduling difficulties decreased after these steps were taken.

In mid-October 1977 there had been several DSS 11 missed uplink acquisitions following Earth occultation of VO-1. It was found that the times in the sequence of events were about 1-1/2 minutes later than the actual times deduced from DSS 11 receiver out-of-lock (enter occultation) and in-lock (exit occultation). To bring times used by all elements of the Project and the Deep Space Network into agreement, the Viking Radio Science Team took the approach of manually tweaking the times calculated by navigation, for inclusion in the sequence of events.

VI. Viking Radio Science Activities

The Viking Radio Science Team performed a large number of experiments during the Viking primary and extended missions. Representative activities are described in the following paragraph; however, not all of the experiments are discussed.

A. Superior Conjunction Relativity Experiment

Reference 1 describes the planning for and the observations made during the Viking superior conjunction in October to December 1977. Only the Orbiter activities following the day of closest approach to the Sun, Nov. 25, are mentioned in this section.

The first Orbiter low-rate telemetry received after this day was on Nov. 26, during the DSS 14 pass. On Dec. 6 the Sun-Earth-probe angle had increased to 3 deg from its minimum of 0.25 deg on November 25. The first post-conjunction Orbiter commanding was done on Dec. 6, from DSS 14 to VO-1 and from DSS 11 to VO-2. By Dec. 9 VO-1 began transmitting continuously in the single-subcarrier mode at 33-1/3 bps.

On Dec. 13 VO-1 operated in the dual-subcarrier mode, at 2 kbps and 8-1/3 bps, for the first time since the conjunction. The link performance was satisfactory, and the signal-to-noise ratios about the same as the corresponding time before solar conjunction. VO-2 went through a similar "wakeup" sequence the next day. By Dec. 20 the Sun-Earth-probe angle had increased to 7 deg and the S-band and X-band links had essentially returned to their preconjunction condition.

B. Quasar-VLBI Experiment

For this experiment, the tracking stations alternately point their antennas at an Orbiter and at a quasi-stellar source (quasar). The Quasar-Very Long Baseline Interferometry experiment occurred during interplanetary cruise, during the primary mission, and several times during the extended mission. DSS 14 and DSS 42 were involved in such an experiment on Feb. 10, 1977.

Late in 1977 there were several quasar-VLBI experiments conducted using radioastronomy facilities at Haystack, Mass. and at Owens Valley, Calif. The necessary coordination between the experiment and the normal Orbiter mission planning was crucial for these, since outside agencies were involved. On Dec. 14, 1977, while the quasar-VLBI data was being accumulated at these two sites, the X-band down-link from VO-1 suddenly disappeared. The cause for the loss of the signal was that at that time the Orbiter began a planned roll maneuver, causing the high-gain antenna to offpoint from the Earth. Previously there had been observations on Nov. 29 and 30 without incident; later, observations occurred without problem on Dec. 15 and on Dec. 29 and 30.

The quasar-VLBI experiment has been likened to a "star-plate" analogy. The Orbiter X-band signal and X-band radiation from the quasars (which are considered as fixed stars) are used to obtain highly accurate angular measurements between the Orbiter and the quasar, so as to tie together the coordinates of the Viking orbits, Mars, and the fixed stellar reference frame.

C. Bistatic Radar

Late in February 1977, approval was given to the bistatic radar experiment. This experiment would consist of having the Orbiter point its high-gain antenna toward the surface of Mars, thus bouncing the X-band and the S-band downlinks off the surface and back to the Earth where they could be received at 64-m stations, using open-loop receiving equipment. The high-gain antenna would either be pointed toward a single point on the surface during the pass (fixed-point observation) or such that the angle of incidence equalled the angle of reflection (specular pass). It was not expected that normal closed-loop downlink carrier or telemetry data could be received because of the frequency smearing resulting from the surface reflection. The bistatic radar experiment was a "guest experiment" with the principal investigator from Stanford University.

The experiment objective was to determine the surface roughness and the electrical and other properties of the surface of Mars in selected regions not accessible by Earth-based radar, by means of spectral analyses of the reflected and direct signals from the surface.

A new bistatic radar telemetry format was created and loaded into the Orbiters' flight data subsystems by the end of October. It emphasized the articulation subsystem channels so that a detailed telemetry record of the high-gain pointing directions could be obtained. The Deep Space Network was involved in the coordination of this experiment with the Project and the experimenters. A special instruction message was transmitted to DSS 14 and DSS 43, the two stations that would be receiving bistatic data. The Orbiter sequences included contingency periods of low-gain operation following the bistatic passes, in the event that the high-gain antenna did not return properly to Earth pointing.

Good reflected data was observed throughout the Nov. 8 bistatic pass at DSS 14. The open-loop recordings were flown back to Stanford University almost immediately for processing.

By Nov. 11 the experiment leader had done sufficient processing of the data to make a first estimate of the average slope of the surface and also of the dielectric constant of the surface. During December and January, bistatic passes were accomplished from both Orbiters and at both DSS 14 and DSS 43. Review of the Orbiter S-band high-gain antenna patterns show that there are sidelobes in the −30 dB to −35 dB relative gain out to at least 30 deg at S-band, thereby further substantiating the plausibility of the 64-m closed-loop lock-up on the downlink carrier. Lock-up of the S-band and X-band downlink carriers and the 8-1/2 bits/s telemetry data occurred during several bistatic radar passes.

The bistatic radar experiment required that system noise temperature measurements be made not only during precalibration but also immediately after the completion of the experiment. Such measurements required that tracking of the Orbiters be discontinued for approximately 15 min while the measurements were made. By January 1978, the Radio Science Team and the Deep Space Network had determined that they could use the maser noise diode on the S-band Polarization Diversity maser and the maser gas tube in the MOD III maser to make noise temperature measurements in lieu of the standard post-calibration ambient noise temperature measurements which required breaking track.

D. Near-Simultaneous Lander and Orbiter Ranging and Doppler Data

A number of radio science experiments are enhanced by the unique Viking situation of having one vehicle on the surface of the planet and a second in orbit around the planet. The Orbiter S-band and X-band doppler and ranging data can be used to calibrate the Lander data for charged particle and other perturbing effects. On Oct. 6, 1977 the traveling wave tube amplifier for the direct S-band link from Viking Lander 2 failed. The other VL-2 traveling wave tube had apparently failed a year previously when it did not come on for a planned direct link. No further attempts to operate a direct link using Lander No. 2 were made after Oct. 6, 1977, and all of the near-simultaneous radio science work was subsequently carried out using Lander 1, together with either VO-1 or VO-2.

Some of the near-simultaneous passes were complex to carry out. During one week in March 1977 there were a total of six near-simultaneous passes over DSS 14 and DSS 63. Each of these was a split pass, in which the station uplink was sent first to the Viking Orbiter, then to the Viking Lander, and finally again to the Viking Orbiter, which meant three separate uplink acquisitions during the pass.

During the first nine months of 1977 there were 59 good ranging passes for Viking Lander 1, which totals to 68% of those scheduled for this Lander. There were 25 good ranging passes to VL-2 out of 38 scheduled for a 66% success ratio. A good pass is one in which at least one good ranging point was acquired.

Particular emphasis was placed on the near-simultaneous ranging passes between November 1977 and March 1978, when communication range was a minimum. Strong signals were needed in order to obtain excellent orbits for Mars and Earth for the superior conjunction relativity experiment which will take place in early 1979. In the process of near-simultaneous doppler and ranging, there are approximately 40 tracking parameters to be estimated simultaneously. The signatures of some of these are similar to those of others, and some are of long period. The number of measurements required, and their spacing, led to an estimate on the part of the Radio Science Team that about one Lander ranging pass per week would be needed during the November-March period. This estimate assumed that the ratio of good to total ranging passes would continue to be approximately 2/3.

E. Solar Wind Experiment

This experiment took place during the primary mission on May 16, 1976 and during the extended mission on April 7,

1977. On the latter day DSS 14 and DSS 43 were each requested to accumulate 10/s doppler data during their overlap period. There was no effect on the normal telemetry acquisition from the Orbiters. The purpose of the experiment was to compare the S-band and X-band doppler perturbations caused by the solar wind on the downlinks from VO-2 to DSS 14 and to DSS 43. The data quality was judged by the Radio Science Team to be excellent from both stations.

F. VO-1 and VO-2 Earth Occultations

At various times during the Viking extended and continuation missions, Mars interposes itself between VO-1 or VO-2 and the Earth, thus creating an Earth occultation. The Radio Science Team members use the occultation data to produce pressure, temperature, and density profiles as well as to estimate the radius at the occultation points over a planet-wide range of latitudes and longitudes. The radii data are particularly valuable in the generation of a comprehensive determination of the shape and topography of Mars. As for the pressure, temperature, and atmospheric density profiles, these are being used to detect seasonal variations in Mars' atmosphere.

VO-1 Earth occultations occurred in the first months of the Viking Extended Mission, and by Nov. 19, 1977 both VO-1 and VO-2 Earth occultations were occurring every day. The VO-1 occultations occurred within the interval spanned by the much longer VO-2 Earth occultations. The VO-2 occultations were nearer apoapsis. The tracking stations saw the following sequence: (a) VO-2 enter occultation, (b) VO-1 enter occultation, (c) VO-1 exit, and (d) VO-2 exit. The station activity profile became quite complicated at times since the Radio Science Team wanted open-loop recordings of the signal during the enter and exit occultation times for both Orbiters. The bistatic radar experiments were also occurring during the same station passes at DSS 14 and DSS 43, and bistatic radar also required use of the open-loop recording equipment. In general, a station would not be required to use this equipment for both Earth occultation and bistatic radar on a given pass. The stations were also provided schedules for timing of the open-loop recorders, so as to pick up the crucial entrance and exit times for each Orbiter. Several Project-Deep Space Network coordination meetings occurred to resolve questions of predicted Earth occultation times, station transmitter tuning strategies, and procedures. VO-1 Earth occultations will continue for the remainder of the mission. VO-2 will again be occulted in April and May 1978 and from October 1978 through end of mission in February 1979.

Late in December 1977, during several of the VO-2 Earth occultations, the decrease in uplink and downlink signal levels at enter-occultation was slow enough that the changes could easily be seen in the spacecraft telemetry and the ground system monitor data. Figure 7 is a plot of the uplink signal strength, the S-band downlink signal strength, and the X-band downlink signal strength, all on a common time scale. Figure 7 is for the VO-2 Earth occultation on Dec. 27, 1977, as observed at DSS 14. All the signal level changes had occurred in a little more than two minutes. All three link quantities varied in the same manner and at about the same rate. In a time of 1-1/2 minutes, all quantities had decreased about 3 dB. Each then recovered 1 dB in about 10 s, then decreased rapidly after that.

VII. Deep Space Network-Viking Orbiter Communication Link Performance

A. Predicted Signal Levels

Predicted signal levels are expressed in decibels below 1 mW (dBm) for the uplink carrier level and the downlink signal level. The signal-to-noise ratios are expressed in decibels. Figures 8 through 11 show the predicted signal levels for the most common uplink and downlink modes on the Viking Extended Mission. The conversion factors used by the Project to define the signal levels for other modes are also provided. Each of Figs. 8 through 11 is a plot as a function of time.

Figure 8 shows predicted uplink signal levels. The three curves shown are predicted Orbiter receiver carrier level in dBm. They are for: (a) 64-m station, transmitting to the Orbiter high-gain antenna; (b) 26-m station, transmitting to the Orbiter high-gain antenna; and (c) 64-m station, transmitting to the Orbiter low-gain antenna. As would be expected, the shape of the two upper curves is identical, since the only variable is station antenna diameter, and the uplink signal level is a function only of the Earth-spacecraft distance. The bottom curve has a different shape because the uplink signal level is a function not only of the Earth-spacecraft distance but also of the angle from the low-gain antenna boresight (cone angle).

Figure 9 shows predicted downlink signal levels. The four curves shown are for: (a) Orbiter high-gain antenna, S-band downlink, dual-subcarrier mode, transmitting to a 64-m station; (b) Orbiter high-gain antenna, S-band downlink, single-subcarrier mode, transmitting to a 26-m station; (c) Orbiter high-gain antenna, X-band downlink, transmitting to a 64-m station; and (d) Orbiter low-gain antenna, S-band downlink, single-subcarrier, transmitting to a 64-m station. The similar shape of the three upper curves is due to the fact that the high-gain antenna is used, and only the Earth-spacecraft range influences the signal level as a function of time. The bottom curve, for low-gain, is dependent on the Earth cone angle as well as the Earth-spacecraft range.

All the curves in Fig. 9 assume that the Orbiter ranging channel is on. If the channel is off, the S-band carrier levels increase by 0.9 dB, and the X-band carrier level increases by 1.4 dB. The Project-assumed difference between 64-m and 26-m S-band downlink carrier levels is 8.5 dB. The difference between the carrier level for the single-subcarrier mode and the dual-subcarrier mode is 5.2 dB, the dual-subcarrier mode producing the weaker carrier.

Figure 10 shows predicted signal-to-noise ratios. Additional signal-to-noise ratios are shown in Fig. 11. In Fig. 10 the top curve is for the 8-1/3 bps single-subcarrier mode, on the Orbiter low-gain antenna, transmitting to a 64-m station. The bottom three curves are all for the high-rate channel in the dual-subcarrier mode, on the Orbiter high-gain antenna. From top to bottom, they are: (a) 8-kbps data rate, block-coded, transmitting to a 64-m station; (b) 16-kbps data rate, block-coded, transmitting to a 64-m station; and (c) 2-kbps data rate, block-coded, transmitting to a 26-m station. All of the curves in Figs. 14 and 15 assume that the Orbiter ranging channel is on. If it is off, the signal-to-noise ratios increase by 0.9 dB.

Figure 11 shows additional predicted signal-to-noise ratios. The upper curve is for the 33-1/3 bps data rate, single-subcarrier mode, Orbiter high-gain antenna, transmitting to a 26-m station. This is the so-called cruise mode, used extensively when playback of science data was not required. The bottom curve is the predicted signal-to-noise ratio for the 33-1/3 bps low-rate channel in the dual-subcarrier mode, Orbiter high-gain antenna, transmitting to a 64-m station. Both these curves assume the Orbiter ranging channel is on; the signal-to-noise ratios increase by 0.9 dB if the ranging channel is off.

All signal-to-noise ratio curves assume a station elevation angle of 25 deg, the standard value used in general Viking mission planning. Very approximately, the signal-to-noise ratio would be almost 1 dB higher near zenith than at 25 deg; it would be nearly 2 dB lower near the 6-deg horizon than at 25 deg. In detailed Viking mission planning, as well as link residual analysis, the elevation angle effects were taken into account. Figures 10 and 11 also show the threshold values and saturation values for the signal-to-noise ratios. Block-coded high-rate data had a threshold of +1.8 dB for the visual imaging playback data, +4.2 dB for infrared data playback, and +4.7 dB for Lander-to-Orbiter relay data playback. For link planning, a pad of 1.2 dB would be added to each of these numbers. Figures 10 and 11 show a threshold of 3.0 dB, which is the "padded threshold" for the imaging data.

B. Link Performance Trends During Viking Extended Mission

The Viking telecommunication analysts assessed performance trends by means of link residuals. In this way, the apparent changes caused by changing communication distances, antenna selection, data mode or rate, could be normalized out. A link residual is defined as the difference, in dB, between the observed value of the parameter and the predicted value. A positive residual indicates that the observed signal is stronger than the predicted one. The predicted values come from the Telecommunications Prediction and Analysis Program (TPAP).

The link quantities assessed included: (a) uplink signal level, (b) S-band downlink signal level, (c) low-rate signal-to-noise ratio, both for single-subcarrier and for dual subcarrier modes, (d) high-rate signal-to-noise ratio, and (e) X-band downlink signal level.

Figures 12 through 16 are summary plots of several of the primary data modes for the Viking Extended Mission. Each figure shows the VO-1 quantities at the top and the VO-2 quantities at the bottom. The plots use the mean from the monthly residual statistics, so there is one point plotted per month. Each plot covers the time span from August or September 1976 until January 1978. Data for October, November, and December 1976 are omitted, because of the severe degradation caused by superior conjunction effects (Reference 1).

Figure 12 shows VO-1 and VO-2 uplink signal level residuals. The circled points are for uplinks from 26-m stations, and the points indicated by triangles are for 64-m uplinks. The plot shows that a change occurred in the telemetered uplink signal level for VO-1 approximately January 1977 (or possibly during superior conjunction). Since that time, the month-to-month variations are believed to be due to differing mixes of stations used for the uplinks. Over the extended mission the VO-1 uplink signal level residual, for a given station, is about 5 to 6 dB lower (more negative) than the VO-2 residual. No changes have occurred in uplink performance for either Orbiter since January 1977.

Figure 13 shows S-band downlink signal level residuals. From month to month VO-1 and VO-2 behave similarly with regard to S-band downlink levels. Although there are sometimes substantial changes from month to month, these changes track between VO-1 and VO-2. Deep Space Station calibrations may be a factor. The 64-m downlinks are indicated by circled points, and the 26-m downlinks by points with triangles. In general, both VO-1 and VO-2 consistently show downlink signal level residuals in the −0.5-dB range; the residuals have remained constant over the extended mission, on average.

Figure 14 shows low-rate channel signal-to-noise ratio residuals. These residuals remained constant for both Orbiters during the first half of 1977, then began a gradual decline through the second half of that year and into January 1978. January 1978 was the time of minimum Earth-Mars distance. Saturation and interference effects are the causes of the decline. By January 1978, the predicted value for single-subcarrier signal-to-noise ratio was greater than 24 dB at the 26-m stations. Also, the predicted dual-subcarrier signal-to-noise ratio was greater than 18 dB at the 64-m stations. The single-subcarrier level is higher than the typical saturated signal-to-noise ratio at the stations. The dual-subcarrier signal-to-noise ratio is visibly disturbed by interference from the 8-kbps and 16-kbps block-coded data content. During the first half of 1977, the average performance of VO-1 low-rate signal-to-noise ratio was 0.5 dB higher than that of VO-2. This difference is caused by approximately 0.5 dB higher signal output from VO-2 than VO-1, and the result is seen in the high-rate signal-to-noise ratio also. (During the Viking primary and extended missions, data rate planning took into account the 0.5 dB difference between Orbiters.) By January 1978, the residuals for low-rate signal-to-noise ratio averaged more than −1.5 dB for both VO-1 and VO-2. Of course, with absolute levels in the high teens and low twenties of dB, there was absolutely no trouble with data quality. The downward trend in Fig. 18 began to reverse itself in February and March, 1978.

Figure 15 shows high-rate channel signal-to-noise ratio residuals. The high-rate channel performance was of the most interest of any link quantity to the Viking Project, because all of the science return from the platform instruments and the relay link was via this link. The high-rate channel performance remained the most constant of any of the links also, which meant that link planning based on this stability was accurate. The 8-kbps data mode was present throughout the extended mission. The 16-kbps mode did not begin until March 1977, when the predicted signal-to-noise ratio came above the 3.0-dB padded threshold required for imaging data. (In fact, for the first several months, the imaging data was returned with a pad of only 0.7 dB instead of the normal 1.2 dB, meaning that the predicted minimum signal-to-noise ratio was 2.5 dB.) The 0.5-dB difference between VO-1 and VO-2 is clear in Fig. 15. The typical 8-kbps signal-to-noise ratio residual for VO-1 was −0.25 dB, and that for VO-2 was +0.25 dB. For each Orbiter the 16-kbps signal-to-noise ratio was about 0.25 dB more negative than the 8-kbps residual. Beginning in October 1977, the 26-m stations were able to receive 2-kbps dual-subcarrier data, and these residuals are indicated on Fig. 15 by the squares. The month-to-month scatter in the 2-kbps residuals is larger than that for the 64-m high-rate reception. This is believed to be due to the much smaller number of data samples for the 26-m high-rate.

Figure 16 shows VO-1 and VO-2 X-band downlink signal levels. The X-band signal levels showed an extreme amount of variability from station-to-station and from pass-to-pass. X-band signal level calibration at the stations may have been the cause. Figure 16 shows that generally, from the one month to the next, trends in VO-2 were mirrored in VO-1. The VO-1 residuals averaged about 1.5 dB more negative than those of VO-2 during the latter half of 1977.

C. Changing Signal Levels in 1977

Viking Orbiter signal levels changed by more than 11 dB from the end of 1976 until the beginning of 1978, as shown in Figs. 8 to 11. Figure 17 shows the two trajectory quantities responsible for these changes. The Earth-Mars communication range varied from a maximum in excess of 38×10^7 km late in 1976 to a minimum of less than 10^7 km on Jan. 19, 1978. The Earth-cone angle for the low-gain antenna varied from 0.25 deg on Nov. 25, 1976 (superior conjunction) to a maximum in excess of 40 deg in late 1977.

During the second half of 1977 the Viking telecommunications analysts produced, on a periodic basis, a one-page summary of the expected signal levels. Table 1 is a reproduction of one of these predictions, the one for the peak signal day on Jan. 19, 1978. The predictions were widely used by on-duty Viking project personnel as well as members of the Deep Space Network for rough-estimate planning and for a quick check of the signal levels being observed. On January 19 the one-way light-time had decreased to 5 min and 26 s. Its maximum value was in excess of 21 min in November 1976.

The first major change in operating mode from the primary mission was the use of 16 kbps for imaging data. This occurred in March 1977. On March 28 the signal-to-noise ratio and the bit error rate for the VO-1 and VO-2 16-kbps playback first exceeded threshold requirements. On that date, over DSS 43, the VO-1 signal-to-noise ratio was 1.9 dB measured, and the bit error rate was 1.4×10^{-2} counted (for that indicated signal-to-noise ratio, the predicted bit error rate would have been 1.7×10^{-2}). VO-2 had a signal-to-noise ratio of 3.2 dB measured, and a bit error rate of 2.9×10^{-3} counted (3.9×10^{-3} would be predicted). Thus the confidence level of prediction of the signal-to-noise ratio near the absolute link threshold was raised and also in the correlation between indicated signal-to-noise ratio and the actual bit error rate.

Early in April the Viking Flight Control Chiefs were given authorization to send ground commands to turn the Orbiter ranging channel off during 16 kbps, if they observed that the indicated 16-kbps signal-to-noise ratio was not sufficiently high. However, the ranging channels were to be left on at all other times unless a tracking station were to announce a major problem, such as failure of the primary S-band maser, prior to the scheduled start of track. The 16-kbps playbacks were planned with 0.7 dB pad through April, which was sufficient to account for observed station performance variations late in March and early in April. For some of the early playbacks, the bit error tolerance in the mission test computer was set to 5 to account for the higher bit error rate expected.

Throughout the period March to September 1977, the Orbiter Science Group requested a waiver to the Viking mission rule requiring the use of 3.0-dB padded threshold for playback of imaging data. This was to enable the use of longer playback opportunities considering the limited 64-m station availability. Beginning with Viking planning cycle 43, effective September 29 for VO-1 and September 30 for VO-2, the full padded 3.0 dB requirement was restored.

Another major change in Viking operations was the use of the 33-1/3 bps data rate during the nonpropulsive maneuvers when the low-gain antenna was in use. The first such use of the 33-1/3 bps rate over a 64-m station was on Sept. 1, 1977, over DSS 63. The signal-to-noise ratio achieved was 5 dB, as predicted. Within a month after that, this data rate was permitted anytime during a 64-m station pass. By early October 1977, the predicted signal-to-noise ratio for low-gain single-subcarrier operation over a 26-m station was 2 dB signal-to-noise ratio for the 8-1/3 bps data. This was far below the 5 dB threshold; however, the Viking Project urgently wanted to use the data mode, because many nonpropulsive maneuvers occurred during 26-m tracks when no 64-m station was available. The choice was between poor-quality data, below the threshold, or no data at all. Even at 2-dB signal-to-noise ratio, high-deck telemetry measurements that contain a large amount of redundancy could provide usable data for determining limit-cycle motion and uplink signal level. In early October, DSS 11 was able to lock the Receiver 2, with a 3-Hz loop filter, and to provide telemetry data at 2+ dB signal level. DSS 61 also managed to lock their receiver and provide 8-1/3 bps data at similar signal-to-noise ratio, when the Orbiter was in the one-way mode. By mid-November, the 26-m 8-1/3 bps single-subcarrier telemetry data reached the normal 5.2 dB threshold. On Dec. 27, 1977, DSS 11 received data from VO-1 on the low-gain antenna, at 33-1/3 bps, and the signal-to-noise ratio was 5 dB, as predicted. The signal-to-noise ratio for this low-gain antenna mode on Dec. 27, 1977 was 12 dB higher than it would have been late in November 1976.

On peak signal day, Jan. 19, 1978, the distance from Mars to Earth was 97.7×10^6 km. The station view periods were changing rapidly at this time, as shown in Fig. 18. At the end of 1977, the tracking set-time changed almost 2 h over a one-month period at DSS 43, working out to about 4 min per day. The indicated VO-2 uplink signal level reached −95 dBm in spacecraft telemetry (64-m station, no uplink modulation), the highest value since interplanetary cruise. The very strong downlink signals, −136 dBm carrier level for dual-subcarrier mode at 64-m stations, also caused the high-rate channel data interference in the demodulation of the low-rate subcarrier to become more prominent. Runs of zeroes into the Orbiter block-coder would result in downward glitches of 5 and 6 dB in the indicated low-rate channel signal-to-noise ratio, reducing it from 16 dB average to about 11 dB minimum.

References

1. Taylor, J., "Deep Space Network to Viking Orbiter Telecommunication Link Effects During 1976 Superior Conjunction", in *The Deep Space Network Progress Report 42-40,* May and June 1977, pp. 57-70.

2. Technical Memorandum 33-783, *Tracking and Data System Support for the Viking 1975 Mission to Mars*: Vol. 1, "Prelaunch Planning, Implementation, and Testing", D. J. Mudgway and M. R. Traxler, Jan. 1, 1977; Vol. 2, "Launch Through Landing of Viking 1", D. J. Mudgway and M. R. Traxler, March 15, 1977; Vol. 3, "Planetary Operations", D. J. Mudgway, Sept. 1, 1977.

3. Stuhr, F. V., *Viking 75 Project Orbiter System, Lander System and Viking Mission Control and Computing Center System to Tracking and Data System Interface Requirements Document,* Vol. II, "Viking Orbiter System to Deep Space Network", Viking Project Document ID-3703111, Dec. 19, 1973.

Table 1. Single-page Viking Orbiter signal levels for peak signal day

Expected signal levels for mid January 1978

Uplink (20 kW, command modulation only)	VO-1	VO-2
26-m, Orbiter HGA	−114	−108.5
26-m, Orbiter LGA	−134	−128.5
64-m, Orbiter HGA	−103.5	−98
64-m, Orbiter LGA	−123.5	−118

Deltas (may be combined)

(a) If station transmits at 10 kW, make levels 3 dB weaker than shown.
(b) If station also has ranging modulation, make levels 9 dB weaker.
(c) If station has no uplink modulation, make levels 2.5 dB stronger.

Single subcarrier downlinks (ranging channel on for Orbiter, 1.5 h from rise/set)

	Downlink AGC	33-1/3 SNR	8-1/3 SNR
26-m, Orbiter HGA	−139.5	> +23[b]	> +23[b]
26-m, Orbiter LGA	−160.5	+5	+10
64-m, Orbiter HGA	−131.5	> +23[b]	> +23[b]
64-m, Orbiter LGA	−152	+15	+20

Deltas (may be combined)

(a) If Orbiter ranging channel is off, make AGC's and SNR's 0.9 dB stronger.
(b) If within one hour of station viewperiod end, make SNR's 1 dB weaker; do not change AGC's.
(c) If on station Maser 2, make SNR's 1 dB weaker; do not change AGC's.

Dual subcarrier downlinks (ranging channel on for Orbiter, 1.5 h from rise/set)

	Downlink AGC	8-1/3 SNR	33-1/3	2 kbps SNR	8 kbps
26-m, Orbiter HGA	−145	+13	+8	+10.5	n/a[c]
26-m, Orbiter LGA	−165.5	< 0	< 0	< 0	n/a[c]
64-m, Orbiter HGA	−136.5	+23	+18	+20.5	+14.5
64-m, Orbiter LGA	−157	+1.5	< 0	< 0	< 0

Deltas: use same deltas as for single subcarrier downlinks.

X-Band downlink (ranging channel on for Orbiter)

	Downlink AGC
64-m, Orbiter HGA	−141.5

Delta: if Orbiter ranging channel is off, make X-band AGC 1.4 dB stronger.

[a]Peak signal day was on Jan. 19, 1978. On this day Earth to Mars range was 97.7×10^6 km. One-way light time was 5 min, 26 s.

[b]Saturated.

[c]Data rate available at 26-m stations.

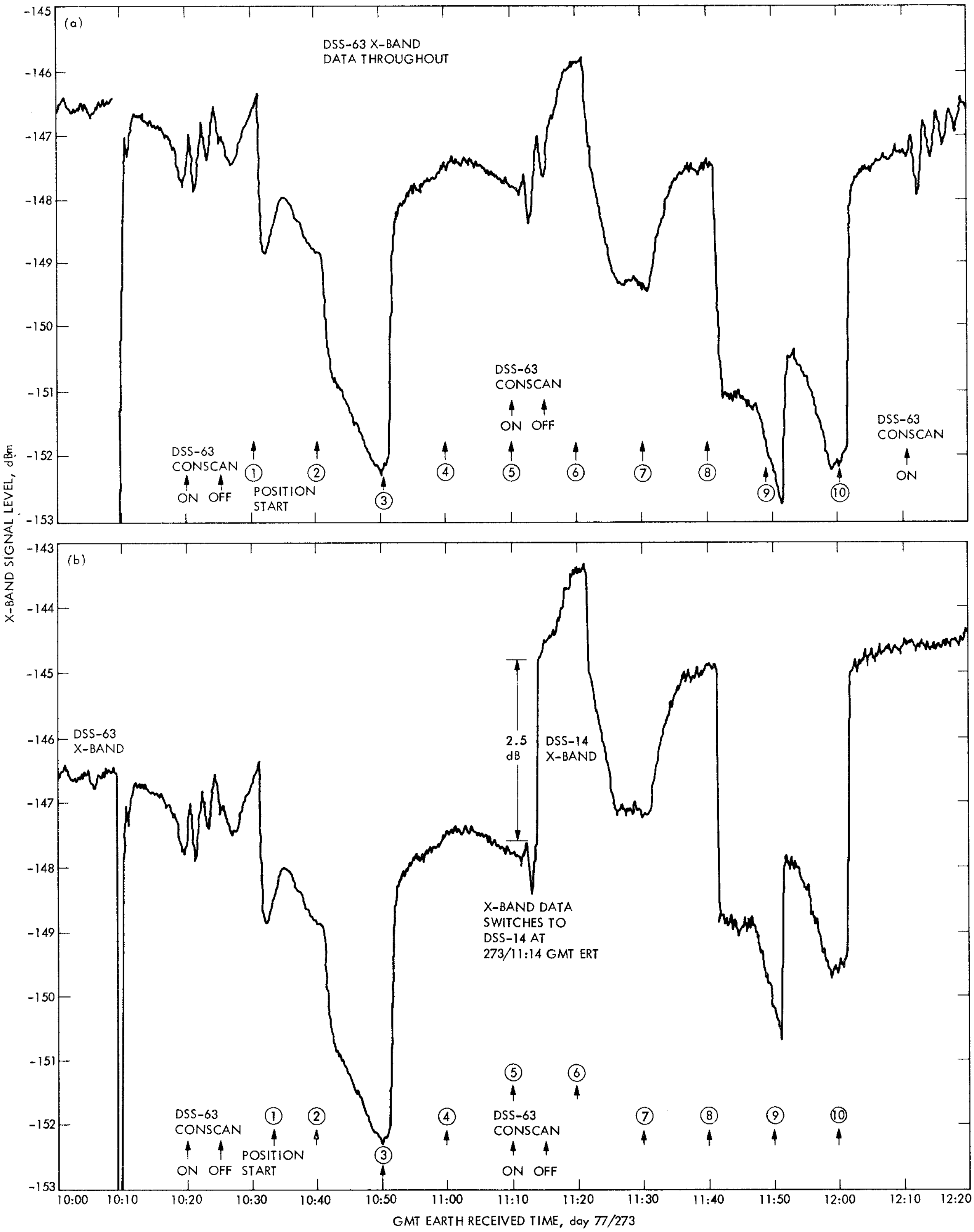

Fig. 1. Viking Orbiter high-gain antenna calibration, Sept. 30, 1977, DSS 63 X-band signal level (a) MTC-A (b) MTC-B

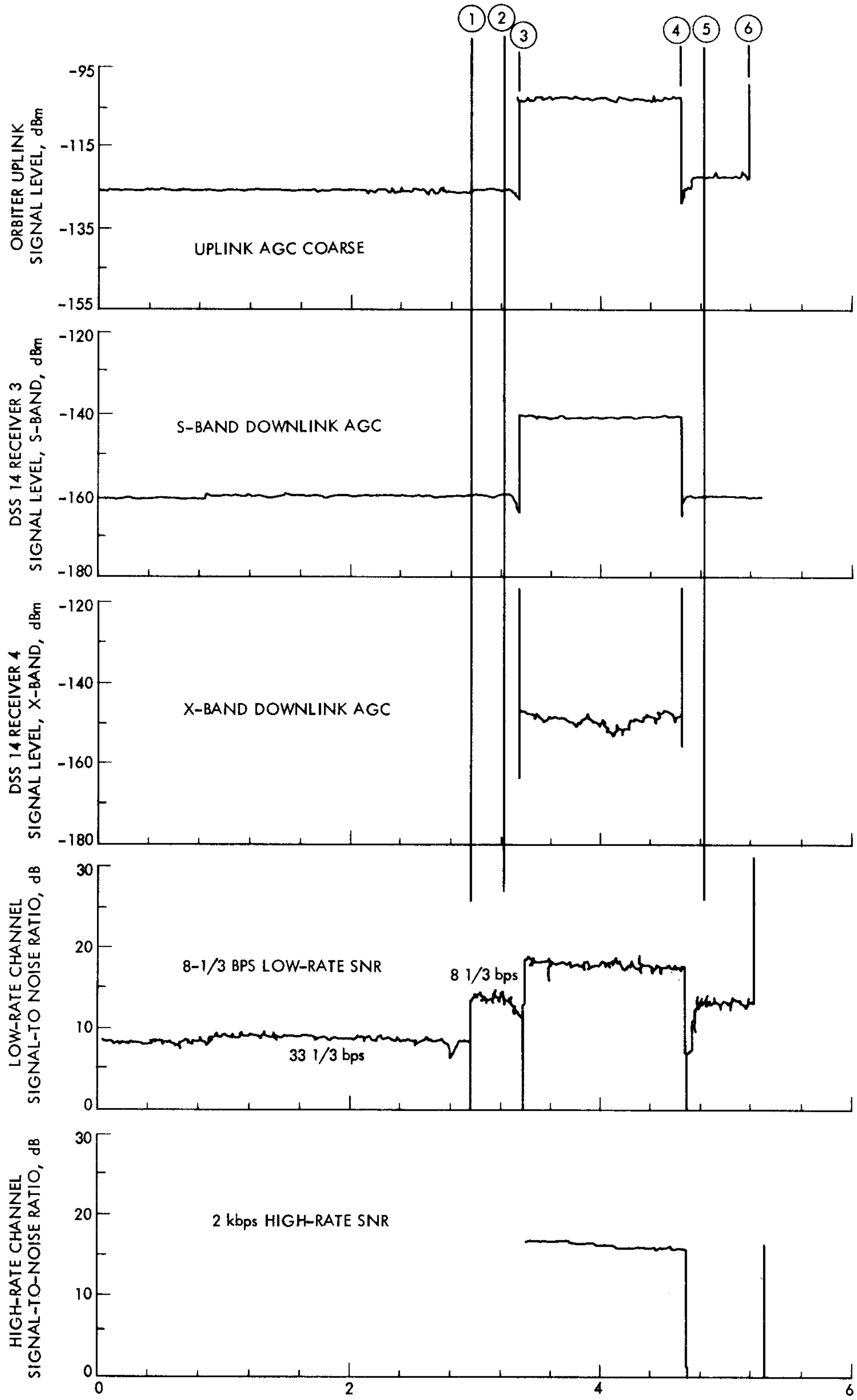

Fig. 2. Link quantities during VO-2 Mars orbit trim No. 13

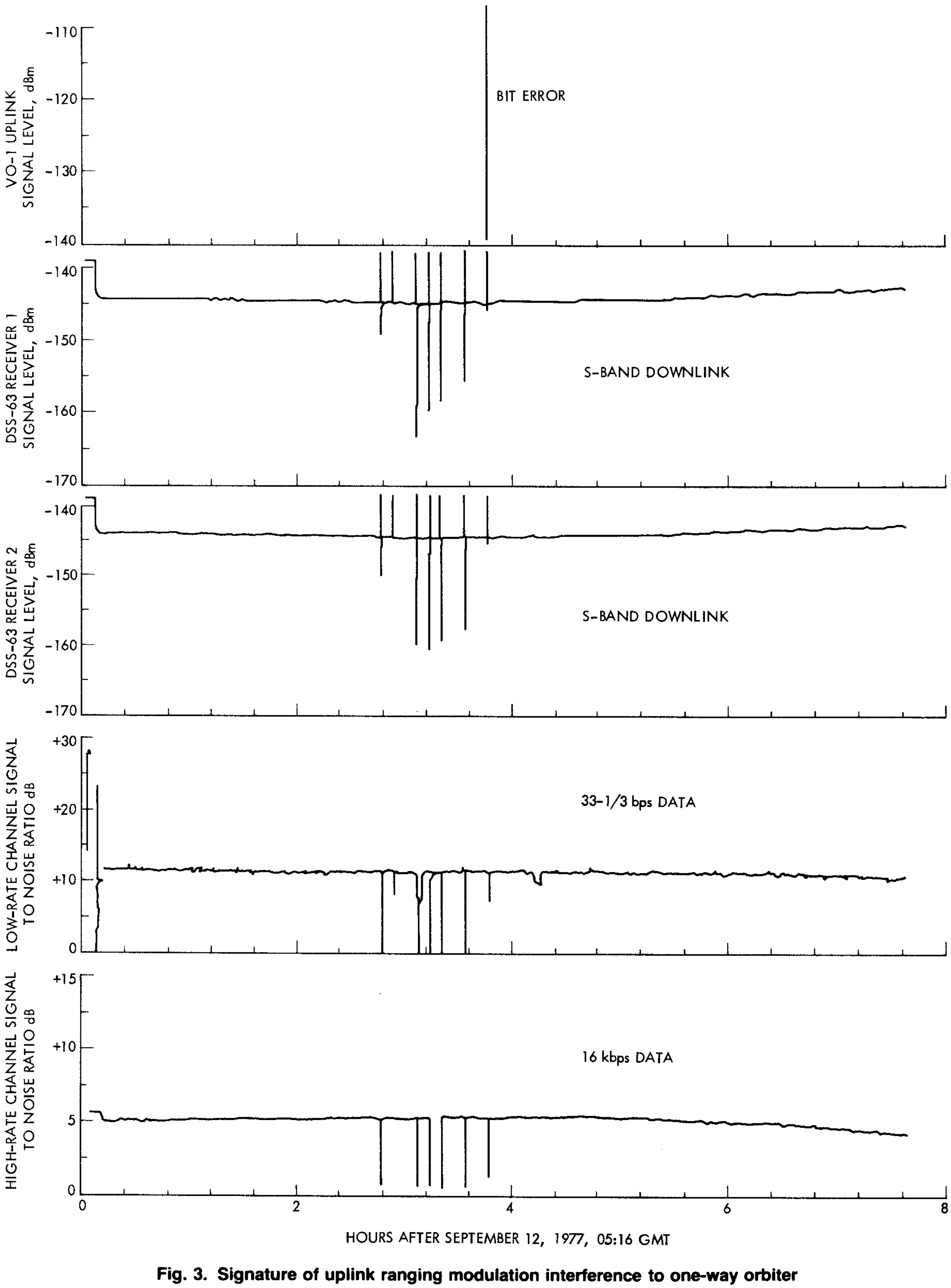

Fig. 3. Signature of uplink ranging modulation interference to one-way orbiter

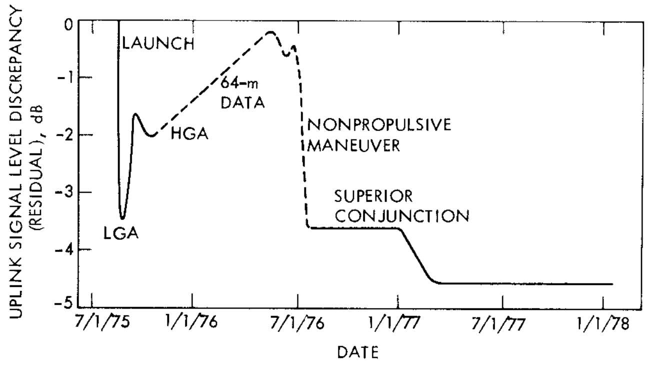

Fig. 4. Overview of variation in VO-1 uplink signal level residual since launch

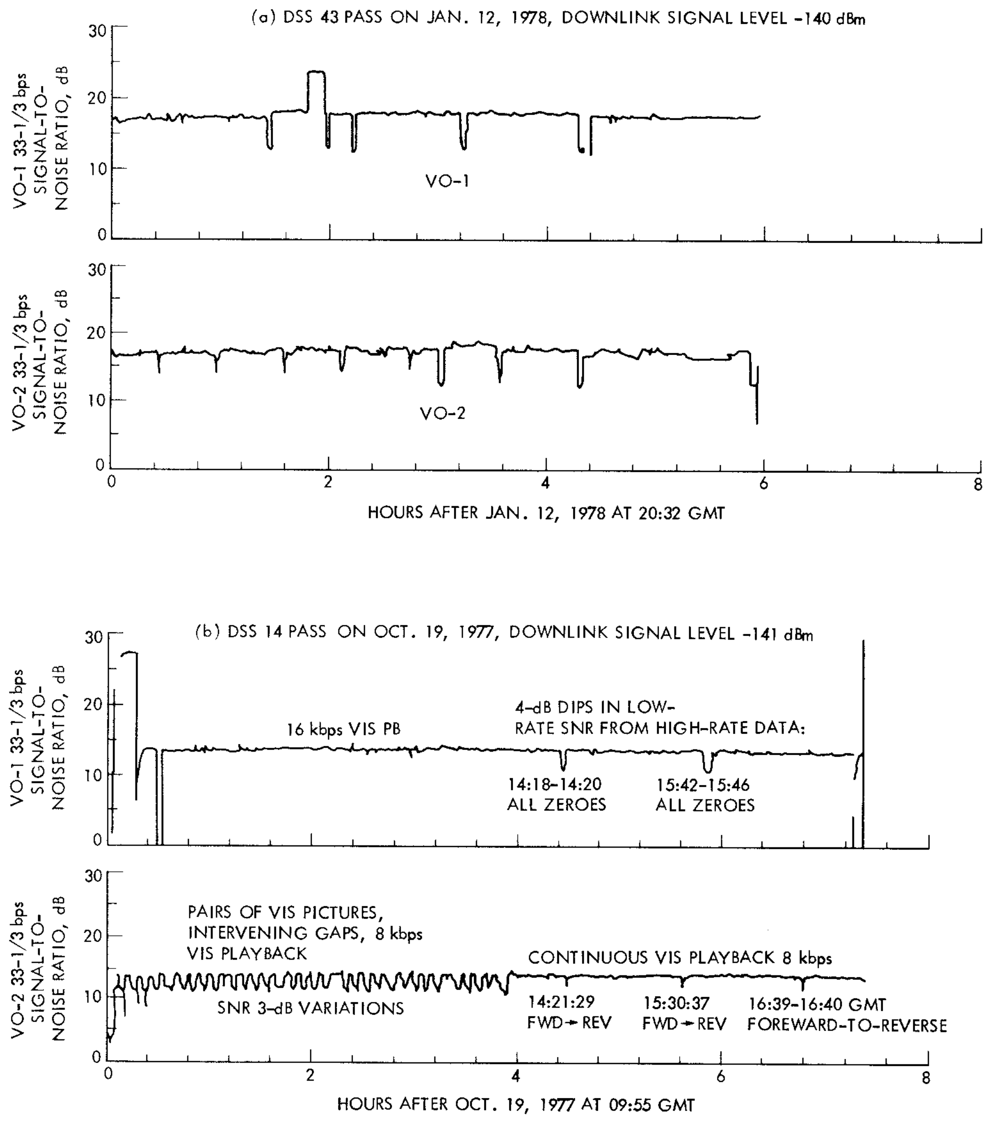

Fig. 5. Low-rate signal-to-noise degradation caused by high-rate data content

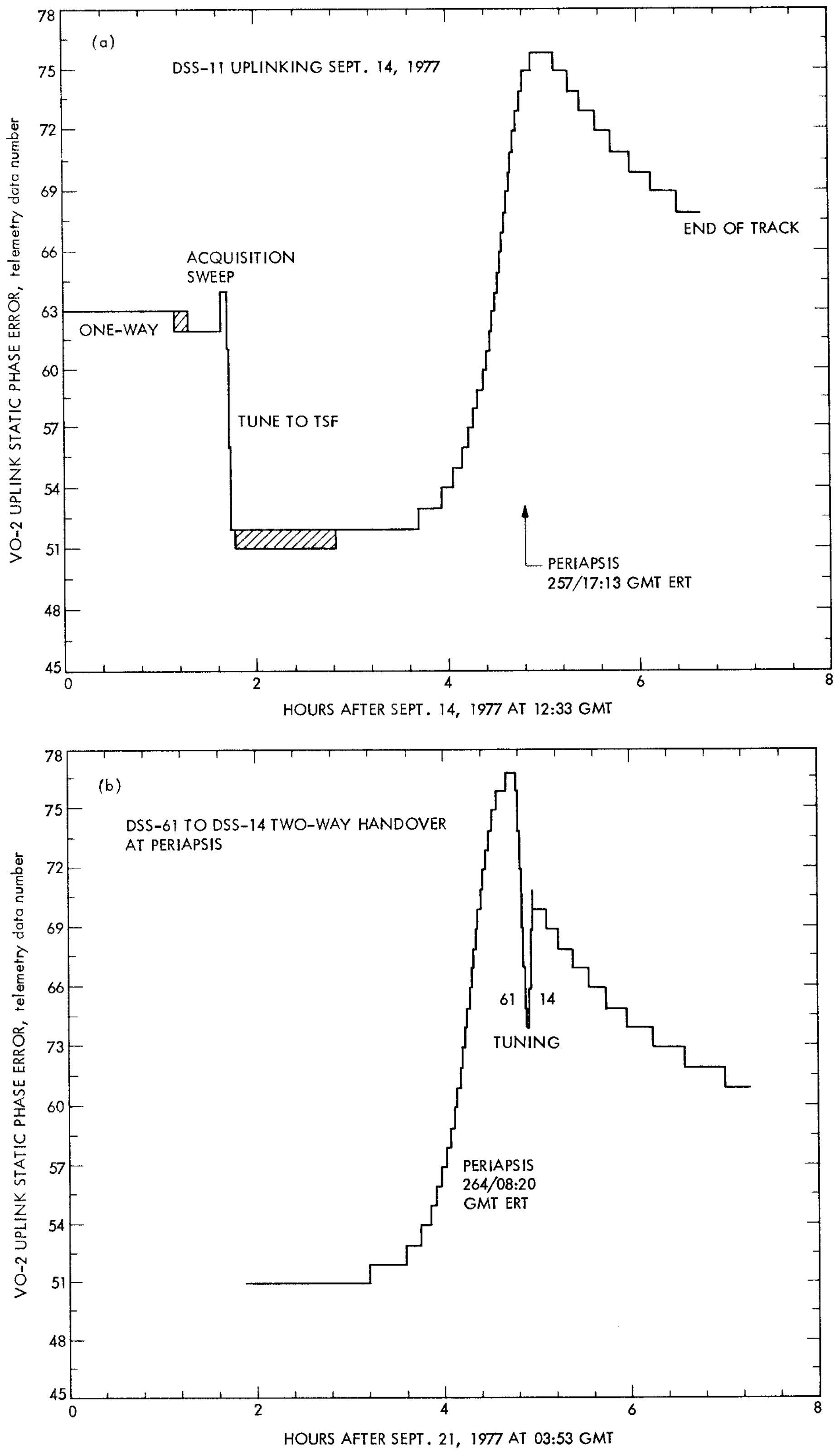

Fig. 6. Uplink acquisitions of VO-2, showing static phase error changes

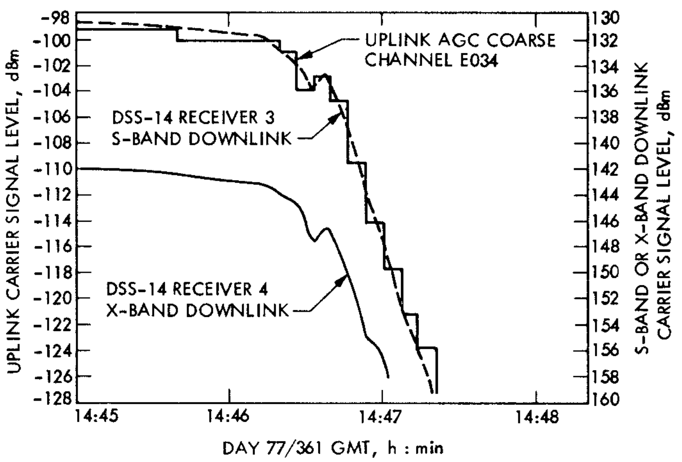

Fig. 7. VO-2 uplink and downlink signal levels prior to entering Earth occultation, DSS-14, Dec. 27, 1977

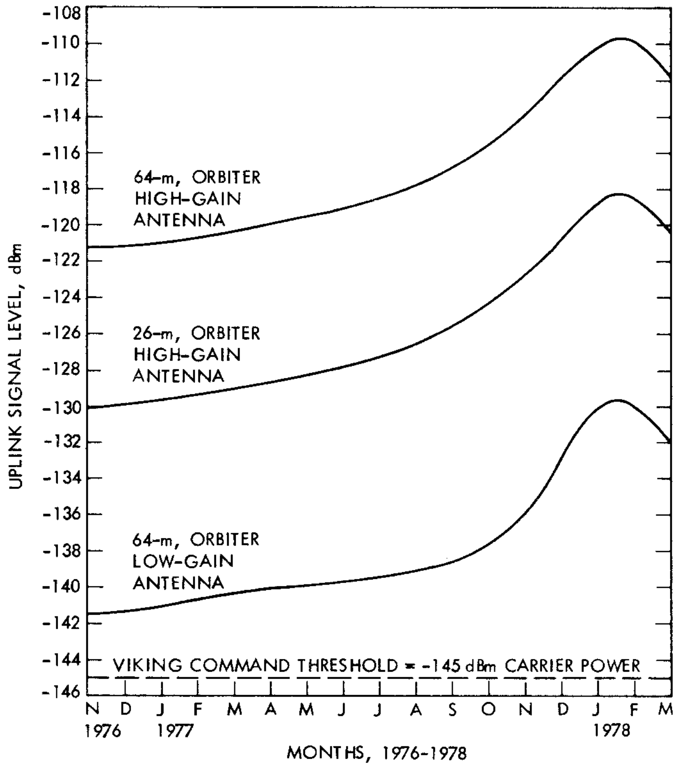

Fig. 8. Predicted uplink signal level, Viking Extended Mission 20-kW transmitter power, command and 9-dB ranging modulation on

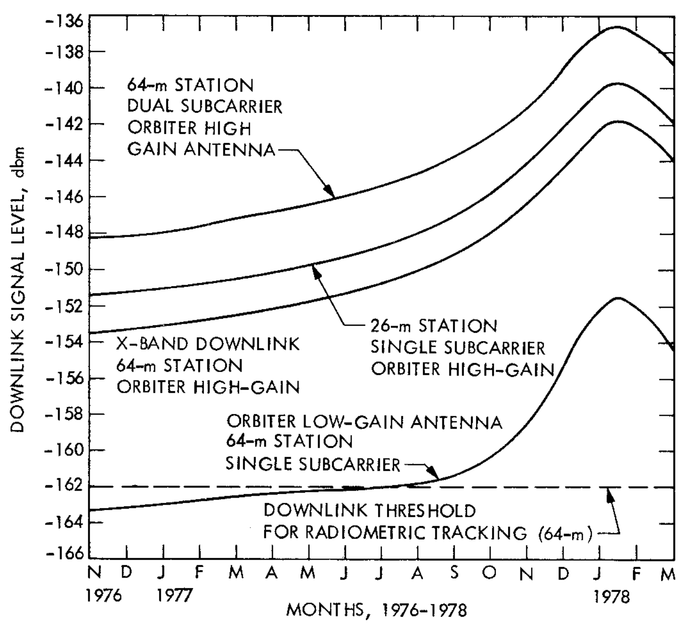

Fig. 9. Predicted downlink signal level, Viking Extended Mission Orbiter high-power mode, ranging channel on

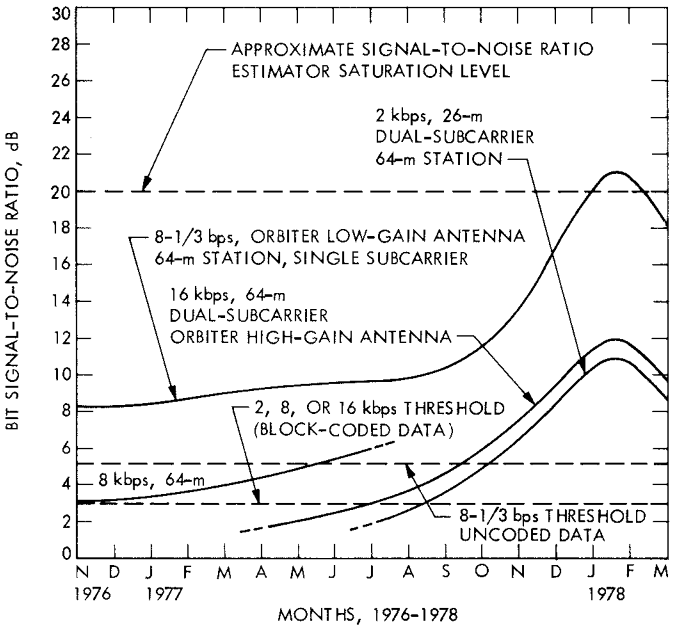

Fig. 10. Predicted signal-to-noise ratio, Viking Extended Mission Orbiter high-power mode, ranging channel on

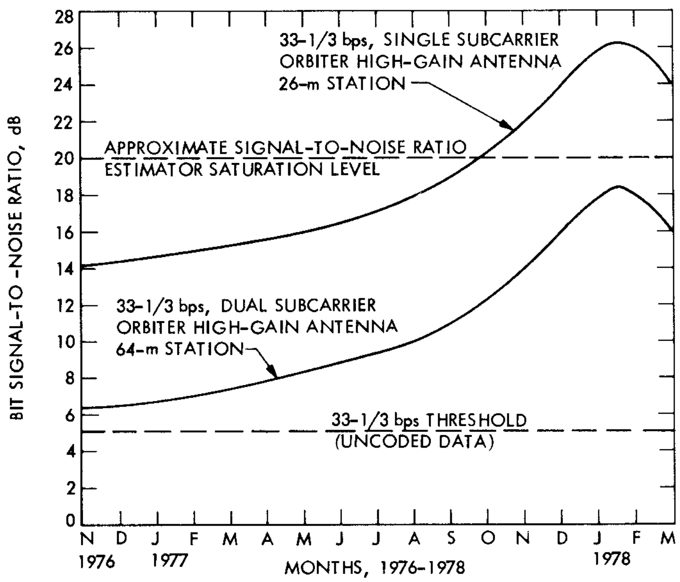

Fig. 11. Predicted signal-to-noise ratio, Viking Extended Mission Orbiter high-power mode, ranging channel on

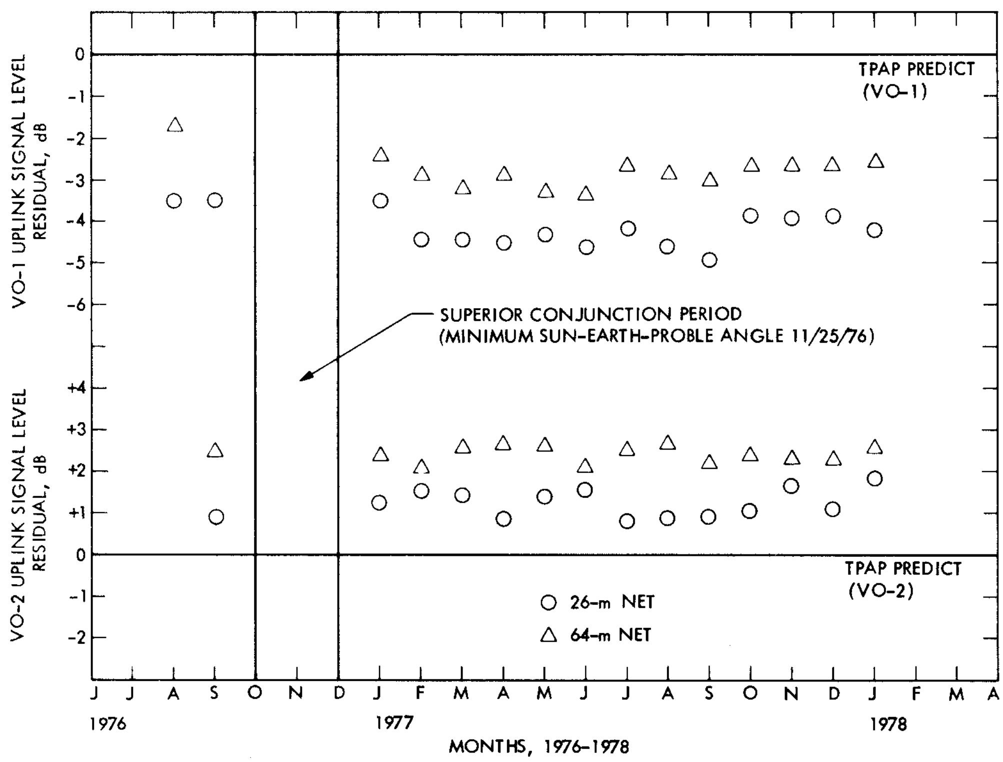

Fig. 12. VO-1 and VO-2 uplink AGC residual (observed mean difference from TPAP predict)

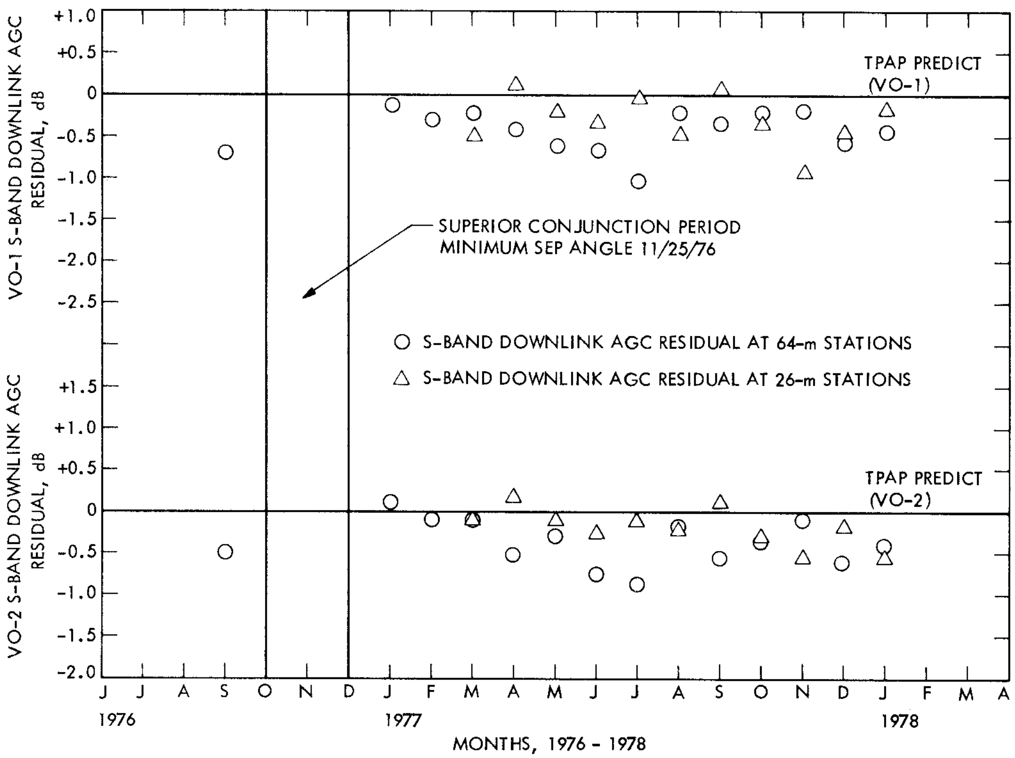

Fig. 13. S-band downlink AGC residual (dual subcarrier and single subcarrier combined, observed mean difference from TPAP predict)

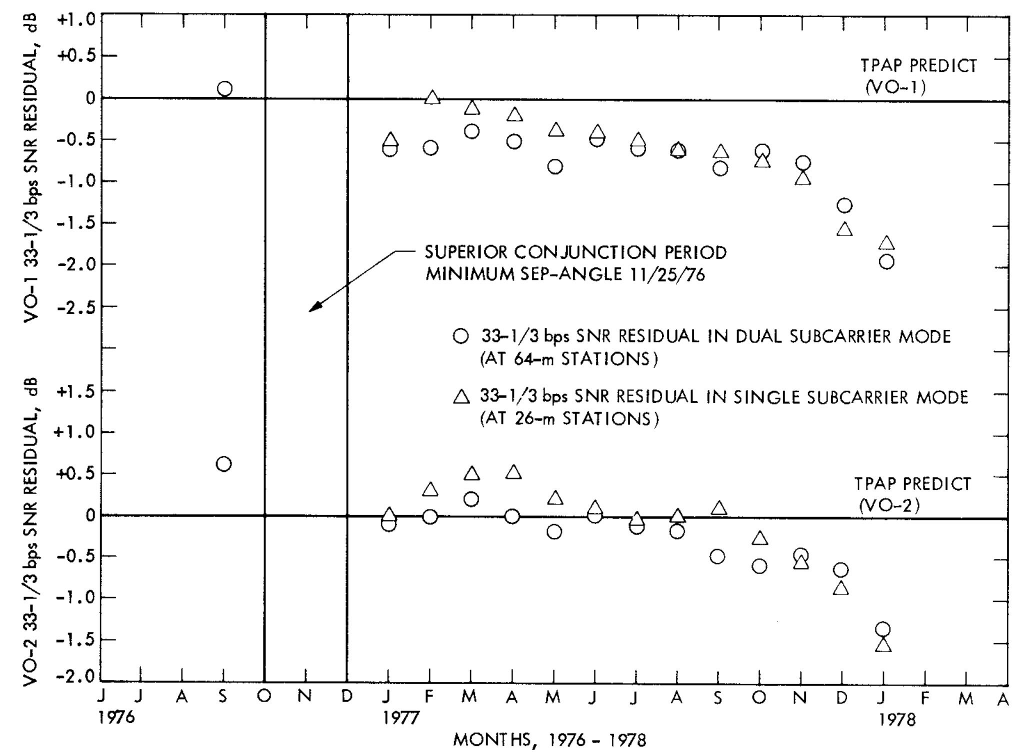

Fig. 14. VO-1 and VO-2 low-rate channel (33-⅓ bps) SNR residuals (observed mean difference from TPAP)

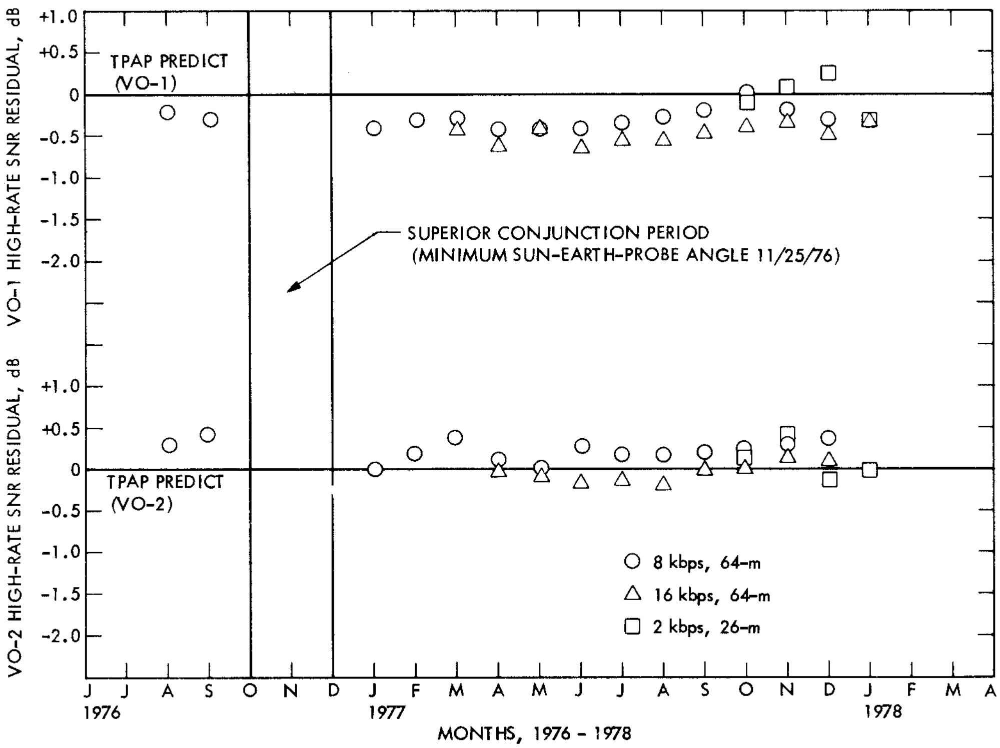

Fig. 15. VO-1 and VO-2 high-rate SNR residual (observed mean difference from TPAP predict)

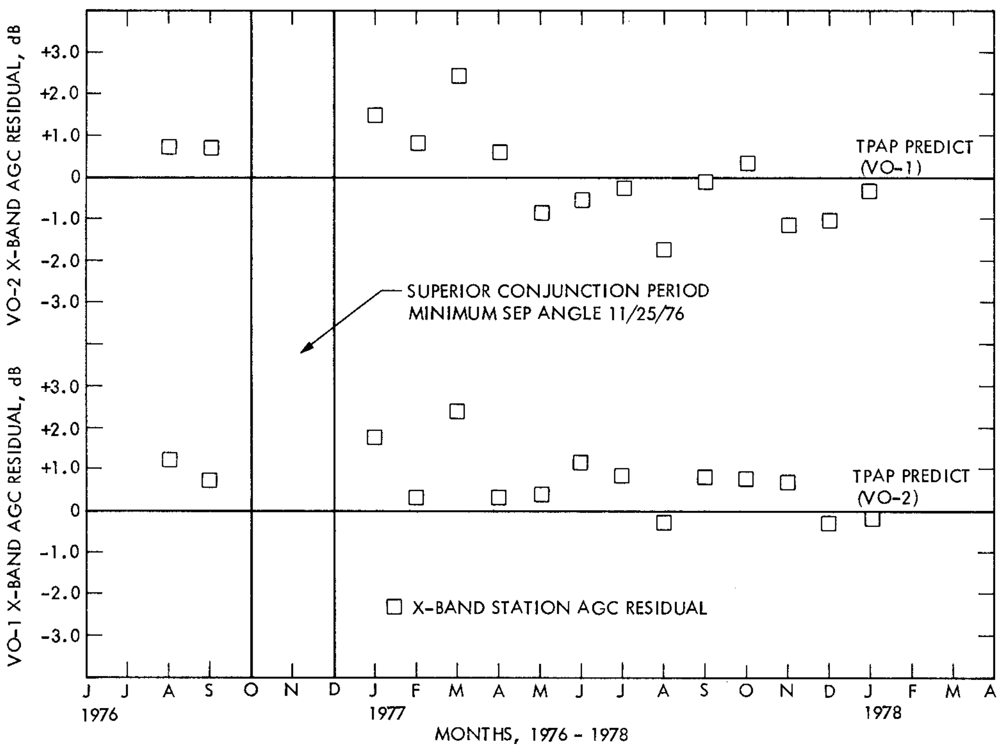

Fig. 16. VO-1 and VO-2 X-band station AGC resiauals at 64-m stations (observed - TPAP predict)

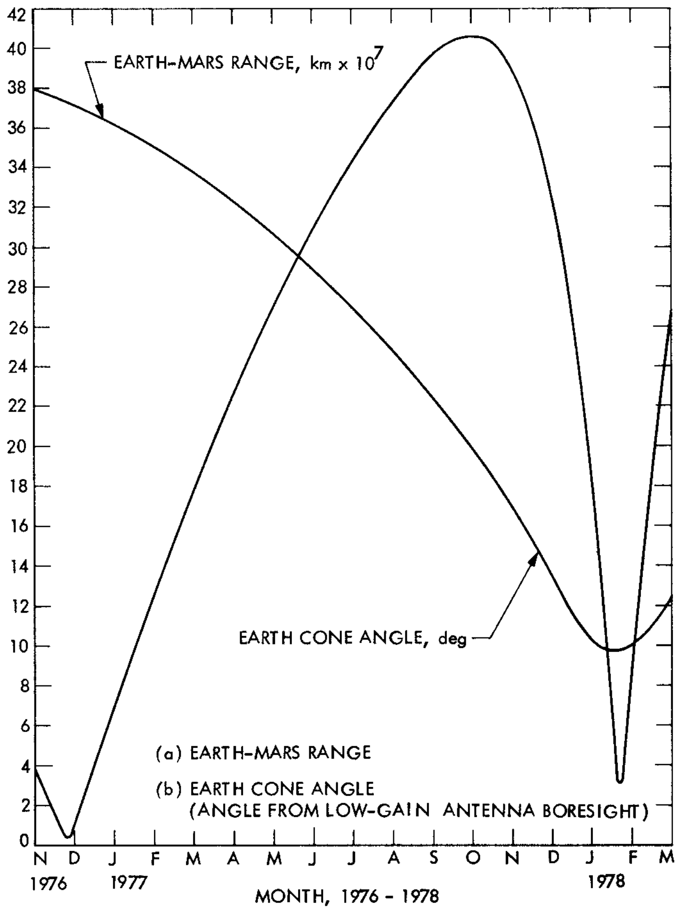

Fig. 17. Trajectory quantities for Viking Extended Mission

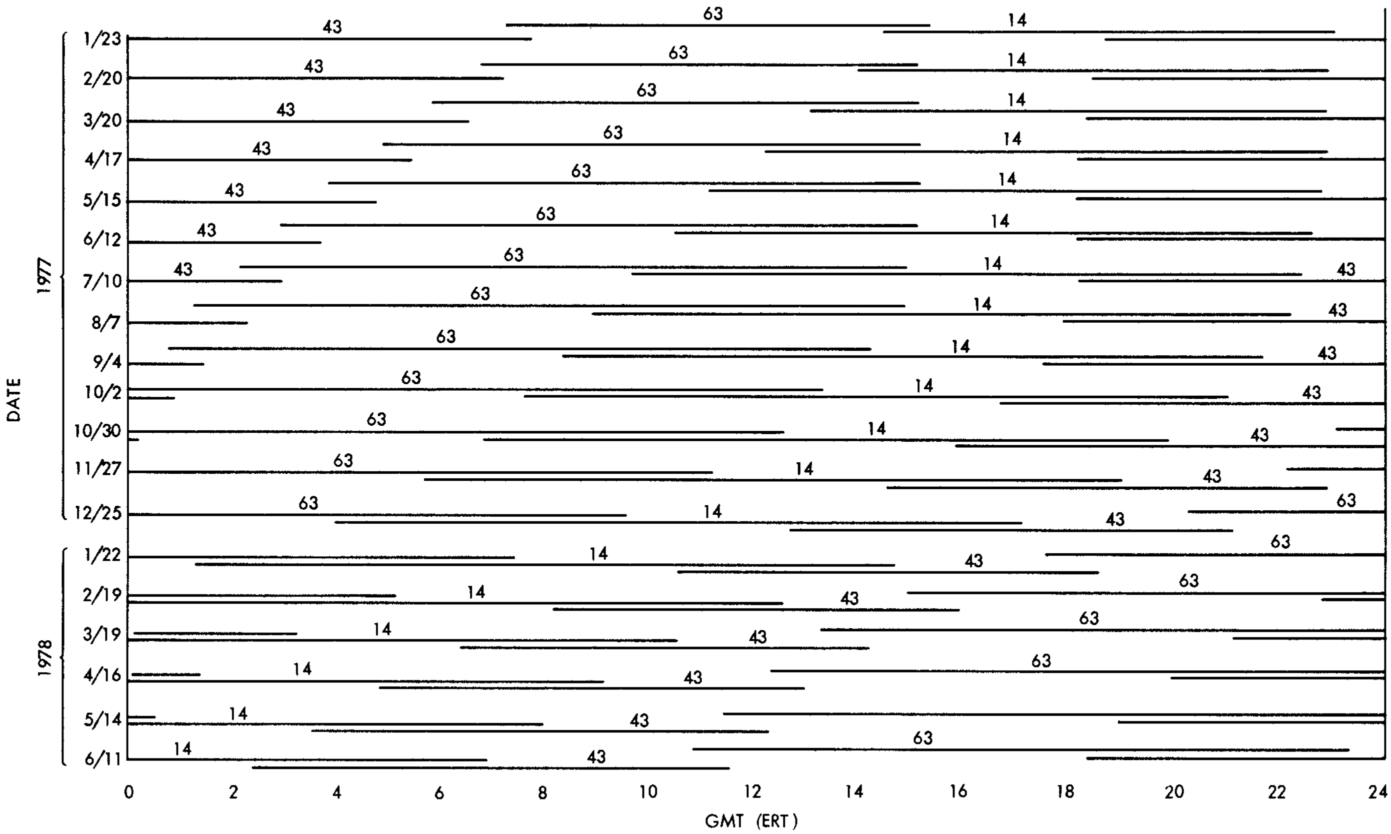

Fig. 18. Deep Space Network station view periods for Viking Extended Mission