The DSN Tracking System

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The DSN Tracking System, one of the eight generic systems of the DSN, has recently undergone a period of extensive software and hardware changes. This article presents a description of the functions of the Tracking System and details the recent changes.

I. Introduction

The Deep Space Network (DSN) Tracking System consists of the hardware, software, personnel and procedures required to perform four primary functions:

(1) Acquire and maintain a communication link (uplink and/or downlink) with a spacecraft

(2) Generate radio metric data

(3) Transmit radio metric data to the data users

(4) Perform radio metric data validation to assure that performance requirements are satisfied

The radio metric data are defined as range, range rate and angle data. These data are used by flight project navigation teams for spacecraft orbit determination, platform parameter determination and ephemeris development. Additionally, as described in Ref. 1, the data have numerous radio science applications for celestial mechanics experiments, planetary atmosphere studies, interplanetary media studies and relativity experiments. Within the DSN, the data are used to monitor the operation of the Tracking System and to validate its performance.

The following sections of this article will present a functional description of the DSN Tracking System and explanations of the many modifications to the system that have been made since the last report (Ref. 2).

II. Functional Description

Figure 1 illustrates the various subsystems and intersubsystem data flow of the Tracking System. The Receiver-Exciter subsystem provides a range modulated uplink carrier to the Antenna Microwave Subsystem where it is amplified and channeled to the antenna. The antenna is precisely pointed by the instructions given to the Antenna Mechanical Subsystem by the Antenna Pointing Subsystem. This allows the uplink carrier to be radiated toward and eventually received by the spacecraft.

At the spacecraft, the carrier is coherently multiplied to provide a downlink carrier, modulated with range data and retransmitted to earth.

The downlink carrier is received and focussed by the antenna and provided to the Antenna Microwave Subsystem.

Here it is amplified and channeled to the Receiver Assembly of the Receiver-Exciter Subsystem. The receiver phase tracks the received signal via a phase-locked loop. The output of the phase-locked loop is provided to the Doppler Extractor Assembly where it is compared to the transmitted frequency. The frequency difference (doppler) is counted by the Metric Data Assembly of the DSS Tracking Subsystem (DTK).

Simultaneously, the receiver provides a range modulated intermediate frequency to the Range Demodulator Assembly of the DTK. Here the ranging signal is demodulated and cross correlated with a model of the transmitted range code. The Planetary Ranging Assembly of the DTK uses the correlation measurement to make a precise determination of the range to the spacecraft.

The range measurement is provided to the MDA where it, as well as the counted doppler and various status and configuration indicators, is formatted for transmission. The MDA provides the formatted data to the Communications Monitor and Formatter Assembly of the Ground Communications Facility (GCF).

The GCF transmits the data to the Network Operations Control Center. The GCF additionally provides an Intermediate Data Record of all data to the end user of the data, typically a project navigation team.

At the NOCC, the radio metric data are received by the NOCC Tracking Subsystem, which generates data displays and alarms used for real-time validation of the data.

The data received by the navigation team are eventually returned to the DSN in the form of ephemeris data for use in generating tracking predictions. These predictions are used for acquisition of the downlink and uplink of the spacecraft as well as radio metric data validation.

Details of the required performance parameters of the elements of the system may be found in Ref. 2.

III. System Modifications

Since the last report concerning the Tracking System, modifications have been made to the software and hardware in the Receiver-Exciter Subsystem, the DSS Tracking Subsystem and the NOCC Tracking subsystem.

A. Receiver-Exciter Subsystem

In July, 1980, implementation of the new microprocessor based exciter frequency controller was begun. The controller, or DCO (digitally controlled oscillator) as it has been dubbed, has the following characteristics:

(1) Control via the Metric Data Assembly or a computer terminal

(2) Capability of storing up to 100 ramps

(3) Minimum ramp duration of 0.1 second

(4) Maximum ramp rate of 100 kHz/second

(5) Maximum phase error (over 8 hours) of 0.0001 cycle

The initial installation of the DCO was hampered by hardware, software and operational problems. The DCO hardware was modified in early 1981 to resolve a problem of sudden large exciter frequency changes. The MDA control interface originally was not compatible for frequency rate reporting and required modification. The operational procedures were, at first, incomplete and resulted in a significant number of errors.

At the completion of implementation in February 1981, the DCO's were installed in the 64 meter and 34 meter subnets. The POCA's remained in the 26 meter subnets.

B. DSS Tracking Subsystem

The Metric Data Assembly (MDA) and the Planetary Ranging Assembly (PRA) of the DSS Tracking Subsystem have had extensive hardware and software modifications during the past year.

1. Metric Data Assembly. The MDA software has been modified to provide, among other items:

(1) A real-time interface with the Meteorological Monitor Assembly. This interface allows the real-time validation of data by NOCC and transference of data to the Occultation Data Assembly (ODA) during VLBI observation sessions.

(2) An interface with the ODA for support of VLBI observation sessions. Besides the previously mentioned MMA data, this interface allows for the transference of the source schedule which is used for data recorder control, source identification, and angle residual calculation.

(3) Automatic control of the DCO and POCA and manual control of the DCO

In the automatic mode of operation, the MDA supplies the control parameters necessary to accomplish the special uplink tuning required to support the Voyager 2 spacecraft and standard uplink tuning required to support the other spacecraft. A complete description of this capability may be found in Ref. 3.

Upon receipt of uplink control predictions (consisting of frequency and time pairs), the MDA computes the parameters (such as rate and time) necessary to tune the uplink to compensate for doppler and allow coherent tracking of the Voyager 2 spacecraft.

Additionally, the MDA can generate the control statements to allow the performance of the "seven point best lock frequency check." This special procedure is performed during Voyager 2 tracks to determine an estimate of the spacecraft's receiver frequency. In order to perform the "seven point best lock frequency check," the MDA constructs a special set of uplink control predicts. These predicts cause the DCO (or POCA) to tune through a series of predetermined changes in frequency as shown in Fig. 2.

Tuning starts at the estimate of the spacecraft receiver best lock frequency. Five minutes prior to the transmitter being turned on, the MDA-generated predicts cause the DCO (or POCA) to snap +1.5 Hz and then continue the tuning necessary to compensate for doppler. Five minutes after the transmitter is turned on, and every five minutes thereafter, the frequency is snapped -0.5 Hz until the lower limit of 1.5 Hz below the estimated best lock frequency is reached. Between snaps the uplink frequency is tuned to compensate for doppler.

Five minutes after reaching the lower limit, the predicts cause the DCO (or POCA) to return to the original estimate of the best lock frequency and to continue tuning through the remainder of the pass. One round trip light time after performing this procedure, the spacecraft signal levels are analyzed to determine the actual best lock frequency. Previously, this procedure required constant operator intervention in order to be accomplished.

For other spacecraft, the MDA computes the control statements for a wide spectrum of sweeps. The type of sweep performed is dependent on both the activity and the relationship between appropriate frequencies. If an uplink acquisition sweep is desired in order to achieve a two-way link with the spacecraft, the operator enters the expected Tracking Synthesizer Frequency (TSF), spacecraft best lock frequency (XA), sweep range and tuning rate. The MDA determines the appropriate direction to tune (by differencing TSF with XA) and the frequencies which encompass the desired sweep range. Possible sweep profiles as determined by the MDA are illustrated in Figs. 3(a) through 3(d). To accomplish these sweeps the MDA generates special uplink control predicts and loads them into the DCO (or POCA).

If an uplink transfer is desired, the operator enters the same information as previously described. In this case, however, the sweep range must be equal to zero hertz. The MDA will generate a predicts set that causes the DCO (or POCA) to tune to the XA and, after the specified time interval, return to the TSF. This type of sweep is illustrated in Figs. 3(e) and 3(f).

Prior to the addition of this capability, a Hewlett-Packard calculator was used to determine the sweep parameters. The parameters were then manually entered into the DCO.

The MDA also provides the control point for manual operation of the DCO. In this mode, DCO control statements are transferred to the DCO. The MDA also provides a display of DCO status.

In order to provide a precise report of tuning activities at the DSS, a new data type, Programmed Frequency data, was developed for inclusion in the radio metric data stream. These data, consisting of precise frequency and frequency rate information, are required to allow for correct processing of the radio metric data by the project navigation teams and to allow remote monitoring of the tuning activities.

Because of the addition of these capabilities the MDA became seriously overloaded causing numerous processing errors. In an attempt to alleviate this problem, floating point hardware was retrofit to the MDA. As of this writing, it had not been determined if this change was completely successful.

2. **Planetary Ranging Assembly**. The quality of ranging data generated by the DSN has been improved by several major modifications to the Planetary Ranging Assembly (PRA). These modification include:

(1) Doubling of the highest frequency component to the 1 MHz

(2) Addition of selectable high frequency components

(3) A new harmonic filter to decrease wave form distortion

All of these changes combine to decrease noise levels on ranging data and to improve ranging capabilities under conditions encountered as the angular separation between the spacecraft and the sun decreases. Figure 4 illustrates the improvement obtained using the new PRA hardware and software. Ranging data acquired by DSS 12 when in its original hardware and software configuration are given in Fig. 4(a). As can be seen, the noise level for these two passes is quite high; more than eight meters during each pass. Figure 4(b) presents data taken after the configuration was modified.

In both of these passes data noise is well less than four meters, an improvement of at least 100 percent. (The absolute differences between the passes are due to orbit and other errors independent of PRA performance.)

C. NOCC Tracking Subsystem

The Prediction Assembly software of the NOCC Tracking Subsystem was replaced by new software. The original software was developed in the mid-1970's to meet existing Tracking System requirements and to provide the NOCC with a replacement for capabilities then residing in the Mission Control and Computing Center (MCCC) 360/75 computer. Because of recent requirements to generate Radio Science predictions and uplink frequency control predictions, the software had been extensively modified to the point where it was difficult to operate and contained many anomalies.

The redevelopment of the software consisted of: making ample use of Network Support Controller (NSC) operating system functions not available when the original software was developed; revising data generation algorithms; updating output formats to correspond to current desires and print capabilities; and most importantly, integrating the functions in a coherent manner.

The result was an improved software package with more easily understood input, and improved running characteristics (run time was decreased well over 50 percent).

IV. Conclusion

Over the past year, various elements of the Tracking System have undergone extensive modifications to both hardware and software. These modifications have, in general, resulted in improved data and increased operational support capabilities. Because of the upcoming Mark IV-A implementations, the Tracking System should remain unchanged over the next few years.

References

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3. Spradlin, G. L., "DSN Tracking System Uplink Frequency Control" in *Deep Space Network Progress Report 42-53*, pp. 108-112, Jet Propulsion Laboratory, Pasadena, CA, October 15, 1979.

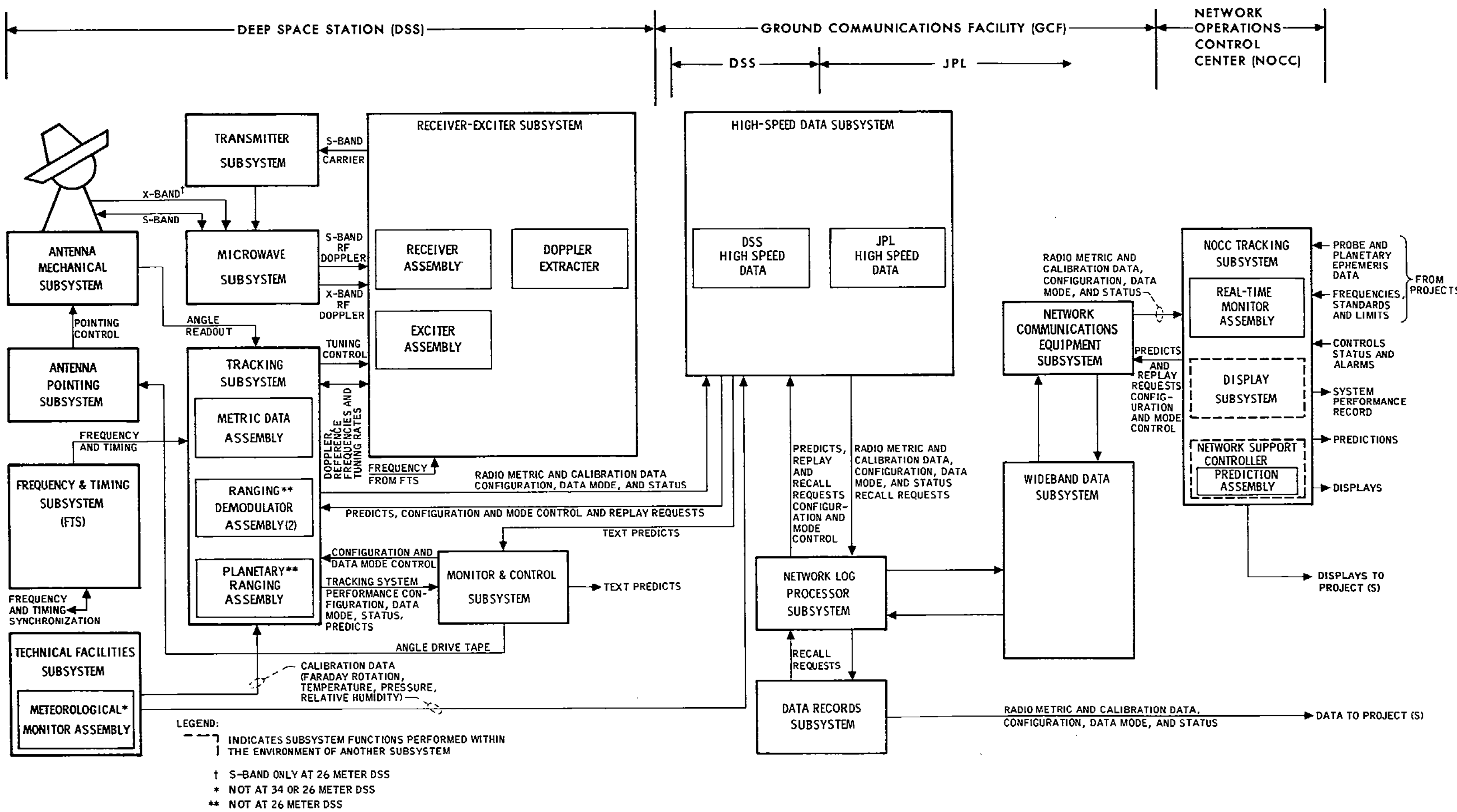

Fig. 1. DSN tracking system

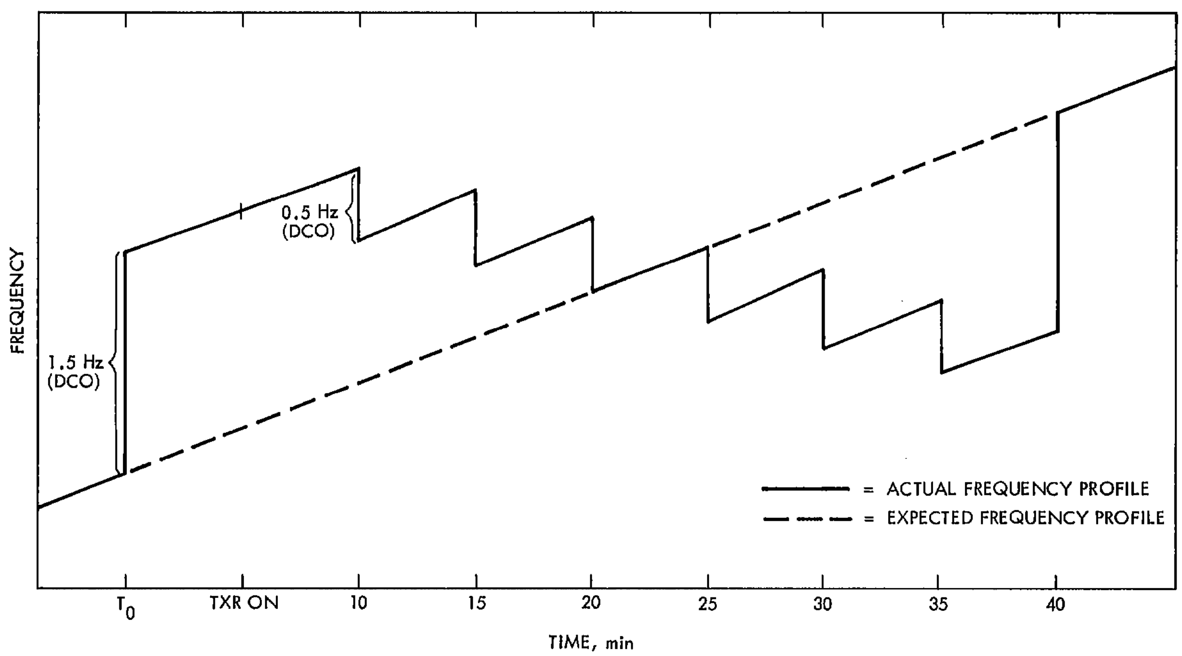

Fig. 2. Voyager 2 best lock frequency check

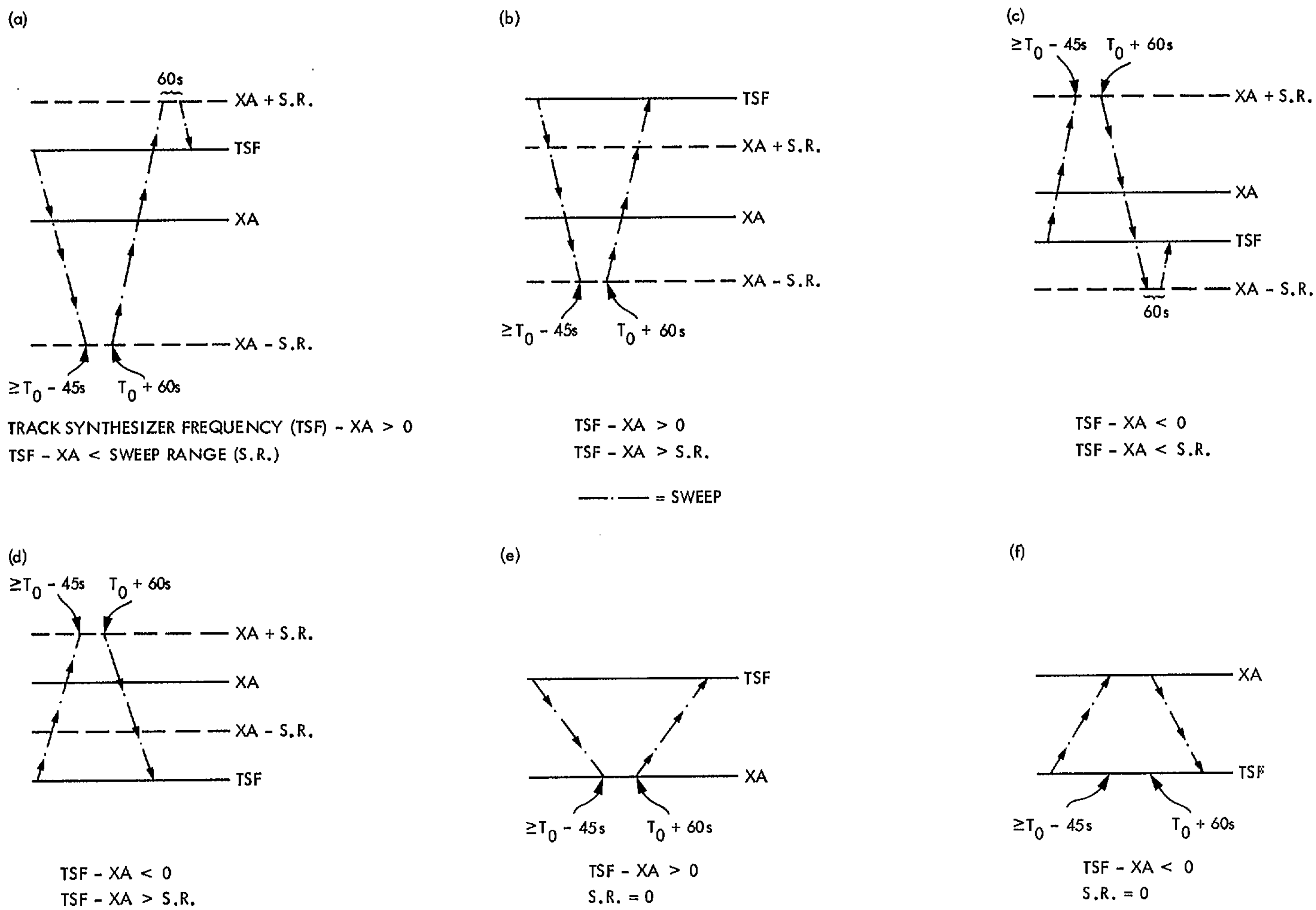

Fig. 3. MDA generated uplink sweeps

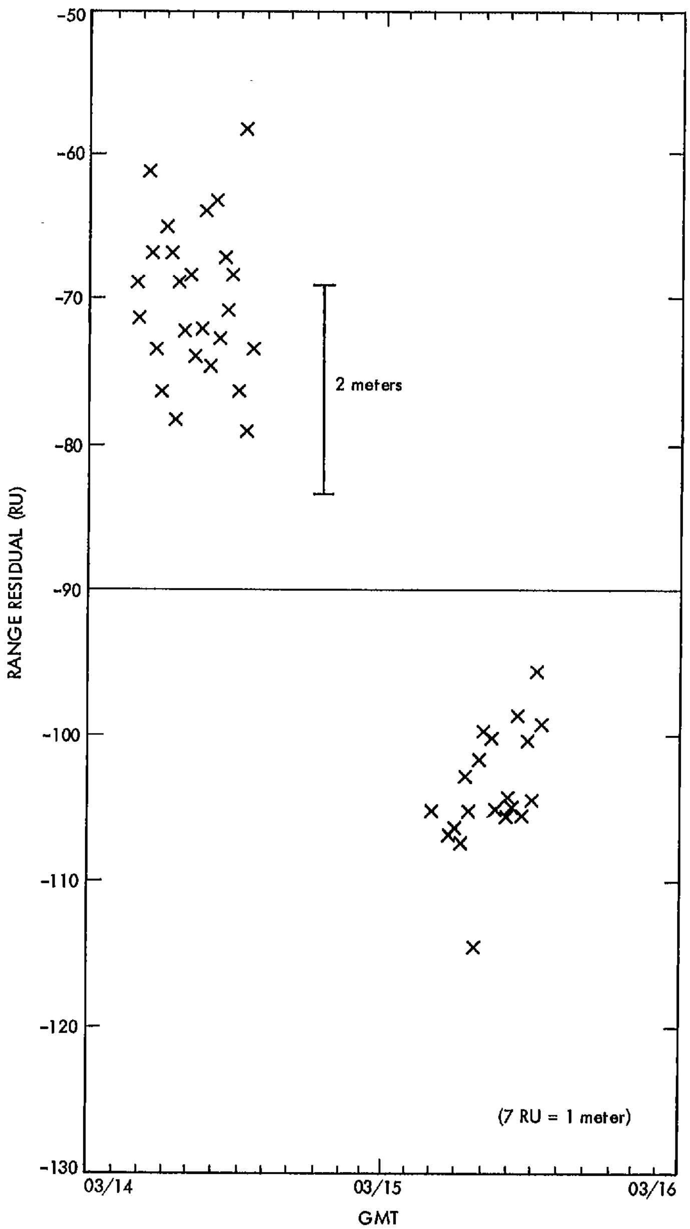

Fig. 4(a). DSS 12 ranging data before modifications

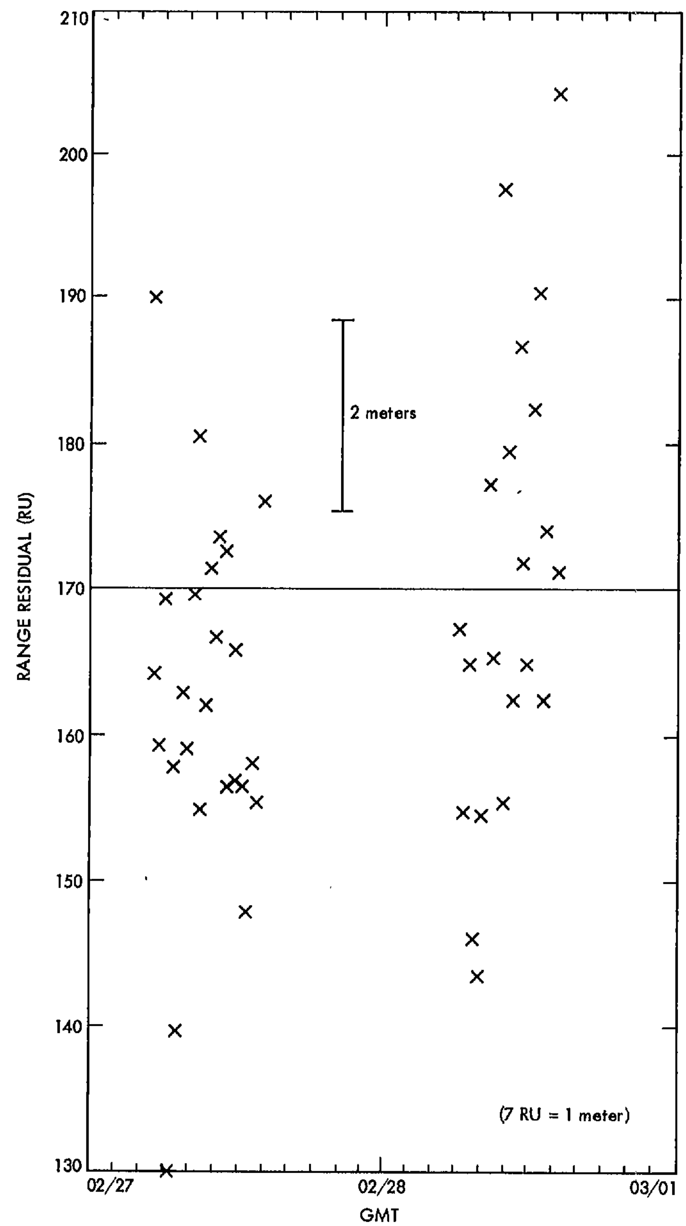

Fig. 4(b). DSS 12 ranging data after modifications