Viking Mission Support

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Previous issues of the Deep Space Network (DSN) Space Programs Summary and the DSN Progress Report devoted attention to management and organization, Deep Space Network configurations for telemetry, command, and tracking, and, more recently, to the influence of the DSN in the design of the Viking mission orbiters and landers. Beginning with this issue of the DSN Progress Report, attention will be focused on reporting Viking-related activity in certain specific areas, as the DSN interface organization progresses from the planning through operational phases of the Viking missions. This article takes up the question of DSN support for Viking navigation and traces progress since the latter part of 1970 through the present time.

I. Introduction

In Refs. 1, 2, and 3, Tracking and Data System (TDS) plans for support of *Viking* were described with particular reference to management and organization, technical documentation, and DSN configurations for telemetry, command, and tracking. Following the redirection of the Project from the 1973 to the 1975 opportunity, attention was devoted to achieving a better understanding of the influence of DSN capabilities and constraints on the design of the *Viking* 1975 Mission.

In Refs. 4, 5, and 6, these questions were addressed in the areas of *Viking* trajectories, *Viking* Orbiters and Landers, and telecommunications including telemetry, command, and tracking. This and subsequent articles will describe significant *Viking*-related activity as the DSN interface organization progresses through the planning, implementation, testing, and operational stages of the mission.

II. Background

Since the decision was made by the Project to use the Type II trajectory described in Ref. 4, a great deal of attention has been given by the Project and the DSN to properly identifying requirements and capabilities respectively for radio metric data needed to accomplish the *Viking* navigation function.

The basic radio metric data provided by the DSN to the *Viking* Project consist of the following items:

(1) Doppler.

(2) Range.

(3) Timing.

These basic data are supplemented with additional information which permits the prime data to be evaluated prior to their use in the Flight Project's orbit determination and navigation processes. The supplementary data include the following items:

(1) Specifications on station parameters, such as accuracy and stability of frequency, timing, phase delay, group delay, etc.

(2) Deep Space Station (DSS) status.

(3) Calibration data for interplanetary medium effects.

(4) Identification of data type, by station and spacecraft.

Because the quality of the radio metric data provided by the DSN directly influences the realization of the navigation goals, the *Viking* Project places great emphasis on the identification of all uncertainties in the data and the reduction of all error sources to the absolute minimum.

While the DSN supports a continuing program aimed at achieving objectives such as these for all flight projects, the exact details of the navigation support provided by the DSN for any particular project depends on its specific requirements.

III. Navigation Requirements

The *Viking* requirements for navigation-related data were first presented to the DSN in Ref. 7, following an extensive review with the *Viking* Project Office in January 1971 at the Langley Research Center.

Table 1 compares the mission requirements on system design (MRSD) as given in Ref. 7 with the DSN capability as presented at that time. The DSN capabilities given in the table are based on the material appearing in Ref. 8 and are consistent with DSN planning for the *Viking* era as reflected in Ref. 9.

Several of the parameters are of special significance to the navigation function and are discussed below.

A. Doppler

Noise in the doppler data arises from two principal sources within the DSSs:

(1) High-frequency noise in the Receiver, Exciter, Transmitter Subsystems. Over a 60-second averaging period, this amounts to 0.00007 meters/second (rms).

(2) Oscillator frequency instability in the Frequency and Timing Subsystem (FTS), which contributes 0.00075 meters/second (rms) over a 60-second period. This assumes a stability of 5 parts in 10^{12} in the FTS oscillators.

When added RSS-wise and converted to a 3-sigma value, the value of 2.1 mm/s given in Table 1 is obtained.

The doppler phase stability is also a function of two DSS parameters:

(1) Variation in electrical path length through the RF system, having a value of 0.5 meters over 12 hours.

(2) Stability of the DSS transmitter frequency (5×10^{-12}) over one round-trip light time (RTLT). For RTLT of 2400 seconds, this is equivalent to 1.8 meters.

The RSS addition of these two contributions gives the 3-sigma value of 5.5 meters/12 hours given in Table 1.

The two remaining doppler quantities of interest, i.e., offset and rate, arise from estimates of the worst possible case *Viking* trajectories where the earth/spacecraft radial velocity might reach ± 17 km/s with accelerations as high as 2.7 m/s^2. Given adequate signal margins in the receiver RF tracking loops, this presents no problem to the Deep Space Instrumentation Facility (DSIF), except that the doppler offset could cross into an adjoining channel as explained in Ref. 5.

B. Ranging

In considering planetary ranging at all 64-meter stations for support of *Viking*, the following error characteristics must be taken into account:

(1) High-frequency noise, which arises in the ranging receiver, depends on both the ratio of ranging power to noise power and on the time between independent samples. Both of these parameters are under the control of the flight project. A typical value for $P_r/N_0 = +4$ dB with a sample time of 250 seconds gives an uncertainty in each independent range sample of 3 meters (rms). A set of curves relating these variables has been developed and is included in Ref. 10.

(2) Further errors in the range measurement result from the accumulated effect of several other factors:

   (a) Instability of the ranging modulation group delay in passing through the RF system contributes about 2 meters uncertainty over a 12-hour period.

   (b) Absolute frequency error of 1×10^{-11} over 1000 seconds is equivalent to an error of 1.5 meters.

   (c) A timing measurement error of 30 microseconds causes a further error of 1 meter for an earth/spacecraft radial velocity of 30 km/s.

   (d) The zero-delay device used to calibrate the station ranging system contains an uncertainty of 2.5 meters.

The 3-sigma value of the RSS total of these uncertainties produced the 12-meter value for range delay given in Table 1.

The overall uncertainty of the ranging system measurements is obtained by including the noise contribution with the delay uncertainties and taking the RSS total. This approach gives a value of approximately 7 meters (rms) which has been adopted as the current DSN standard for ranging uncertainty.

The remaining ranging-related items are concerned with the acquisition time of the standard operational DSN planetary ranging system (Tau) relative to that of the developmental ranging system (Mu).

The figures given in the table reflect the Project's earlier interest in the Mu system where the acquisition time was given by

$$T_{acq}\,(\text{Mu}) = 74\,\frac{N_0}{P_r} \approx 240 \text{ seconds}$$

where

N_0 = noise power in the ranging receiver

P_r = ranging power in the ranging receiver

By comparison, the standard DSN operational planetary ranging system (Tau) under the same conditions had an acquisition time given by

$$T_{acq}\,(\text{Tau}) = 4550\,\frac{N_0}{P_r} \approx 14800 \text{ seconds}$$

All other parameters in both systems remain the same.

More recent developments in this area are discussed in *Section IV*.

C. Differenced Ranging Versus Integrated Doppler

The difference between S-band doppler phase delay and S-band ranging group delay is of prime importance in calibrating out the effect of charged particles in the ionosphere and interplanetary medium on the doppler data. This technique takes advantage of the fact that charged particles affect range increments obtained from the accumulated doppler count and those obtained from differencing range measurements by nearly equal but opposite amounts. The doppler phase velocity is advanced while the ranging group velocity is retarded. The Differenced Ranging Versus Integrated Doppler (DRVID) technique is described in Ref. 11.

It is obvious that the stability of the difference between the phase and group delays has a direct influence on the quality of the calibration data obtained from DRVID.

The DSN value for this parameter expressed in terms of the uncorrelated drift over a 12-hour period is estimated to be 10 nanoseconds or 1.5 meters.

In the operational planetary ranging system planned for *Viking*, the DRVID data will be available as soon as the clock or highest frequency component of the range code has been acquired by the ground receivers. This will take 1 to 10% of the time required for the full code acquisition, which in turn depends on signal-to-noise considerations as described above. The minimum acquisition time of about 80 seconds applies in both cases. The ranging acquisition sequence for the Tau system is shown in Fig. 1. It would appear, therefore, that there should be no difficulty in satisfying the Project's requirements for DRVID data within 15 minutes of receipt of two-way doppler under reasonable signal-to-noise conditions.

D. Timing

In the *Viking* time period, the DSN expects to have the lunar time sync system in operational use throughout the 64-meter network. This will provide 20-microsecond (one sigma) timing synchronization between 64-meter stations and between National Bureau of Standards (NBS) and the Goldstone master clock. The *Viking* timing requirements given in Table 1 can easily be met by this capability.

E. Equivalent Station Locations

The Project requires a tracking system model for which the equivalent station location errors will not exceed the following values:

Equivalent station radius error r_s = 4.5 meters

Equivalent station longitude error r_λ = 9.0 meters

Since these equivalent station location errors are the result of combining many parameters into a specific model of the Project's choosing, the DSN is responsible only for providing the parameters listed in Table 1, either by means of a specification or a magnetic tape containing the desired calibration data. The DSN will, however, assist the Project in developing an error model suitable to its needs.

IV. Recent Progress

Since the original discussions on the navigation requirements, a considerable refinement in both the Project's statement of requirements and the DSN statement of capabilities has taken place. The progress in this area is reflected mainly in the sections of the SIRD (Ref. 8) dealing with radio metric requirements.

Requirements for S- and X-band performance data have been added as an adjunct to the radio science experiments as well as to provide an alternative to the DRVID technique for charged-particle calibration.

The need for rapid ranging acquisition on the Lander, discussed in Ref. 6, has been restated in terms of a single uplink rather than dual simultaneous uplinks. This allows the use of a single high-power (100 kW or greater) uplink which provides sufficient ranging power at the Lander or Orbiter to achieve the acquisition time desired with the standard DSN operational planetary ranging system (Tau). In constraining *Viking* flight operations to a single uplink during ranging periods when rapid acquisition is required, this solution is not entirely satisfactory, but it is acceptable for short periods when the single uplink constraint can be tolerated.

V. Conclusion

With the publication of the SIRD, the statement of Project navigation requirements is virtually complete. However, much remains to be done to fully understand, identify, and separate the TDS and Orbiter or Lander contributions to total system errors. This work is necessary in order to allow the DSN response to the SIRD, that is, the NASA Support Plan, to be prepared by the end of this year in accordance with the *Viking*/TDS schedule.

It is quite likely that the continuing DSN process of refining its navigation-related capabilities could result in the availability of radio metric data of significantly improved quality by the time of the *Viking* Mission. Care is being taken to ensure that the mission design is such that advantage can be taken of these improvements, should they eventuate, to enhance the mission navigation process.

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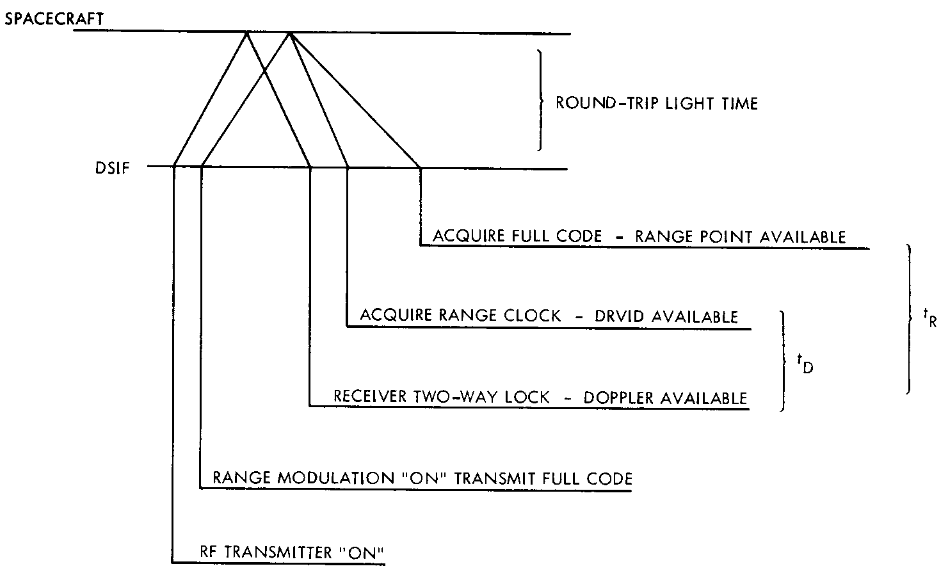
Table 1. *Viking* metric data quality[a]

Parameter	MRSD requirements	DSN capabilities
Angle error (peak value)	0.06 deg	0.06 deg
Angle resolution	0.002 deg	0.002 deg
Doppler noise	2.1 mm/s	2.1 mm/s
Doppler phase delay stability	6 m/12 h	5.5 m/12 h
Doppler offset	±262 kHz	±207 kHz
Doppler rate	41 Hz/s	>50 Hz/s
Ranging group delay	15 m	12 m
Ranging high-frequency noise	15 m	3 m (rms)
Ranging acquisition time	30 min	<4 min
Ranging ambiguity	>3000 km	150,000 km
DRVID		
Phase/group delay	4.5 m/12 h	4.5 m/12 h
Acquisition time	15 min	15 min
Timing		
Master clock to NBS	1 ms	60 μs
Interstation time sync	150 μs	60 μs
Equivalent station locations (σ_{R_S}, σ_λ)	4.5 m, 9.0 m	—
DSS locations (σ_{R_S}, σ_λ)	—	0.5 m, 1.0 m
Polar motion (σ_X, σ_Y)	—	0.7 m, 0.7 m
Predicted earth rotation (UTI)	—	4.0 ms
Charged particles (DRVID)	—	1.0 m/12 h
Tropospheric refraction	—	0.5 m/12 h
Electrical path length	—	0.5 m/12 h
Frequency instability	—	5×10^{-12}

[a]3-sigma values unless stated otherwise.



RANGE ACQUISITION TIME $t_R = 4550\ N_0/P_R$ (TAU) (MINIMUM 80 s)

DRVID ACQUISITION TIME $t_D \approx 0.1 \times t_R$

Fig. 1. Operational planetary ranging acquisition sequence