Voyager Near Simultaneous Ranging Transfers

G. L. Spradlin
Deep Space Network Operations Section

During testing of near simultaneous ranging techniques, a major shortcoming of the standard DSN uplink transfer procedure was uncovered. Use of the standard procedure resulted in loss of phase coherence between received and reference range codes for the round trip light time following a transfer. It is the intent of this article to report on the philosophy behind, and the operational procedure developed for near simultaneous range transfers, a new uplink transfer procedure that will enable the DSN to generate good range data during the interval from transmitter off to loss of the coherent downlink.

I. Introduction

A unfortunate geometry, zero declination, will exist at Saturn encounter for both Voyagers. This geometry will make it impossible to solve for the spacecraft's declination by fitting doppler data as is normally done in the orbit determination process. An alternative technique for deriving the spacecraft's declination is by use of range data taken near simultaneously from stations at widely separated latitudes, and triangulating to solve for the needed declination angle. This dependence upon range data will require that highly accurate range measurements and range delay calibration information be available to the navigators and radio scientists. It has been towards this end that countless hours have been (and continue to be) spent proving and refining network ranging procedures and analytical techniques for data quality verification.

Periodic tests of the near simultaneous ranging (NSR) technique were conducted during late 1976 and early 1977. The purpose of these tests was to verify that the range accuracy requirements for Voyager navigation could be met, and also to develop the operational procedures that would be imposed on the DSN by this new data collection scheme. The results of these tests are the subject of Reference 1.

As a result of analysis of the data collected during the near simultaneous ranging tests (and noted in Ref. 1), it was discovered that standard DSN procedures for station-to-station uplink handovers had resulted in loss of range code phase coherence, and hence loss of range data during the round trip light time following a handover. It was suggested that phase compensatory tuning might be utilized by the network to solve this problem, and prevent the loss of range data after uplink handovers.

In support of the near simultaneous range data collection effort, the DSN has accepted the phase compensatory tuning recommendation, and developed operational procedures for carrying it out. The remainder of this article describes this plan, and presents the operational procedure that the network will be utilizing in support of the near simultaneous ranging effort.

II. NSR Transfer Philosophy

Every two weeks, once a month per spacecraft, the Voyager Project is planning to gather navigation and radio science data (S-band doppler and range data, and X-band doppler and range when available) by means of a "tracking cycle". The tracking cycle consists of four consecutive 64-meter antenna tracks beginning with DSS 43 and ending with DSS 43. It should be noted, however, that an attempt to collect NSR data may be made whenever two DSSs are scheduled simultaneously to track a single Voyager spacecraft; this includes colocated stations, and stations of the same general view period (64-meter and/or 26-meter antennas).

The data of prime importance during the tracking cycles (or other simultaneous tracking periods) are the NSR data. During these overlaps, attempts will be made to maximize the return of high quality two- and three-way doppler and NSR measurements. Since two stations cannot concurrently have sustained uplinks with a single spacecraft, collection of the NSR data will require that numerous uplink transfers be made during the overlaps to provide data redundancy and hence data confidence.

These numerous transfers present more of a problem for the network than a cursory glance might reveal. The "standard" DSN transfer, where: (1) the incoming DSS and the outgoing DSS both tune to the spacecraft's receiver VCO center frequency, XA, (adjusted for one-way doppler and light time); (2) the incoming DSS turns on its transmitter and the outgoing DSS turns its off two seconds later; and (3) the DSSs both tune to their respective Track Synthesizer Frequencies (TSFs) and remain there until the end of the track or the next transfer, cannot generally be used for uplink transfers while NSR data are being generated. This tuning pattern, while adequate to transfer the uplink, will change the phase relationship of the ground reference and received range codes, and will thus result in the loss of range data from the outgoing DSS for the round trip light time. To avoid this loss of NSR data, an alternate tuning procedure has been developed.

The new transfer procedure that has resulted from analysis of the problem will, upon completion of all required tuning, restore both the frequency and code phase relationships required for good ranging throughout the round trip light time following an uplink transfer. The only data loss is that during the period of the tuning. This transfer procedure, dubbed the NSR transfer, takes advantage of the programming and precision tuning capabilities of the Programmed Oscillator Control Assembly (POCA) available at the 64-meter DSSs. The procedure calls for both incoming and outgoing DSSs to execute precision symmetrical tuning patterns between specified limits, at fixed rates, and at specific times. Figure 1 graphically depicts a NSR transfer and its related events.

In Fig. 1, it can be seen that the transfer procedure requires utilization of four ramps to achieve the desired symmetrical tuning pattern. All ramps are done at the same rate, 5 Hz/sec (POCA); the initial direction of the first ramp is dependent upon whether XA is above or below TSF. The distance tuned, ΔHZ, is simply

$$\Delta HZ = XA - TSF$$

Since the XA is a doppler dependent frequency, it constantly changes. Therefore the ΔHZ for any given transfer time will be different. That is, sometimes a sweep of +30 HZ will be required, or +2.1 HZ or −12.4 HZ, etc. It is for this reason that the upper and lower limit registers of the POCA are used; otherwise, new rates and ramp start times would have to be determined for each transfer to account for the different distances to be tuned, and to retain the desired symmetry. As four frequencies are needed for POCA limits: TSF + ΔHZ, TSF, TSF − ΔHZ, TSF, and they must be encountered in this sequence, it will be necessary to reload each POCA limit once during the transfer sequence. Nominal times for these updates have been indicated at transfer + 1 min. 20 sec., and at transfer + 2 min. 40 sec.

In Fig. 1, UL1 and LL1 represent the initial upper and lower limits respectively. (Note: if ΔHZ is a negative number the first sweep will be in the direction of a lower frequency and LL1.) UL2 and LL2 represent the updated POCA limits. The Ts and Rs represent the contents of the four POCA rate/time registers with all rates at either plus or minus 5 Hz/sec. (POCA) (as appropriate) and times as follows:

T0 = Time of transfer minus 1 minute
T1 = Time of transfer plus 1 minute
T2 = Time of transfer plus 2 minutes
T3 = Time of transfer plus 4 minutes

The total time to execute the entire transfer and tuning pattern is approximately 5 minutes with the time changing by a few seconds depending upon the magnitude of ΔHZ.

Other events indicated are the actual transfer time, and the incoming and outgoing range modulation on/off times. Transmitter on at the incoming DSS is at the even minute followed by transmitter off two seconds later at the outgoing DSS. Transfer time is defined as the time of transmitter on at the incoming station. Range data prior to the first ramp start time may be of value; therefore, range modulation at the outgoing station will not be turned off until a convenient time after the start of tuning (range modulation off at transfer −20 sec, nominally). Similarly, range modulation at the incoming DSS is not applied until tuning is complete (nominally, range modulation on at transfer + 4 min. 10 sec.).

Clearly, the NSR transfer requires the use of a POCA. When transfers are required for the collection of NSR data where a POCA is not available a "standard" transfer is to be executed. Or, in the unique case of DSS 12 and DSS 14, a TSF transfer is to be used. (DSS 12 and DSS 14 are unique in that they are each equipped with a ranging subsystem unlike DSSs 42/43 and 61/63 where ranging systems are shared, also DSSs 12 and 14 are close enough that tuning for transfer is unnecessary, i.e., almost identical doppler shifts.)

While it is unfortunate that the network must adapt to a new transfer procedure in support of NSR data collection, it should be noted that development of a fixed procedure has been one of the design goals in an effort to make the required adaptation as painless as possible.

The uplink tuning rate selected, 240 Hz/sec (S-band), is compatible with Voyager Telecommunications provided signal level estimates for Jupiter Encounter (and beyond). Ground receiver tuning will be avoided by:

(1) Selection of the 30-Hz-wide bandwidth at the Block IV Receiver-Exciter Subsystem, and,

(2) Zeroing the Static Phase Error (SPE) of the receivers prior to beginning the NSR transfer sequence.

III. NSR Transfer Procedure

To aid in the transfer of information, a new transfer message, the NSR TRANSFER MESSAGE (Fig. 2) has been designed. This form provides all needed information (frequencies and event times) for both incoming and outgoing stations. The blanks on the NSR TRANSFER MESSAGE are to be filled in by the Network Operations Control Team (NOCT). To assist in completing the form, an HP 9810 calculator program has been written that, given the inputs necessary for a "standard" transfer, will convert these to (also, output) NSR transfer information required to complete the form. Section IV provides an example of how the program and transfer message are to be utilized.

The same considerations utilized for determining an optimal tuning strategy were also used in determining a ranging strategy. It is not anticipated that ranging parameters will be altered prior to encounter. Arrangements have been made to provide these inputs through the Sequence of Events (SOE). A line item will be provided that will warn of an approaching overlap period, and provide some general reminders including the necessary range parameters. It is of paramount importance that the Planetary Ranging Assembly (PRA) not be interrupted during the overlap period; this is regardless of the transmitter or range modulation status. Any and all inputs, such as a round-trip light time (RTLT) update, must be made prior to the critical data collection period.

The SOE items will include, in addition to the above mentioned ranging parameters:

(1) A statement that announces the beginning of the NSR data collection period, and provides initial conditions.

(2) A warning of an approaching period of NSR transfers that should be a trigger to the NOCT to prepare the necessary NSR TRANSFER MESSAGE(S).

(3) A statement to commence multiple NSR transfers, the GMT of this statement should coincide with the first transfer.

(4) A statement that announces the end of a NSR transfer period.

The following items should be remembered as they directly impact the NSR data:

(1) Frequent uplink transfers will result in frequent doppler mode (two-way vs. three-way) changes; the NOCT must be careful that the correct mode is indicated to avoid extensive data editing.

(2) The good/bad doppler switch (manual) should be set to indicate bad doppler data during uplink tuning, and one RTLT later when the tuning is received in the downlink. This will again eliminate the need for data editing.

(3) The doppler sample rate should be set to one sample per ten seconds during all transfer periods. It should be left at one sample per ten seconds continuously at 64-meter DSSs throughout the tracking cycle.

(4) NSR transfers should be performed on thirty-five minute centers:

    (a) Beginning at ten degrees elevation (64-meter antennas) or at the indicated SOE start time whichever is later,

    (b) At the midpoint of the DSS 43/63 overlap until the overlap exceeds approximately two hours (three NSR transfers),

    (c) And an odd number of NSR transfers *always* must be completed (3, 5 etc.),

    (d) And no more than five transfers are to be attempted during 64-meter overlaps. More transfers may be requested during DSS 12/14 NSR data collection periods. The maximum number may later be reduced to three transfers during 64-meter overlaps.

In addition to providing the NOCT with the aforementioned HP 9810 program, a program copy will be provided to each 64-meter DSS. This should help expedite the transfer of NSR transfer information. It is not necessary for each DSS to have the XA and TSF of the other involved DSS. Zeros may be entered in the program for inputs relative to the other station; this will not affect the NSR transfer information output for the station utilizing the program. It is further suggested that the DSSs adopt the NSR TRANSFER MESSAGE form as a recording medium.

IV. Example

A SOE item that indicates the beginning of a NSR multiple transfer period has been noted. At a convenient time, about an hour prior to the noted SOE item the NSR TRANSFER MESSAGE for the first transfer is prepared. This first transfer time is to be 235000; this is somewhat later than the event time of the SOE, but is the first predicts data point available after ten degrees (10°) of elevation angle has been reached. DSS 14 is outgoing and is currently at a TSF of 44028500 Hz. The transfer will be to DSS 43 whose TSF will also be 44028500 Hz. From the tracking predicts the respective transfer time (23:50:00) XAs are found to be:

$$XA\ (14) = 44028546.7\ \text{Hz}$$

$$XA\ (43) = 44028490.9\ \text{Hz}$$

Now load the NSR TRANSFER PROGRAM into the HP 9810 calculator, and simply enter the data requested by the program (Fig. 3) as follows:

(1) "XFER GMT =" enter the transfer time, 23:50:00

(2) "OUTGOING TSF =" enter DSS 14's TSF, 44028500

(3) "OUTGOING XA =" enter DSS 14's XA, 44028546.7

(4) "INCOMING TSF =" enter DSS 43's TSF, 44028500

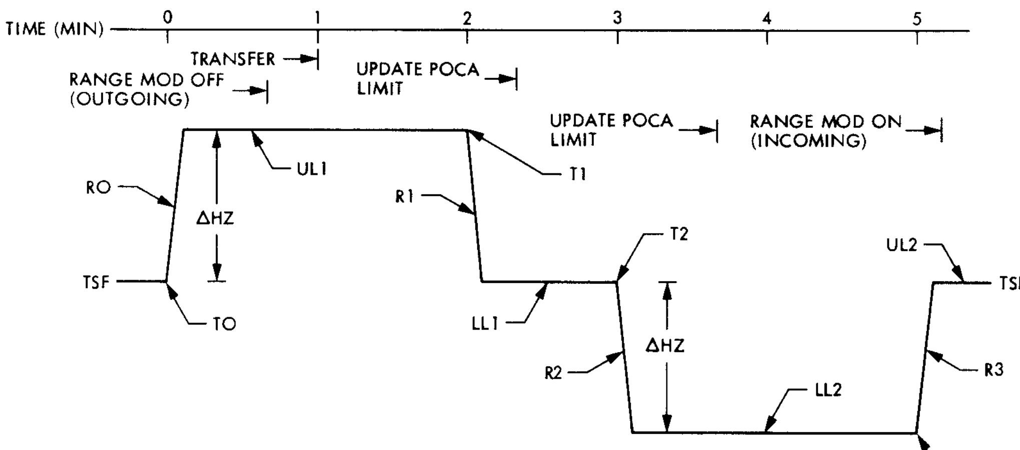
(5) "INCOMING XA =" enter DSS 43's XA, 44028490.9

(6) The NSR TRANSFER MESSAGE is now filled out from the program output, and then either read or faxed or both to the involved DSSs. The DSSs should be reminded of the notes at the bottom of the form (Fig. 4) as they are important to the successful completion of the NSR transfer.

Once the program card becomes available at the 64-meter DSSs, it may prove most expeditious to simply verify that the DSSs have arrived at the same frequencies as those computed by the NOCT. Each DSS will have available its own TSF and XA, but not those of the other involved DSS; therefore, comparison of results will be limited to only those items that directly apply to that DSS.

Reference

1. H. L. Siegel, C. S. Christensen, D. W. Green, F. B. Winn, "On Achieving Sufficient Dual Station Range Accuracy for Deep Space Navigation at Zero Declination," AIAA/AAS Astrodynamic Specialists Conference, Jackson Hole, Wyoming, September 7-9, 1977.



NOTES:

1. ΔHz = XA (OF TRANSFER) - TSF, COMPUTED TO ONE TENTH Hz
2. ALL TUNING RATES ARE 5 Hz/sec, THE SIGN ON R0 & R3 IS THE SAME AS THAT OF ΔHz
THE SIGN ON R1 & R2 IS OPPOSITE THAT OF ΔHz
3. UL1 = POCA INITIAL UPPER LIMIT FREQUENCY = TSF + (ΔHz)
4. LL1 = POCA INITIAL LOWER LIMIT FREQUENCY = TSF = UL2
5. LL2 = TSF - (ΔHz)
6. T0 = TIME OF TRANSFER - 1 min
7. T1 = TIME OF TRANSFER + 1 min
8. T2 = TIME OF TRANSFER + 2 min
9. T3 = TIME OF TRANSFER + 4 min
10. PRA MUST NOT BE INTERRUPTED REGARDLESS TRANSMITTER OR RANGE MOD STATUS
11. DOPPLER SAMPLE INTERVAL = 10 sec
12. RECEIVER BANDWIDTHS SET 30 Hz-WIDE, NO TUNING AT TRANSFER REQUIRED
13. TRANSFERS TO OCCUR ON 35 min CENTERS

Fig. 1. NSR transfer and related events

NSR TRANSFER MESSAGE

TRANSFER NUMBER ________

S/C ________
DAY ________
OUTGOING DSS ________
INCOMING DSS ________
PRDX SET ID ________
CONTROLLER ________

OUTGOING DSS TSF: ____________________ HZ

ITEM	GMT	ACTION
A.	____________	TUNE FROM TSF TO ____________ HZ
B.	____________	RANGE MOD OFF
C.	____________	TRANSMITTER OFF
D.	____________	TUNE TO TSF
E.	____________	TUNE FROM TSF TO ____________ HZ
F.	____________	TUNE TO TSF

INCOMING DSS TSF: ____________________ HZ

A.	____________	TUNE FROM TSF TO ____________ HZ
B.	____________	TRANSMITTER ON
C.	____________	TUNE TO TSF
D.	____________	TUNE FROM TSF TO ____________ HZ
E.	____________	TUNE TO TSF
F.	____________	RANGE MOD ON

NOTES:

1. ALL TUNING RATES ARE "PLUS" OR "MINUS" 5 HZ/SEC.
2. UNLESS A PRA FAILURE OCCURS, THE PRA SHOULD REMAIN UNINTERRUPTED REGARDLESS OF TRANSMITTER OR RANGE MODULATION STATUS.
3. RECEIVER SPE SHOULD BE NULLED PRIOR TO EACH TRANSFER.
4. TRK AND LIMIT ENABLE (POCA) MUST BE RESET PRIOR TO EACH RAMP.
5. A NEW POCA UPPER OR LOWER LIMIT MUST BE ENTERED AT TRANSFER PLUS ONE MINUTE-TWENTY SECONDS, AND AGAIN AT TRANSFER PLUS TWO MINUTES-FORTY SECONDS.

Fig. 2. NSR transfer message form

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   **  MSR  **
TRANSFER PROGRAM


XFER GMT=
         235000.0*
OUTGOING TSF=
      44028500.0*
OUTGOING XA=
      44028546.7*
INCOMING TSF=
      44028500.0*
INCOMING XA=
      44028490.9*


OUTGOING DSS
ITEMS A THRU F
         234900.0
       44028546.7

         234940.0

         235002.0

         235100.0

         235200.0
       44028453.3

         235400.0


INCOMING DSS
ITEMS A THRU F
         234900.0
       44028490.9

         235000.0

         235100.0

         235200.0
       44028509.1

         235400.0

         235410.0
```

Fig. 3. Example of program output

NSR TRANSFER MESSAGE

TRANSFER NUMBER 1

S/C	99
DAY	000
OUTGOING DSS	14
INCOMING DSS	43
PRDX SET ID	XXXX
CONTROLLER	GLS

OUTGOING DSS TSF: 44028500 HZ

ITEM	GMT	ACTION
A.	234900	TUNE FROM TSF TO 44028546.7 HZ
B.	234940	RANGE MOD OFF
C.	235002	TRANSMITTER OFF
D.	235100	TUNE TO TSF
E.	235200	TUNE FROM TSF TO 44028453.3 HZ
F.	235400	TUNE TO TSF

INCOMING DSS TSF: 44028500 HZ

ITEM	GMT	ACTION
A.	234900	TUNE FROM TSF TO 44028490.9 HZ
B.	235000	TRANSMITTER ON
C.	235100	TUNE TO TSF
D.	235200	TUNE FROM TSF TO 44028509.1 HZ
E.	235400	TUNE TO TSF
F.	235410	RANGE MOD ON

NOTES:

1. ALL TUNING RATES ARE "PLUS" OR "MINUS" 5 HZ/SEC.
2. UNLESS A PRA FAILURE OCCURS, THE PRA SHOULD REMAIN UNINTERRUPTED REGARDLESS OF TRANSMITTER OR RANGE MODULATION STATUS.
3. RECEIVER SPE SHOULD BE NULLED PRIOR TO EACH TRANSFER.
4. TRK AND LIMIT ENABLE (POCA) MUST BE RESET PRIOR TO EACH RAMP.
5. A NEW POCA UPPER OR LOWER LIMIT MUST BE ENTERED AT TRANSFER PLUS ONE MINUTE-TWENTY SECONDS, AND AGAIN AT TRANSFER PLUS TWO MINUTES-FORTY SECONDS.

Fig. 4. Completed NSR transfer message