Viking 1 Planetary Phase Tracking Operations: Mars Orbit Insertion Through Landing

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This article describes tracking operations during the Viking 1 planetary phase. Particular attention is paid to special planning for critical phase tracking operations, and to the degree of success subsequently achieved by these special plans during the actual operations. In-depth coverage is provided for Mars orbit insertion (MOI), periapsis passage tracking, and Lander direct links. The article concludes that on balance, tracking operations during the Viking 1 planetary phase (to date) have been effectively implemented and quite successful.

I. Introduction

On June 19, 1976 at 22:20:35 GMT the Viking 1 spacecraft initiated a 38-min motor ignition that subtracted sufficient velocity from the spacecraft to place it in a highly elliptical orbit about the planet Mars. The Viking 1 spacecraft had been launched from the Air Force Eastern Test Range (AFETR) almost exactly 10 months earlier (Aug. 20, 1975, at 21:22:00.6 GMT), and the successful completion of the Mars orbit insertion (MOI) motor burn dramatically marked the ending of the long (relatively) dormant cruise phase and the beginning of the intensely active planetary phase.

The initial stage of the planetary phase consisted of a photographic exploration of the Martian surface by the Viking 1 Orbiter spacecraft (VO1) in an attempt to find a safe haven for the Viking 1 Lander spacecraft (VL1). The successful landing on the Martian surface of the Viking 1 Lander on July 20, 1976, at 12:12:07.1 GMT, marked the initiation of the second stage of the planetary phase—a detailed all-encompassing scientific exploration of the Martian surface and atmosphere.

The complete success of the Mars Orbit Insertion was an absolute requirement for realization of the central Viking mission objectives. The criticality and difficulty in establishing and maintaining the telecommunications links to the spacecraft by the Deep Space Network during the MOI phase were second only to the launch phase, and hence a very intensive effort was jointly mounted by the Viking Project and the DSN to devise various tracking strategies to optimize tracking operations and attain all mission goals during the critical MOI period.

This report will detail the preplanning for the MOI period, as well as for the subsequent orbital operations and the direct Lander links. The performance of the DSN during the critical planetary periods will then be analyzed; in particular, the report will focus on the success of the various tracking strategies devised for these periods.

II. MOI Overview

In order to properly align the Viking 1 spacecraft so that its 38-min MOI motor burn would place it into the correct Mars-centered orbit, the spacecraft was programmed to undergo a sequence of three turns: a roll turn, a yaw turn, and a second roll turn. The combination of the resulting geometric orientation (unfavorable cone and clock angles) and the use of the low-gain antenna was expected to cause the loss of both the uplink and downlink signals from shortly after the start of the yaw turn until the end of the second roll turn and return to the high-gain antenna. Following the burn, the spacecraft was to go through the same turns and undergo loss of signal in reverse order to restore it to its original orientation.

In view of the above, it was considered necessary to design uplink and downlink strategies which would:

(1) Give the best opportunity for a fast uplink reacquisition prior to the start of the MOI burn

(2) Allow quick acquisition of the downlink prior to the start of the burn

(3) Have the overall effect of allowing the burn to be observed in the two-way mode with undisturbed radio metric and telemetry data.

(4) Enable reacquisition of the uplink and downlink as soon as is practical following the turn unwinds

During April 1976, a series of meetings was held between representatives of the Orbiter Performance Analysis Group (OPAG), Flight Path Analysis Group (FPAG), and the DSN to work out the specific details of the uplink frequency strategy. As a result of these meetings, the key features of the Viking 1 MOI were formulated as follows:

(1) The ground transmitter would be maintained (on) throughout the critical MOI period.

(2) Uplink ramping would be performed during the preburn period of low uplink signal level.

(3) An "insurance" sweep would be performed immediately after the uplink ramping (in item 2) to insure an uplink in the contingency of the uplink being lost during the ramping period.

(4) The reacquisition of the uplink during the post-burn period would be delayed (by approximately 10 min from the earliest opportunity) so that FPAG could clearly gauge in near-real-time the end of the MOI burn and the beginning of the post-burn roll turn in the doppler data (earlier uplink tuning would have disrupted the doppler (ground) reference frequency).

The downlink strategies for the MOI period were devised by the DSN Tracking Network Operations Analyst (Track NOA).

A detailed description of both uplink and downlink strategies is presented in Sections III and IV.

III. MOI Uplink Strategy

A. Preburn Uplink Strategy

The pre-MOI burn uplink strategy, in accordance with the Section II guidelines, was designed with the intent of acquiring the spacecraft receiver at the earliest possible time, perhaps before the switch back to the high-gain antenna with its subsequent return of the downlink signal.

During the course of the yaw and roll turns, the uplink signal strength was expected to gradually decrease and a series of antenna nulls would then be encountered. Near the end of the roll turn the signal strength would begin to gradually increase. To take advantage of this situation, Deep Space Station (DSS) 14 at Goldstone DSCC would ramp the uplink frequency in a linear approximation of the change of XA (spacecraft receiver best lock with doppler accounted for), starting at the beginning (ground transmit time) of the yaw turn. By doing this, the spacecraft receiver would receive a constant frequency and could be expected to be reacquired whenever the signal rose above its threshold. To insure reacquisition, an "insurance" sweep covering approximately 50 Hz (at voltage controlled oscillator (VCO) level) around XA was designed to be executed coincident with the switch to the high gain antenna. The result of either (or both) of these sweeps would be the reacquisition of an uplink and good two-way data approximately five minutes before the start of the burn.

Figure 1 illustrates this tuning strategy as compared to the significant spacecraft events.

The detailed tuning instructions for DSS 14, based on a nominal burn start time of 22:03:08 GMT, (DSS transmit time), were as follows (with frequencies at digital controlled oscillator (DCO) level):

Start tuning	21:27:00	GMT
Tuning rate	+0.0275	Hz/s (DCO)
Start frequency	43993800	Hz (DCO)
Start insurance sweep	21:57:00	GMT
End insurance sweep	21:59:25	GMT
Sweep lower limit	43993750	Hz (DCO)
Sweep upper limit	43993940	Hz (DCO)
Tuning rates	+2.0000	Hz/s (DCO)
	−1.9900	Hz/s (DCO)

B. Post-Burn Uplink Strategy

Approximately 4 min after the end of the MOI burn the turn unwinds (the mirror image of the turns) were to commence, with their associated losses in uplink and downlink. It would not be possible to ramp the uplink in a manner similar to the pre-MOI burn strategy as these ramps would have to occur during the observation of the burn itself, thus perturbing the radio metric data. The Flight Path Analysis Group (FPAG), in order to accurately assess the burn in near real-time, required that the two-way radio metric data have an unperturbed reference frequency. Additionally, FPAG desired to observe the start of the first roll unwind. Thus, the post-MOI uplink reacquisition was to be delayed until one minute after observing the start of the roll unwind, thereby simplifying the acquisition procedure.

The post-MOI burn uplink strategy, as designed to accommodate the above constraints, consisted of a single sweep from the pre-burn Track Synthesizer Frequency (TSF2) to a new tracking synthesizer frequency (TSF3) at a rate of 1 Hz/s (DCO). This sweep would effectively encompass the XA frequency plus 100 Hz and minus 50 Hz (VCO), accommodating any trajectory uncertainties as a result of the burn. Start time of the sweep was to be one minute after the start of the roll turn unwind in Earth return time (ERT), and coincident with the loss of downlink due to turn.

The post-burn uplink tuning instructions for DSS 14 were as follows:

Start tuning	23:22:00 GMT
Start frequency (TSF2)	43993940 Hz (DCO)
Tuning rate	−1.0000 Hz/s (DCO)
End frequency (TSF3)	43993640 Hz (DCO)
Sweep duration	5 min

The above described tuning can be seen in Fig. 1.

IV. MOI Downlink Strategy

A. Preburn downlink strategy

As described earlier, because of unfavorable antenna orientation, the downlink signal level was expected to gradually degrade to approximately −186 dBm during the yaw turn and further decrease during the second roll turn. It would be necessary then to quickly acquire the signal after the end of the roll turn in order to have solid telemetry lock throughout the ground data system before the start of the burn.

To accomplish this, the station was to sweep the prime receiver (Receiver 3, Block IV) at a high rate (2000 Hz/s S-band) using the acquisition (ACQ) mode with the acquisition-trigger-at-zero-beat (ATZ) signal enabled. The sweeping was to start five minutes before the end of the roll turn in order to ensure receiver lock as early as possible. In order to accommodate any trajectory uncertainties and the contingency of a missed uplink acquisition, the receiver sweep would be wide enough (frequencies corresponding to two-way doppler (D2) ±12 kHz) to detect both the one- and two-way signals. Additionally, since there would be the possibility (however remote) that glitches between the one- and two-way mode would be seen on the ground before the end of the roll turn, the receiver operator was to be prepared to restart the ACQ mode receiver sweeps if the signal was lost.

The actual tuning instructions given to DSS 14 for this downlink acquisition were as follows:

Sweep start	22:25:00 GMT
Sweep upper limit	44678710 Hz (DCO)
Sweep lower limit	44677510 Hz (DCO)
Sweep rate	100.0 Hz/s (DCO)

B. Postburn Downlink Strategy

Since the uplink acquisition sweep was required to be delayed (as described in Sec. III, Paragraph B.), there would be a period of one-way tracking following the end of the yaw turn unwind. It would be necessary then to sweep the receiver through a range of one-way frequencies large enough to account for the high doppler rates due to periapsis passage, trajectory uncertainties introduced by the insertion burn, and auxiliary oscillator frequency uncertainties.

During the yaw unwind following the burn, the downlink signal level was expected to gradually increase from threshold (−175 dBm in 10 Hz RF filter) to approximately −162 dBm. The strategy to secure a reasonably fast downlink acquisition under these difficult conditions was composed of two elements as follows:

(1) The receiver to be set at the predicted D1 when the signal level reaches −170 dBm, in the hope of allowing the signal to "walk through" the receiver.

(2) If this fails, the receiver to be swept in the ACQ mode at a time when the signal level reaches −167 dBm, and at a sweep rate calculated for a signal level of −165 dBm. Specifically, the receiver was to be swept through frequencies equivalent to D1 ± 500 Hz (S-band) and at a rate of 100 Hz/s (S-band) while in ACQ mode with ATZ enabled, and in a radio frequency (RF) bandwidth of 10 Hz.

The specific receiver instructions given to DSS 14 are as follows:

Receiver set to	44678151.5 Hz
Start sweep	23:44:10 GMT
Upper limit	44678195 Hz (DCO)
Lower limit	44678145 Hz (DCO)
Rate	5.0 Hz/s (DCO)

The change from one-way to two-way mode was expected to occur approximately 15 min after the end of the yaw turn (ERT).

The instructions given to DSS 14 for this two-way reacquisition were as follows:

Frequency upper limit	44678335 Hz (DCO)
Frequency lower limit	44678135 Hz (DCO)
Sweep rate	25.0 Hz/s (DCO)

C. "Fast" X-Band Acquisition

A concern of the OPAG during the MOI sequence was the possible loss of Canopus lock. One of the contingencies advanced in response to this concern was the use of X-band to determine the spacecraft orientation. Basically, this entailed having the DSS able to acquire an X-band downlink within a few seconds after its appearance, and, at a time when the signal level would be in the area of only −155 to −160 dBm. To meet this objective, the Track NOA proposed the following acquisition sequence, to be tried at the end of roll unwind 2, following the MOI burn:

(1) Block IV X-band receiver to be used in ACQ MODE, ATZ enabled, and with an RF bandwidth of 10 Hz

(2) Sweep to start 5 min before end of roll turn

(3) Sweep to be D2 ± 850 Hz (X-band)

(4) Sweep rate to be 850 Hz/s (X-band)

(5) Data rate to be 1/s from sweep start to end of roll turn plus 5 min.

If successful, this procedure would be expected to lock the X-band signal some 6 or 8 s prior to the end of the roll turn.

V. MOI Burn Profile

The actual MOI burn parameters are as follows:

Burn start	22:38:03 GMT (ERT)
Burn stop	23:15:52 GMT (ERT)
Magnitude (ΔV)	405 m/s (radial component)

A profile of the two-way doppler rate of change (DD2) during the burn is seen in Fig. 2. Additionally, Figs. 1 and 3 illustrate the effect of the burn and subsequent periapsis passage on the XA frequency (in DSS transmit time) and the two-way doppler (ERT). Figure 4 provides an overall time line for the significant MOI events.

VI. Periapsis Receiver Ramping

A. Introduction

During the Viking 1 orbital phase, X-band radiometric data are being used as an important data type in several radio science experiments including studies of the Martian gravity field, atmosphere and ephemerides as well as relativity and solar corona experiments. It was and continues to be important, therefore, to maximize the quality of the radio metric data especially at periapsis.

To assure good data, it is necessary to ramp the X-band receivers. Ramps were designed, therefore, with an emphasis on:

(1) Minimizing receiver phase error, with the intention of keeping phase error less than 10 deg

(2) Minimizing the number of cycle slips (<19 in a 12-h period)

(3) Keeping the receivers in lock during the periods of high frequency rates and

(4) Operational simplicity

By executing the designed ramps, it was hoped that good quality X-band radio metric data through the periapsis period could be attained.

B. Receiver Ramp Design

During the period near periapsis the nominal X-band two-way doppler frequency rates extended from a maximum positive excursion of ~40 Hz/s (X-band) to a maximum negative excursion of ~ −40 Hz/s (X-band). This region of high rates lasted approximately four hours starting at 2 h before periapsis.

A sequence of receiver ramps, spanning this time period, was designed that would allow good X-band radio metric data to be acquired. Generally, each ramp was to start and stop when the doppler rate was one-third of its maximum positive or negative excursion. The ramp rate was to be equal to two-thirds of the receiver frequency change rate. Starting frequency for the ramps was to be the frequency at the start time of the first periapsis ramp. By choosing the ramps in this manner, there would be three ramps, the optimum number since this would require no reprogramming of the rate and frequency registers of the programmable oscillator control assembly. For rates above 40 Hz/s (X-band), additional ramps would have to be added. These ramps would be chosen in a manner similar to that of the initial three ramps.

A typical X-band receiver ramp sequence (with ramp frequency inverted for better comparison to D2 frequency) is shown in Fig. 5. The receiver frequencies for this periapsis are shown in Fig. 6.

Parameters for this sequence are:

Start ramping	06:55:00 GMT
Frequency	41368020 Hz (DCO)
Ramp rate 1	−0.3035 Hz/s (DCO)
Start ramp 2	08:06:00 GMT
Ramp rate 2	0.0000 Hz/s (DCO)
Start ramp 3	08:14:00 GMT
Ramp rate 3	0.2173 Hz/s (DCO)
End ramping	09:32:00 GMT
Ramp duration	157 min

C. Phase Error Analysis

Of prime consideration in designing the ramping strategy is the need to minimize phase error, consistent with the minimization of operational difficulty. Figure 5 illustrates the dynamic phase error of a typical ramping sequence. As can be seen, the dynamic phase error generally lies within the 10 deg desired limit. Figure 6 shows the static phase error for the same sequence. It can be seen here that the SPE remains well under the 10 deg desired maximum.

The total phase error is shown in Fig. 7. Here, it can be seen that the dynamic and static phase errors interact in such a way as to generally keep the total phase error below the 10 deg desired maximum. This limit is exceeded slightly for approximately 15 minutes during the period of highest (positive) two-way doppler rates.

Finally, all phase error was computed for a bandwidth of 10 Hz, and a receiver margin of 15 dB. By increasing this bandwidth, it would be possible to further reduce total phase error.

VII. Lander Tracking Operations

A. Introduction

On July 20, 1976, approximately sixteen hours after the first Viking Lander was to touch down on the surface of Mars, DSS 43, Australia, was to commence the initial direct link with the lander. This acquisition, as well as subsequent acquisitions would have the following characteristics:

(1) The uplink acquisition would be made in the "blind," that is, with no downlink signal from the lander.

(2) Two receivers, each connected to a different antenna and with a 15- to 20-dB difference in signal level, were to be acquired.

(3) There would be, initially at least, large frequency and temperature uncertainties.

(4) The total acquisition time would be limited.

In order to accommodate these characteristics, very conservative uplink and downlink acquisition strategies were devised. These strategies were also to be used on all subsequent lander direct links including those of the second Viking Lander. A typical timeline for the lander direct link is seen in Fig. 8.

B. Uplink Acquisition

Frequency estimates specifying the uplink tuning pattern were provided to the DSN by the Lander Performance Analysis Group (LPAG). The choice of frequencies to be swept became quite complicated when one considered that the lander radio frequency subsystem (RFS) would be undergoing temperature (hence, frequency) changes due to:

(1) The Martian atmospheric effects, such as wind and diurnal temperature cycles.

(2) The turning on and off of the traveling wave tube amplifier (TWTA).

Using models of these effects, LPAG would determine an estimate of RFS temperatures and frequencies. The large temperature uncertainties combined with rather large frequency uncertainties for Lander 1:

$$3\sigma \text{ XA receiver 1} \sim 123 \text{ Hz (VCO)}$$

$$3\sigma \text{ XA receiver 2} \sim 116 \text{ Hz (VCO)}$$

resulted in the need for a very large uplink sweep range. The nominal lander uplink acquisition sweep (until in situ measurements of the temperature and frequency measurements allowed for change) was to have a range of channel 13 center frequency (22,010,119 Hz) plus and minus 470 Hz.

The starting frequency of the sweep would be chosen such that the start frequency and channel center frequency were in the same direction away from the receiver best lock frequency (XMTREF). Thus, for example, the initial acquisition sweep was to start 470 Hz above the channel 13 center frequency (or 22,010,589 Hz), since the XMTREF was approximately 16 Hz below the center frequency. Upon completion of the sweep, the station was to tune to a tracking synthesizer frequency (TSF) chosen to minimize the SPE of the primary command receiver (Receiver 1) during the remainder of the direct communication system (DCS) link.

Information supplied by LPAG indicated a frequency tuning rate region (at S-band) of:

$$44 \text{ Hz/s} < \text{frequency rate} < 219 \text{ Hz/s}$$

The choice of a sweep rate was influenced by:

(1) The desire to allow no more than 20 deg phase error due to both dynamic and static effects

(2) The need to complete a large sweep in a limited period of time

(3) The need to acquire receiver 1 through the low-gain antenna

Thus, the sweep rate (conservatively) chosen was 44 Hz/s or approximately 0.45 Hz/s (VCO).

Finally, the transmitter on-time was to be chosen to accommodate an expected 25 deg elevation landmask for the lander and the time necessary to slew the high gain antenna (HGA; a 0.76-m-diam, az/el drive antenna) from its stowed position to its tracking position. Combining all of the above mentioned parameters, the uplink acquisition procedure was planned to be as follows:

(1) Transmitter on at the HGA at "track" position time minus a one-way light time and at a power level of 20 kW.

(2) Tuning rate to be 0.45 Hz/s (VCO).

(3) The sweep to cover, at most, Channel 13 center frequency ±470 Hz.

(4) The duration of the sweep to be approximately 51 minutes.

The uplink sweep pattern in terms of spacecraft received frequencies is shown in Fig. 9.

C. Downlink Acquisition

Due to temperature and power constraints the Viking Lander S-band transmitter was to be turned on for at most 92 min (for long DCS links) starting approximately 70 min after the completion of the uplink acquisition sweep. It would therefore be necessary to sweep the receivers in such a manner as to quickly acquire the two-way downlink and to allow for the acquisition of a one-way downlink as a contingency.

The following information concerning the one-way and two-way downlink frequency was available:

(1) The frequency uncertainties for the lander auxiliary oscillator frequencies were quite large:

$$3\sigma \text{ AUX OSC 1 frequency} \sim 8200 \text{ Hz}$$

$$3\sigma \text{ AUX OSC 2 frequency} \sim 2200 \text{ Hz}$$

(2) The two-way doppler frequencies were expected to be highly accurate.

(3) The difference between one- and two-way doppler was to be approximately 12,000 Hz with one-way doppler (D1) at the higher frequency, i.e.,

$$-\text{TFREQ} + 96\,\frac{240}{221}\,\text{XMTREF} \cong 12 \text{ kHz}$$

This information, as well as the fact that the station configuration (configuration code 61) called for a Block IV receiver as prime with a Block III receiver as backup led to the choice of an easily workable, albeit unique receiver sweep strategy that had a high probability of acquiring either the one- or two-way downlink.

Basically, the Block IV receiver would be swept at a very high rate (2000 Hz/s, (S-band) through the range of doppler frequencies defined by

$$(\text{D1} - X) \pm (12000 + X) \text{ Hz}$$

where X would, in general, equal $\sim$ 2 kHz.

Thus, the sweep was to encompass both the one- and two-way downlink frequencies. The sweep was to be executed with the receiver programmed oscillator control assembly in ACQ mode with the ATZ signal enabled. This would automatically terminate the sweep upon detection of the downlink signal. Additionally, the sweep was to start approximately 5 min before the time that the downlink signal was expected to be seen. Using this high sweep rate, the entire range of frequencies would be swept approximately every 12 s.

The downlink acquisition procedure planned was therefore:

(1) The receiver DCO programmed to be swept at 2000 Hz/s (S-band) or 100 Hz/s (DCO) through receiver frequencies corresponding to the range:

$\text{D1} - 16 \text{ kHz} \leq \text{frequency} \leq \text{D1} + 12 \text{ kHz}$ (where $\text{D1} > \text{D2}$)

(2) At expected downlink minus 5 min flag doppler as two-way data and start receiver using ACQ mode with ATZ.

D. Lander Tracking Predictions

Since the ephemeris of Mars is fairly well known, predicts were expected to be highly accurate, with the exception of the observables D1 and XA. These frequencies, as mentioned earlier, would have quite large uncertainties. Thus, to accommodate these uncertainties, predicts were to be generated twice a week during the early tracking period. As more experience was gained, the predicts would be generated on a weekly schedule.

E. Ranging

Approximately 2 h after the start of the short downlink lander pass and after the period of real-time imaging, a short period ($\sim$10 min) of time was to be allocated for ranging to the lander.

The ranging accuracy requirements supplied by LPAG were quite liberal, calling for 15 m acceptable one-way 1σ range jitter and 15 components to resolve range ambiguity; these under conditions of -2 dB carrier suppression and an expected ranging power to noise ratio of 1.75 dB. Additionally, since a precise lander location needed to be determined quickly, pipelining of the range code to acquire multiple range points was considered. Pipelining is a previously unused option of the planetary ranging assembly (PRA) which simply allows sequential retransmission of the ranging code, thus making possible many repeated acquisitions within a limited time. With the additional help of an option to transmit immediately, it was felt that three range points of good accuracy could be acquired in less than 10 min.

The ranging parameters chosen under the guidelines of project requirements were: T1, 38 s; T2, 9 s; and 15 components, for a total integration time of 2 min, 44 s. An additional 20 s would also be added before the start of transmission to allow the lander ranging subsystem to settle into normal operating condition.

VIII. Viking 1 Planetary Phase Operations Analysis

A. MOI Uplink Acquisition Performance

1. Preburn period. As mentioned in Sec. III, Paragraph A., it was expected that the uplink would be lost during the yaw and roll 2 turns; in anticipation of this circumstance the uplink was ramped to closely match XA and an "insurance" sweep was performed immediately after the end of the roll 2 turn. Subsequent to the event, Viking Project (OPAG) analysis showed the uplink was maintained throughout the ramping period, attesting to the efficacy of the ramping procedure and thus additionally having rendered the insurance sweep unnecessary.

2. Postburn period. The postburn uplink acquisition subsequent to the conclusion of the yaw unwind turn (described in Section III, Paragraph B.) was successful, and the uplink was maintained routinely from this period forward.

In summation, MOI uplink acquisitions were exactly according to plan and completely successful.

B. MOI Downlink Acquisition Performance

1. Preburn acquisition. According to plan, the Block IV S-band Receiver (No. 3) was placed in the ACQ mode (ATZ enabled) 5 min prior to expected signal reappearance after roll 2 turn (at approximately 22:32:00 GMT). The Receiver 3 sweep pattern and acquisition is seen in Fig. 10. The expected time of signal reappearance was 22:31:52 GMT, and Receiver 3 locked the downlink at 22:32:00 GMT, which can be seen in Fig. 10 to be the first zero crossing after signal emergence. The Block III S-band receiver lock time was 22:31:58 GMT.

2. Postburn one-way downlink acquisition. As described in Section IV., Paragraph B., the first phase in the attempt to acquire the one-way downlink shortly after its emergence at threshold was to allow the doppler to "walk through" the receiver (which was set at a constant frequency). This plan was unsuccessful, and the receiver "tuning" (i.e., referenced to the predicted doppler value) can be seen in Fig. 11. The signal passed through the receiver at 23:42:26 GMT, and at a signal level of approximately −168 dBm. One can see in Fig. 11 that at the expected acquisition time, three receiver frequency "spikes" occurred, which might easily explain the aborted acquisition. Upon careful examination, almost all of the spikes seen in Fig. 11 have a value very close to: $\pm n\ \{20\}$, S-band Hz (n = small integer). 20 Hz S-band is exactly equal to 1 Hz DCO, so it would appear quite possible that the misacquisition was ultimately due to an erratic synthesizer.

The second phase in the acquisition plan was to place the Block IV Receiver (3) in the ACQ mode at 23:44:10. Goldstone DSS 14 elected (at their option) not to use the ACQ mode, but instead to try and lock the Block IV Receiver using the lockup frequency from the Block III S-band receiver. Block IV receiver lock to the downlink was not achieved until 23:46:41 GMT, and (with hindsight!) the ACQ mode plan for 23:44:10 might have achieved a quicker acquisition. The Block III S-band receiver lock-up time was 23:43:40 GMT.

3. Postburn two-way downlink acquisition. At 00:00:22 GMT, the ground receivers were thrown out of lock by the one-way/two-way downlink transition. The Block IV S-band Receiver (3) was put in the ACQ mode according to plan (and as described in Section IV., Paragraph B.) and acquired the downlink very rapidly – at 00:03:12 GMT, well ahead of the Block III acquisition at 00:04:42 GMT.

C. Fast X-Band Acquisition

As previously mentioned (Sec. IV., Paragraph C.), the DSN would attempt to lock the X-band signal within seconds after its reappearance at the conclusion of roll 2 unwind. The Orbiter Performance Analysis Group predicted a roll 2 unwind time of 00:23:03 GMT, June 20, with the X-band signal crossing (above) threshold some 10 to 20 s prior to that time. The instructions given to DSS 14 were as follows:

Start sweep time	00:18:00 GMT
Frequency upper limit	41368122 Hz (DCO)
Frequency lower limit	41368102 Hz (DCO)
Sweep rate	10.0 Hz/s (DCO)

The Viking 1 Fast X-band acquisition results are seen in Fig. 12. Acquisition of the X-band signal occurred at 00:22:52 GMT, a full 11 s before the end of roll 2 unwind.

Since the OPAG criterion for a successful fast acquisition was an acquisition at least several seconds before the end of the (roll 2) turn, the procedure as demonstrated here must be adjudged a complete success.

In summation, except for the (relatively insignificant) failure to lock at a very low signal level during the one-way signal reappearance post MOI burn, all Block IV receiver acquisitions were extremely rapid and successful. The failure to lock during the one-way signal reemergence is attributed to an erratic synthesizer.

D. Periapsis Receiver Ramping

The periapsis receiver ramping strategy described in Sec. VI was predicated on usage of the high-gain antenna (HGA) during the periapsis pass. However, because of photographic requirements, many of the periapsis passes utilized the low-gain antenna (LGA), and in fact, the LGA orientation on some passes caused the signal to degrade from a nominal −161 dBm to threshold (−175 dBm) or below. During the LGA periapsis passes, it was found that the receiver ramping scheme (appropriately translated from X-band to S-band levels) was very helpful in just keeping the S-band Block IV receiver in lock! The receiver ramping strategy was thus amended to:

HGA passes: Ramp Block IV X-band receiver

LGA passes: Ramp Block IV S-band receiver

The effectiveness of the S-band receiver ramping has been attested to by the DSS receiver operators, while Viking Radio Science has to date been satisfied with the X-band receiver ramping operations.

E. Lander Operations

1. Uplink acquisition. At 05:10:00 GMT on July 21, DSS 43 turned on its transmitter and began the initial uplink acquisition with the Viking Lander precisely as described in Section VII., Paragraph B. This strategy translated to frequencies for July 21, had the following parameters:

Transmitter on	05:10:00 GMT
Start tuning	05:10:40 GMT
Starting frequency	22011247 Hz (VCO)
Tuning rate	−0.45 Hz/s (VCO)
Tune to	22010302 Hz (VCO)
Start tuning to TSF	05:45:40 GMT
TSF	22010770 Hz (VCO)
Tuning rate	+0.45 Hz/s (VCO)
Stop tuning	06:03:00 GMT
Sweep duration	52 min 20 s

The acquisition sweep was executed with precision and without complication. However, following the acquisition of the Lander downlink signal approximately one hour after the end of the sweep, it was found that Receiver 1, the primary (and emergency) command receiver connected to the low-gain antenna, had not been acquired during the sweep. In fact, this receiver was actually observed to "lock up" in telemetry received several minutes after the downlink was acquired. This anomalous behavior became the subject of much study by the Lander Performance Analysis Group, including lengthy (up to eight hours in one case) sweeps attempted in order to acquire the receiver and has not, as of this writing, been fully explained.

2. Downlink acquisition. At 07:10:00 GMT, following the guidelines of the downlink acquisition strategy, Australia DSS 43 began sweeping its receivers to find the Viking Lander signal. The planned acquisition sweep had the following parameters:

Start acquisition sweep		07:10:00 GMT
Expected downlink		07:12:47 GMT
Sweep upper limit		44753046.55 Hz (DCO)
	or	D1 − 12000 Hz (S-band)
Sweep lower limit		44751846.55 Hz (DCO)
	or	D1 + 12000 Hz (S-band)
D1 − D2		~7000 Hz (S-band)
Sweep rate		2000 Hz/s (S-band)

As can be seen, the sweep encompassed both the one- and two-way downlink frequencies as well as reasonable uncertainties in these frequencies. Approximately two minutes later than expected, 07:14:31 GMT, the two-way downlink was acquired. This acquisition confirmed the efficacy of the uplink acquisition procedures but brought up a question concerning the downlink acquisition procedures: Was the sweep rate too fast for this signal level (−148 dBm)? A similar difference between expected and actual acquisition of signal (AOS) times occurred on the next Lander direct link as well. After consultations with the Lander Performance Analysis Group it was learned that the expected AOS time was actually the time that the traveling wave tube amplifier was turned on and a radio frequency downlink would not be observed until approximately 90 s later. Thus, the downlink was actually acquired the first time that the receiver swept through the downlink signal.

3. Ranging. Ranging modulation was turned on at DSS 43 at 07:20:20 GMT and the transmission of the ranging code began 20 s later, according to the procedures described earlier. Integration of the third range point was completed at approximately 08:08:13 GMT; the range channel was observed to be shut off at 08:08:25 GMT. Pseudo-DRVID, a comparison of differenced range points with integrated doppler to provide validation of the range points, was computed with the following results:

Acquisitions	Pseudo-DRVID (RU)
1/2	4.6
1/3	16.5
2/3	11.9

Thus, three good range points were indeed acquired in the allotted ranging time and with 13 s to spare!

IX. Prediction Accuracy

The predictions used for the MOI period were generated from a polynomial coefficient tape (PCT) delivered by the FPAG approximately 24 h prior to MOI. The accuracy of these predictions (identified as set VA 58) can easily be gauged by an examination of the Network Operations Control Center (NOCC) pseudo-residual program output. Doppler pseudo-residual data (defined as actual data − predicted data) for selected times throughout the DSS 14 MOI pass are presented in Table 1.

The prediction accuracy as seen in the pseudo-residual output is quite good, particularly when considering that the accuracy (after the burn) is dependent upon both inherent trajectory uncertainties and the accuracy of the MOI burn itself. The prediction accuracy before the burn (~22:38) is at least as good as the accuracies which have been obtained on recent planetary flybys.

X. Summary

The Viking 1 MOI period, with its crucial need for the acquisition and maintenance of the telecommunications links, effectively challenged the DSN tracking system. The Viking project and the DSN jointly evolved strategies to accommodate the MOI complexities, and these strategies were successful. Overall, tracking operations during the Viking 1 MOI period and subsequent planetary phase must be considered an unqualified success.

Table 1. Doppler pseudo-residuals, June 19 and 20

Time (GMT)	Δ(A−P), Hz	Doppler mode	Event
17:52:02	+ 0.3	2	Start of pass
22:37:00	+12.5	2	Before MOI burn
23:17:00	−98.8	2	After MOI burn
23:47:02	−33.6	1	High doppler rate period
00:04:02	+34.0	2	High doppler rate period
05:26:02	+28.3	2	End of pass

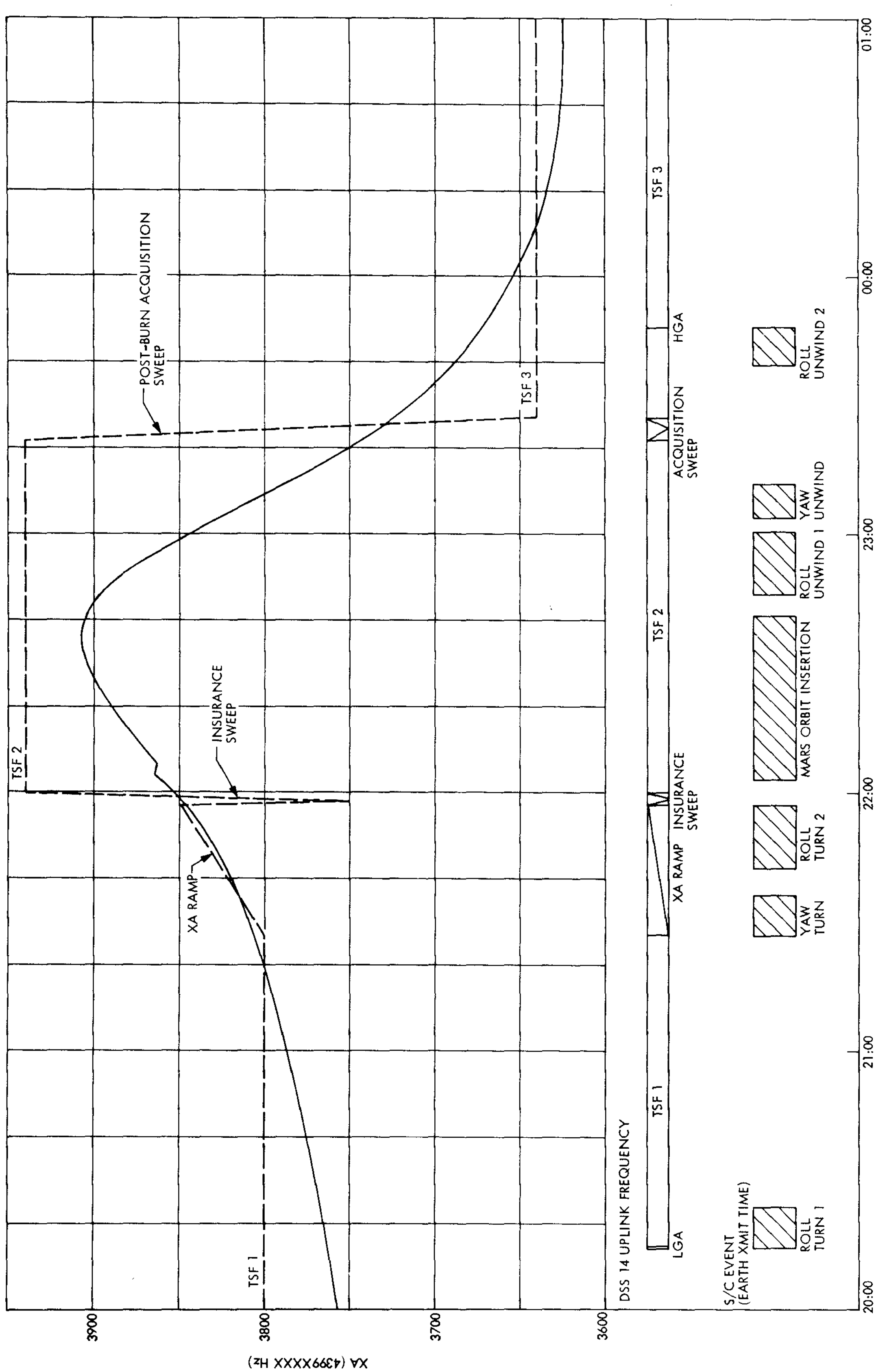

Fig. 1. Actual MOI XA with uplink sequence versus GMT

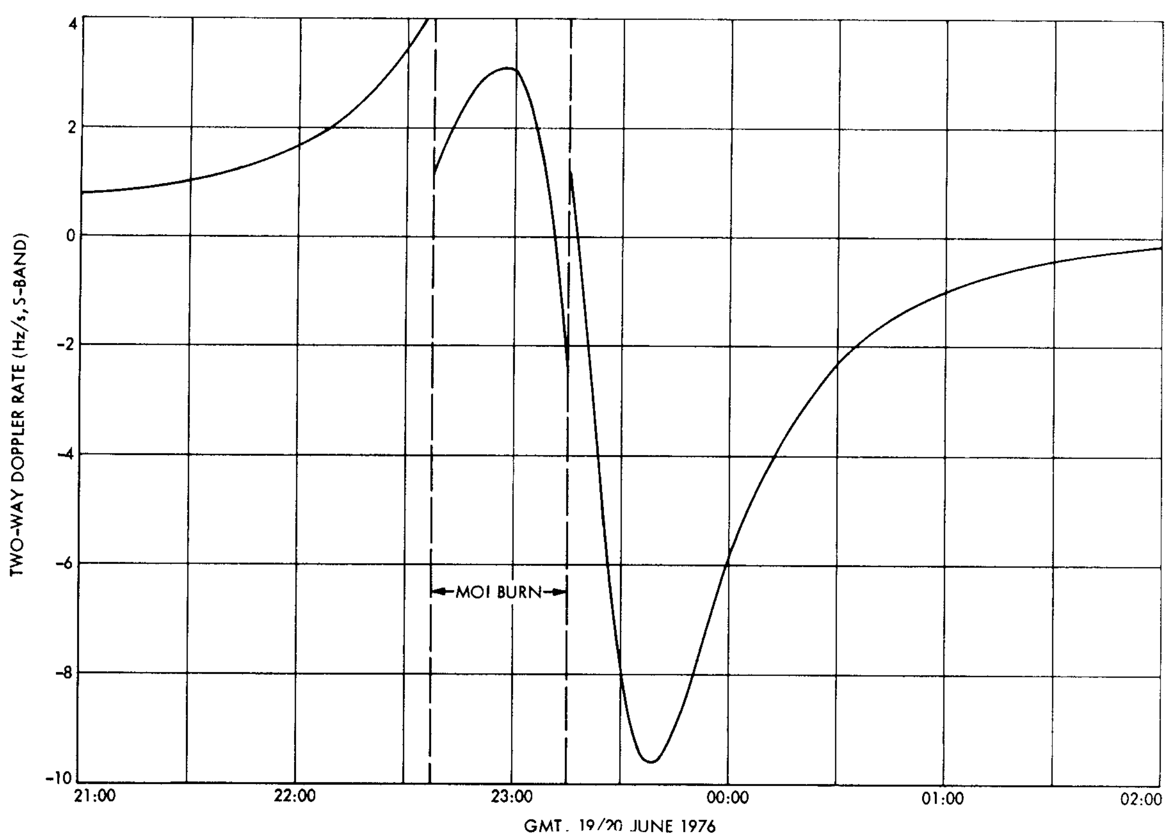

Fig. 2. Viking 1 two-way doppler rate

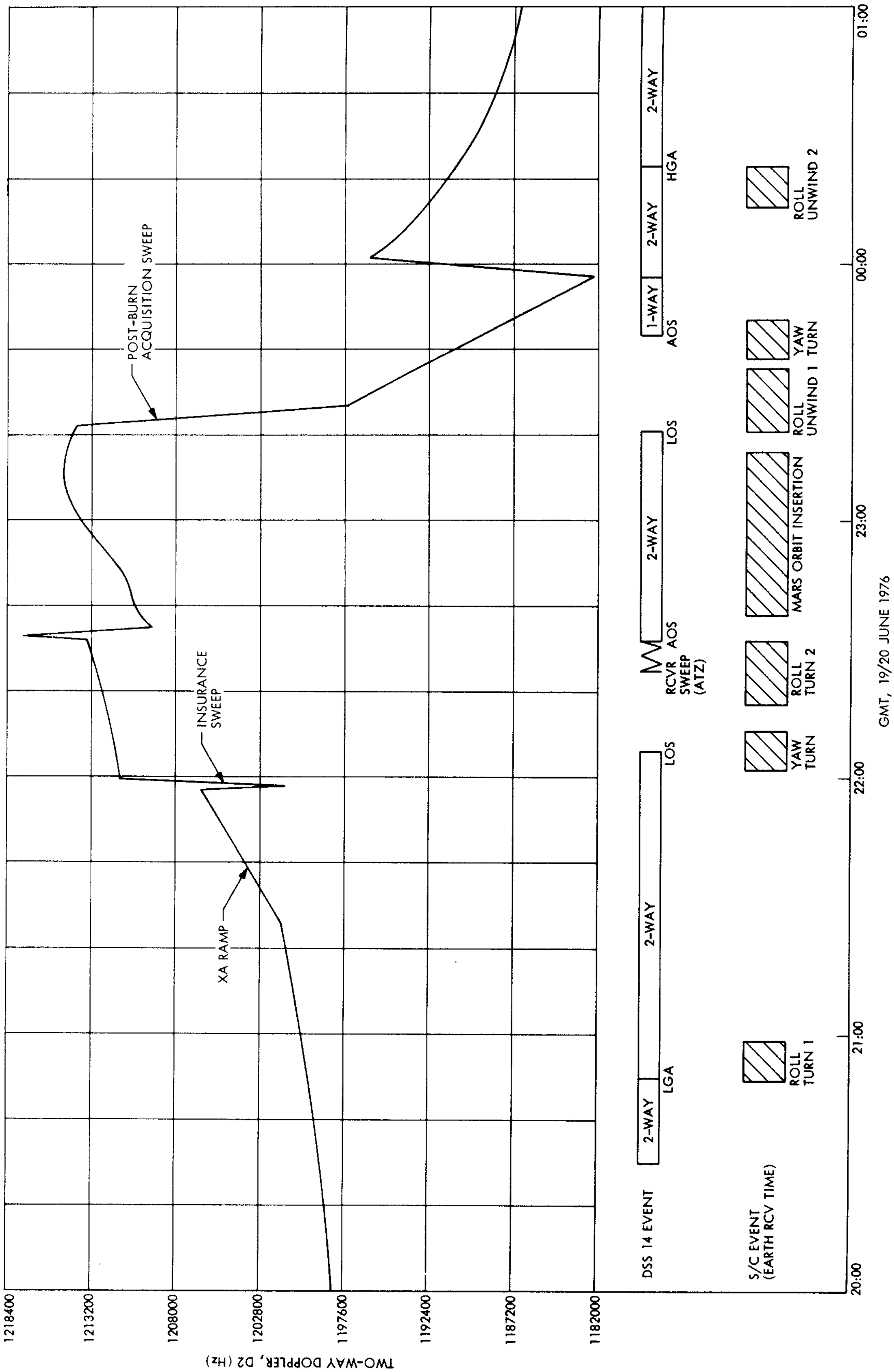

Fig. 3. MOI two-way doppler with downlink sequence versus GMT

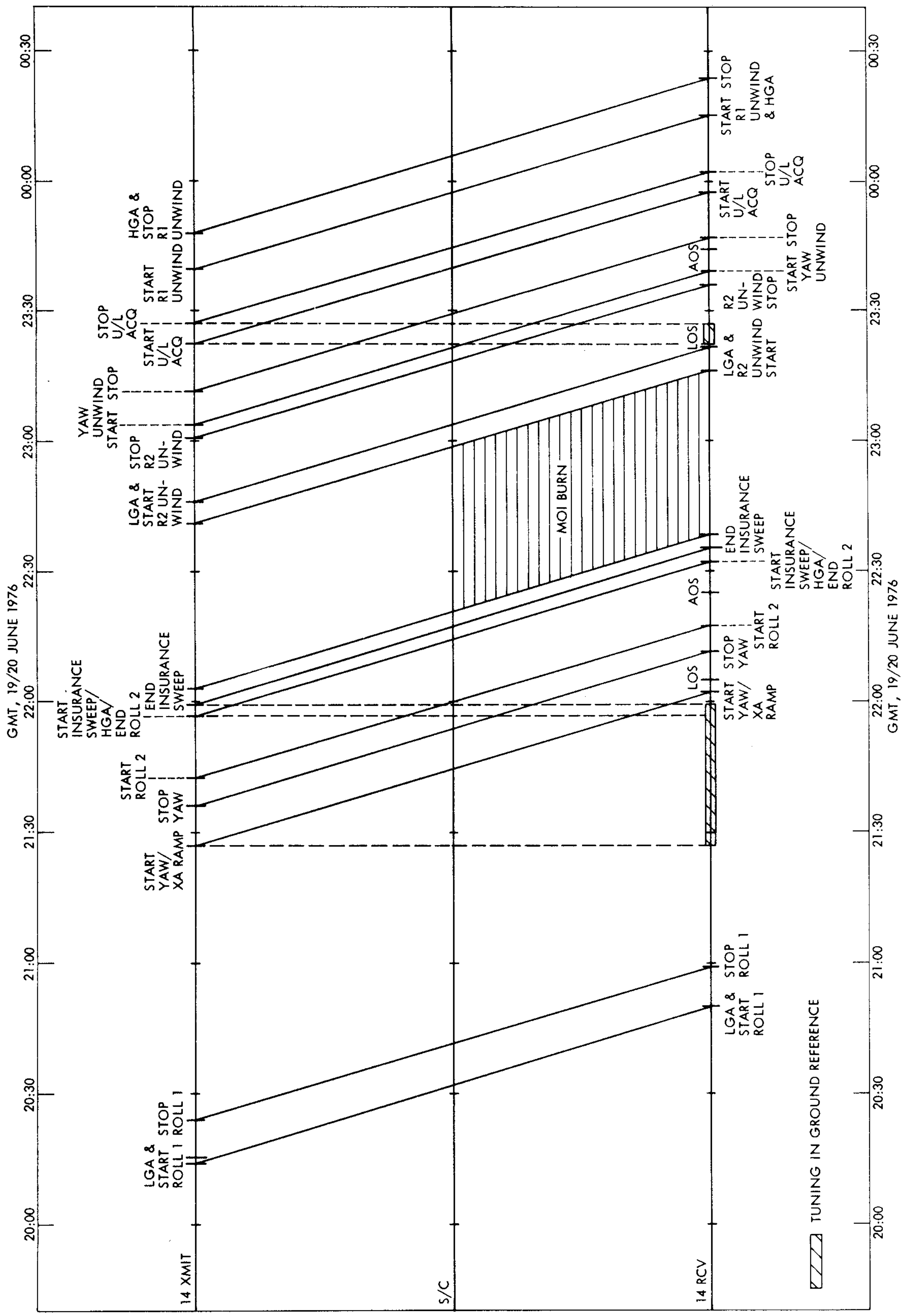

Fig. 4. Viking 1 MOI timeline

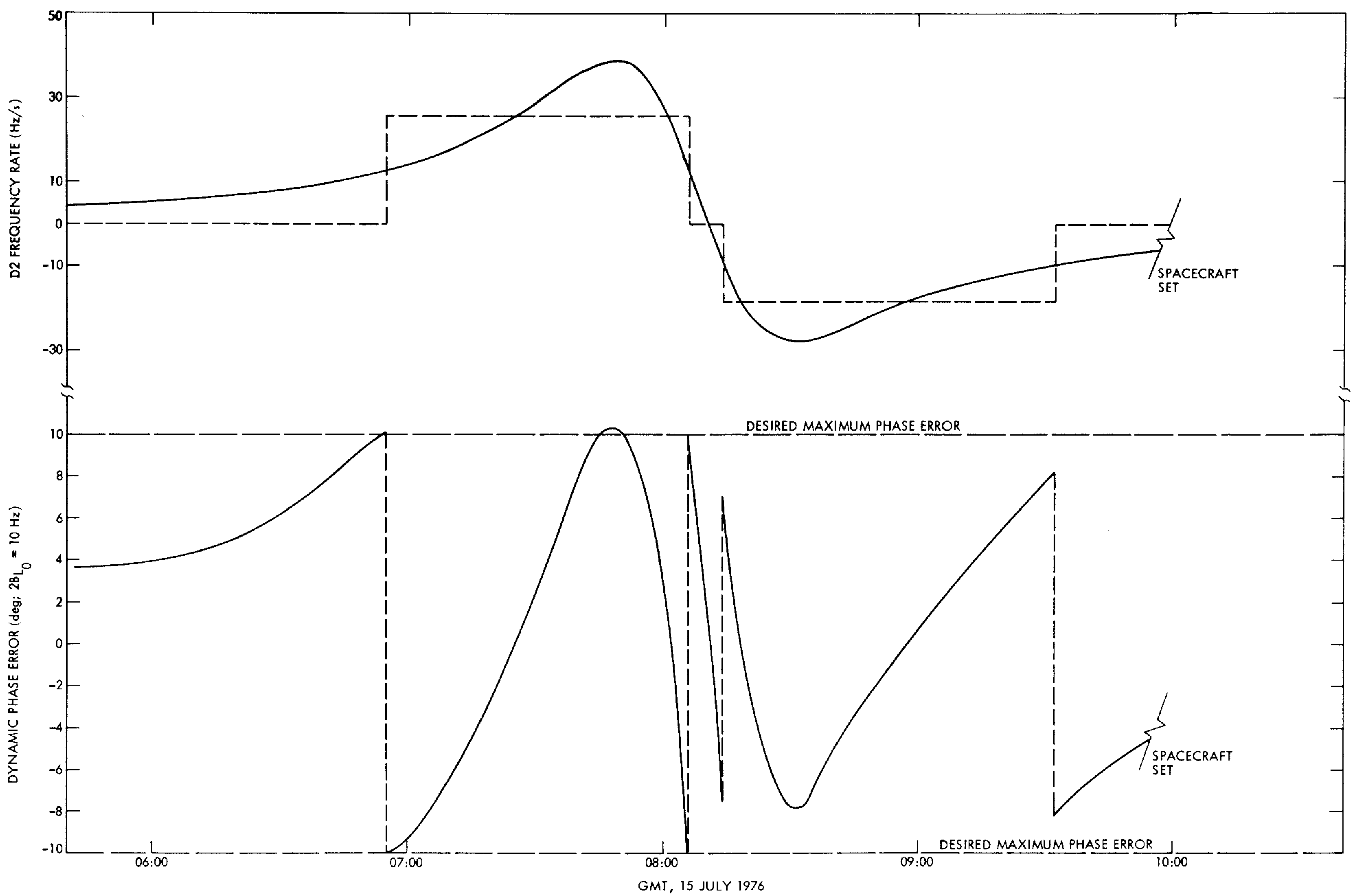

Fig. 5. Typical X-band receiver ramp with dynamic phase error versus GMT (DSS 43, Viking 1)

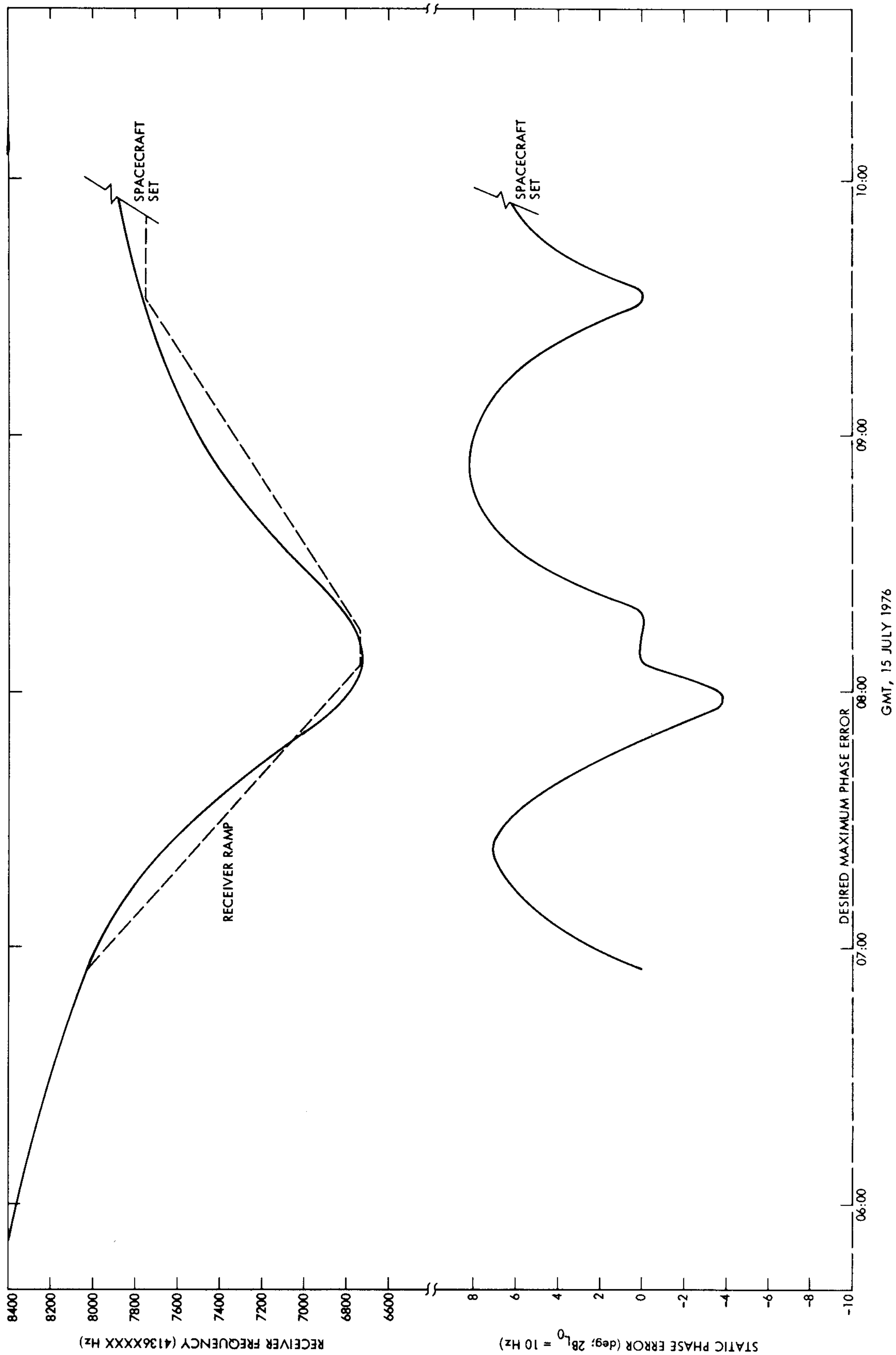

Fig. 6. Typical X-band receiver frequencies with static phase error versus GMT (DSS 43, Viking 1)

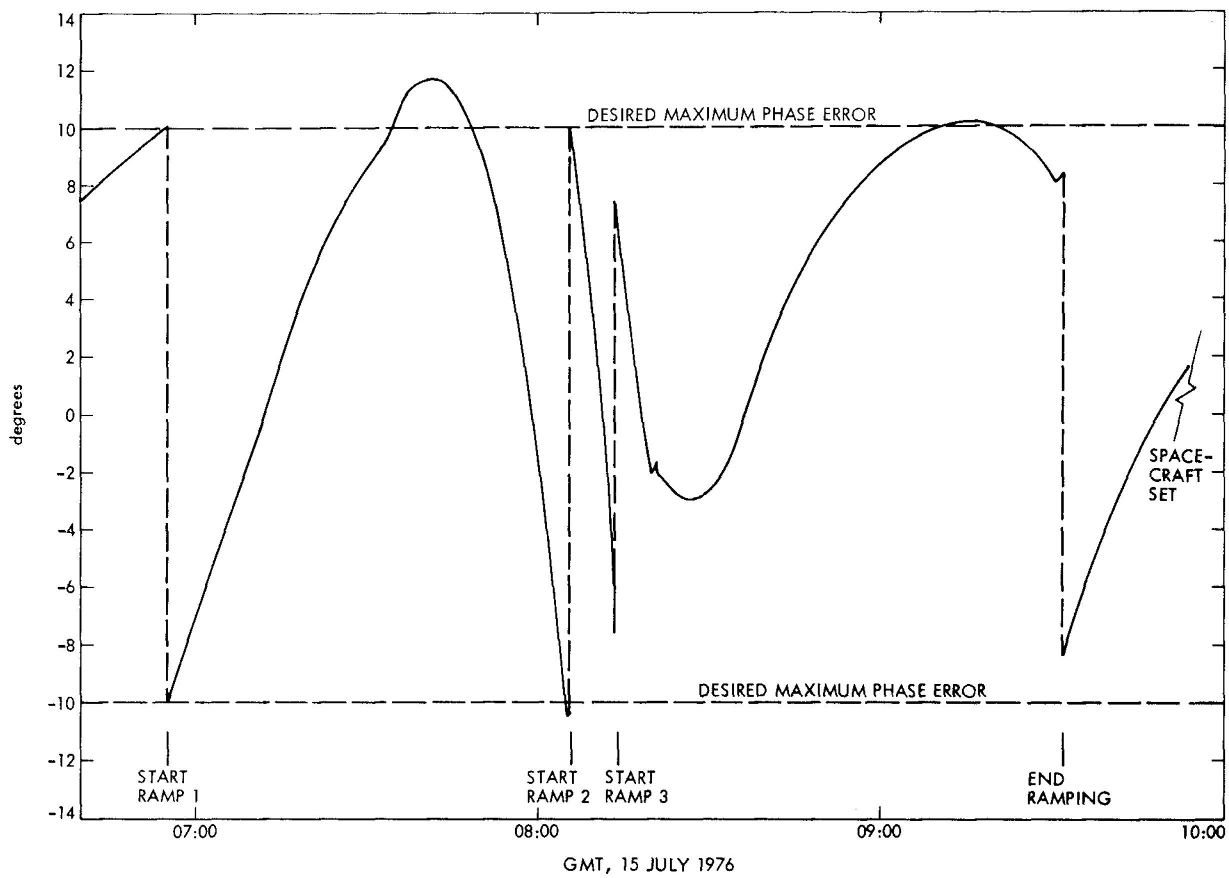

Fig. 7. Total phase error, typical X-band receiver ramp

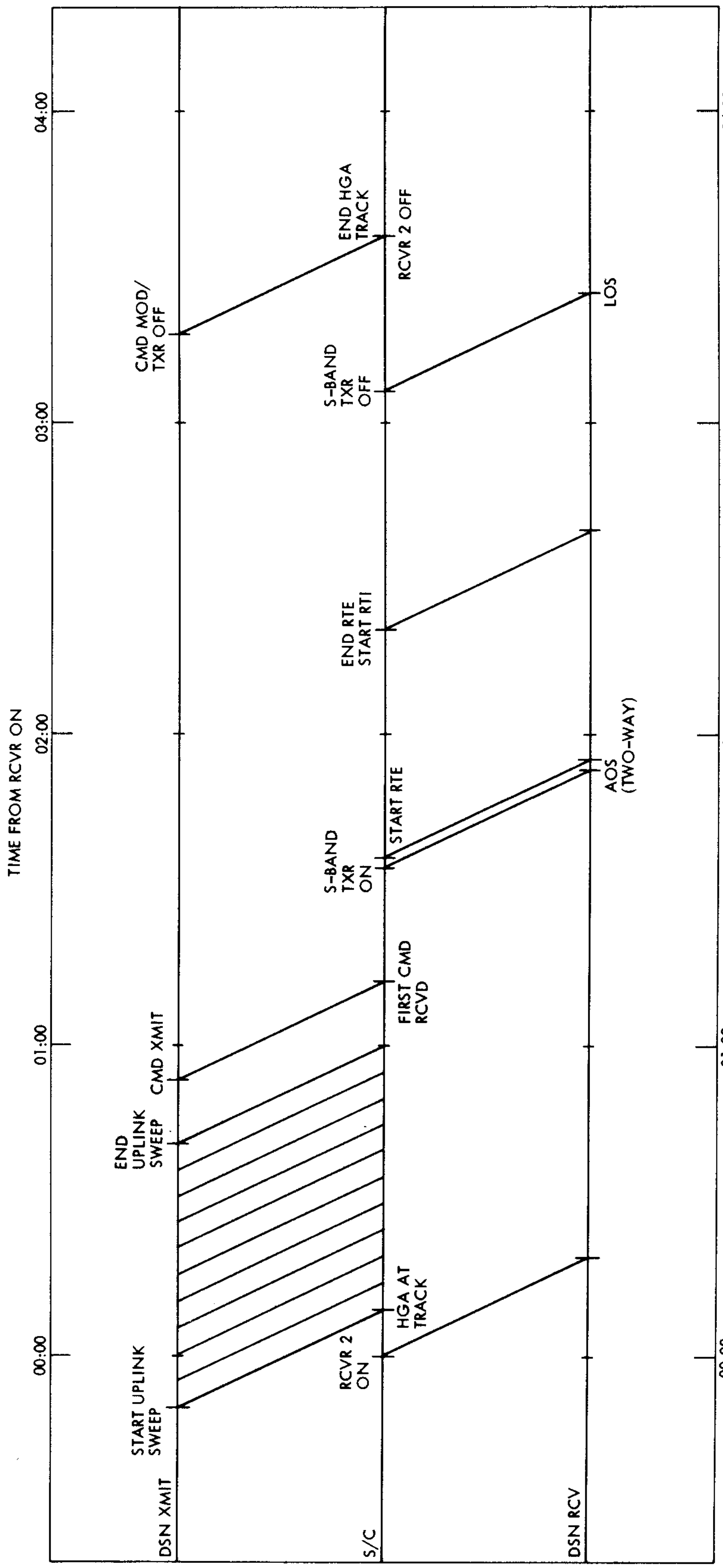

Fig. 8. Viking lander 1 long downlink timeline (1 round trip light = 38 min)

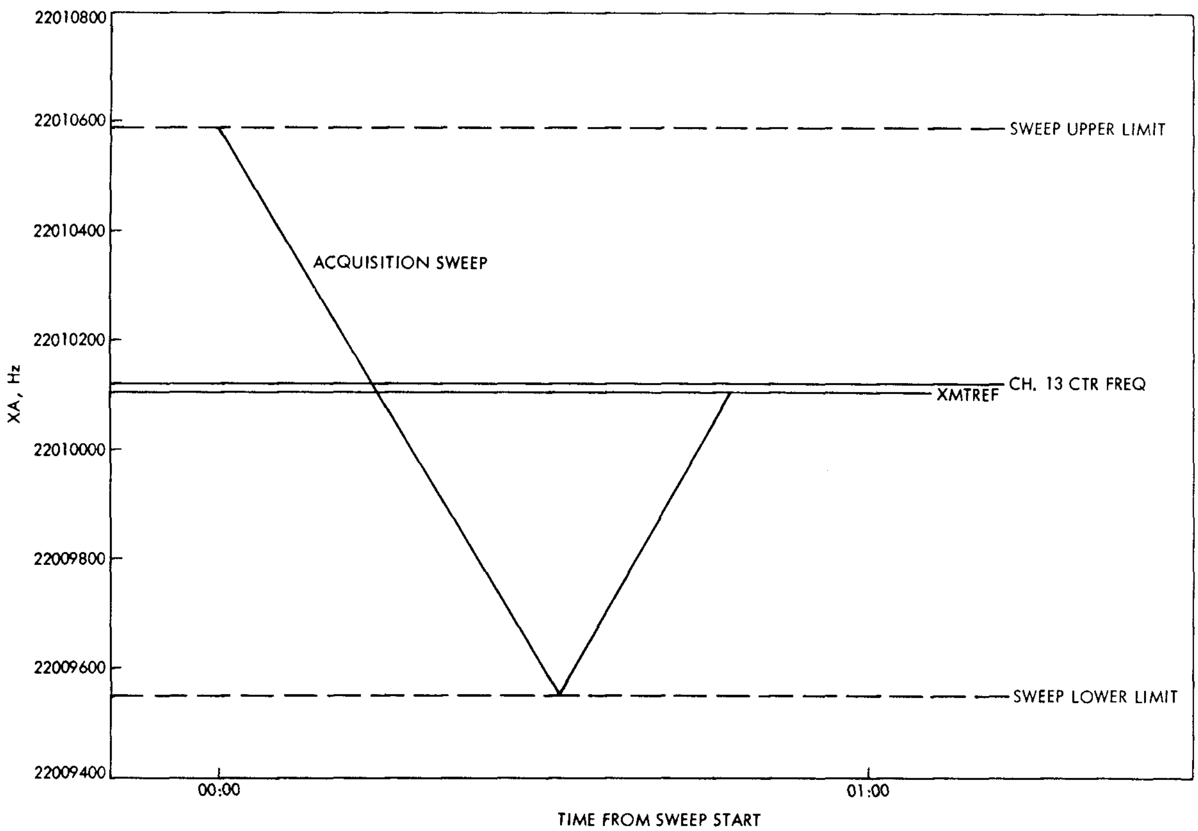

Fig. 9. Typical uplink acquisition sweep—Viking lander 1 (spacecraft received frequencies)

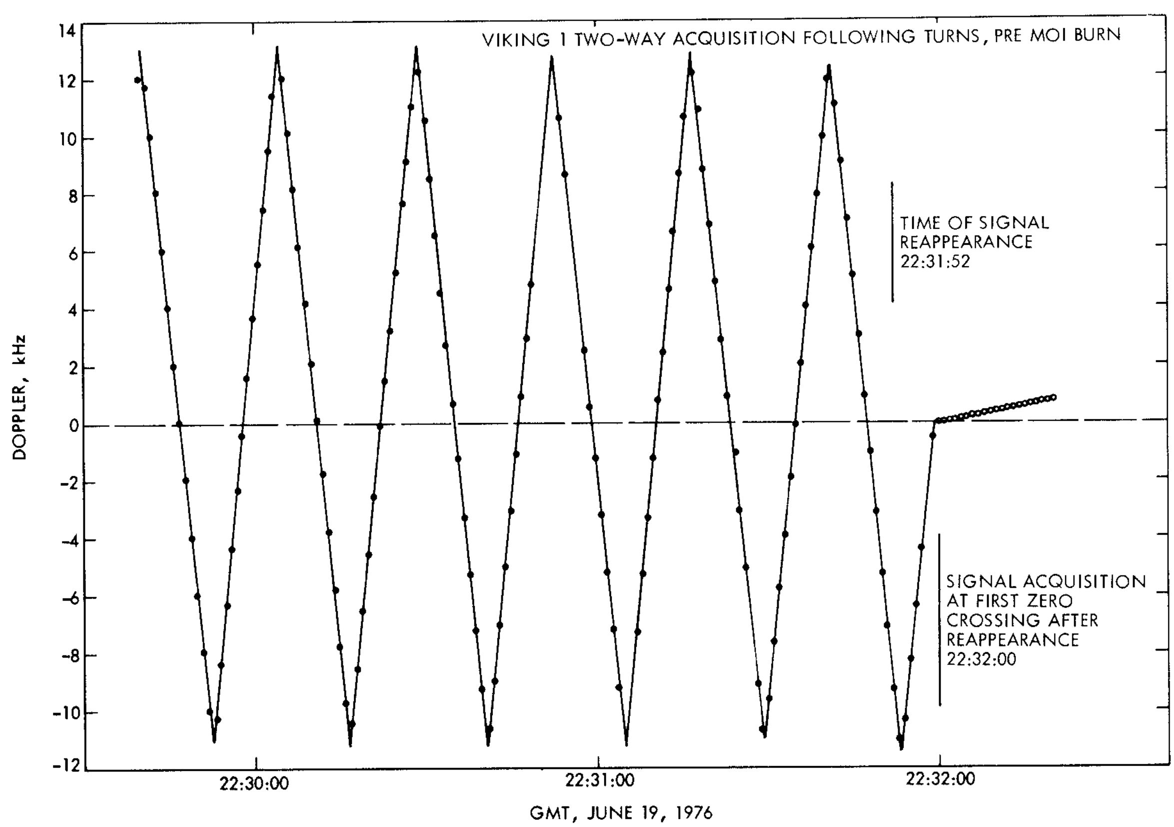

Fig. 10. Viking 1 two-way acquisition following turns, pre-MOI burn

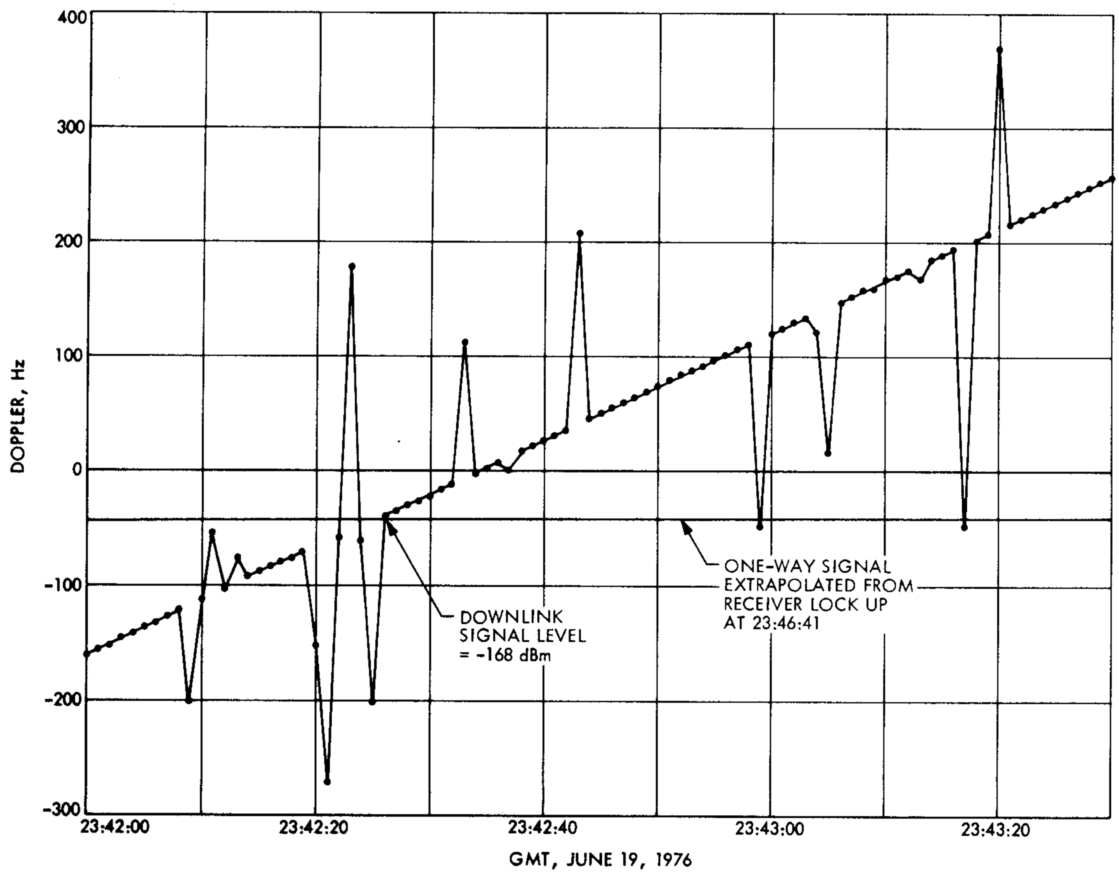

Fig. 11. Attempt to lock one-way signal, Viking 1 post-MOI burn

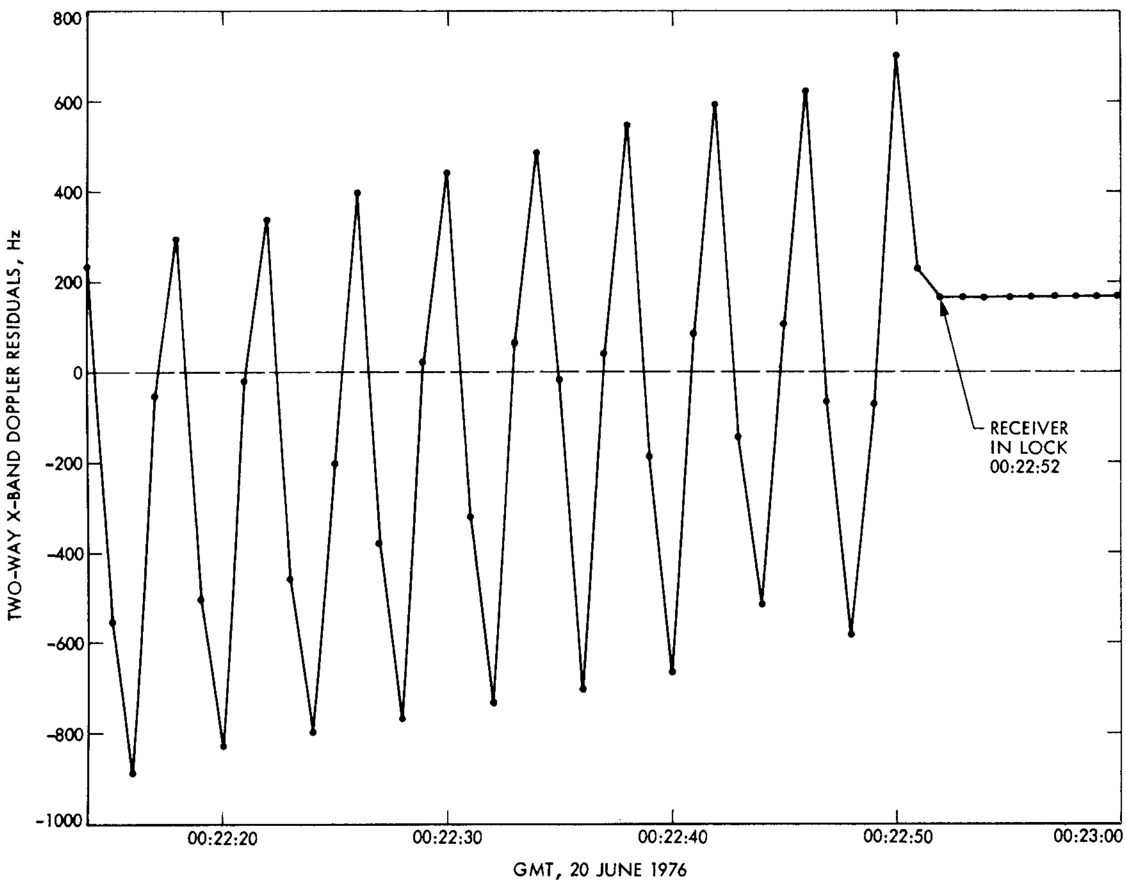

Fig. 12. Viking 1 fast X-band reacquisition following MOI burn