An Experimental Investigation of the Effects of Antenna Pointing Errors on Range Delays

T. Y. Otoshi
Radio Frequency and Microwave Subsystems Section

T. H. Taylor
Deep Space Network Support Section

The effect of antenna pointing errors has been a possible source of error on range and VLBI time delay measurements that has not been previously investigated. This article presents the results of some S-band tests performed specifically to study this effect. The test procedure involved the intentional mispointing of a 26-meter antenna while ranging to a zero delay device (ZDD) connected to a collimation tower antenna. The observed range changes were less than 0.25 meters when the collimation tower target was within the 3 dB points of the main beam of the 26-meter antenna.

I. Introduction

A possible source of error on ranging and VLBI time delays is the unknown change in range (time) delays occurring when the antenna pointing angle changes from boresight (on target) to an angle offset from boresight. In this article, the boresight angle is defined as the pointing angle at which the target is on the peak of the main beam. An offset from boresight can occur if the antenna pointing system is inaccurate, or when an error has been made in locating the target boresight position, or when using conical scanning.

To study the effects of mispointing the antenna, far-field ranging tests were attempted with the DSS 14 antenna and the Viking Orbiter Spacecraft during April 1977. The results of these tests were unsatisfactory because of a large differenced range minus integrated doppler (DRVID) noise level of about 7 ns (corresponding to 1 meter of range delay). For the test data to be meaningful, it was necessary that range changes of 0.1 meter could be observed. Integrating data over longer periods to minimize noise did not succeed because the data processing at that time did not adequately remove the charged particle delay variation due to the earth's ionosphere and solar plasma.

Recently, some success has been obtained by DSS 42 personnel with collimation tower measurements for ranging. The collimation tower at DSS 42 is located approximately 3587 m (2.23 miles) from the 26-m antenna, or $0.7 D^2/\lambda$ away at 2295 MHz where D is the 26-m dish diameter and λ is the wavelength. Although this collimation tower is not in the far-field of the 26-m antenna, some of the earlier data at DSS 42 showed that good agreement had been obtained between the optical (survey) delay and measured delays to the collimation tower. It became increasingly apparent that if the collimation tower method could be proven to have minimal effect from ground multipath and near-field errors, then an antenna

pointing test could be done with the DSS 42 collimation tower similar to that attempted previously with the Viking Orbiter Spacecraft. Such a test was subsequently designed and requested of DSS 42. The purpose of this article is to document the test procedure and test results of the pointing error test that was successfully performed by DSS 42 personnel with the Mu-II ranging system and the collimation tower and the 26-m antenna at DSS 42.

II. Test Requirements and Procedure

The purpose of the test was primarily to determine the effects of antenna pointing errors on range delays and secondarily to determine if a collimation tower could be used for this and other types of measurements. The test setup consisted primarily of (1) a 2.44-m- (8-ft-) diameter parabolic antenna with a zero delay device installed on top of the DSS 42 collimation tower and (2) a 20-kW transmitter, a 26-m antenna, a ranging machine, and all of the tracking hardware and software normally used for station delay calibrations and spacecraft tracking.

The test plan was as follows:

(1) Configure the 26-m antenna for RCP polarization and the ranging modulation for 3-dB carrier suppression.

(2) Point the 26-m antenna to the collimation tower and perform range measurements at the following elevation angle offsets (in degrees) from boresight:

0.00, 0.24, 0.22, 0.20, 0.16, 0.12, 0.08, 0.04, 0.00, -0.04, -0.08, -0.12, -0.16, -0.20, -0.22, -0.24

At each offset angle, record the AGC signal levels in dBm and range values corrected by a suitable number of DRVIDs.

(3) Restore the antenna to the collimation tower boresight and repeat the measurements for the same offset values in azimuth.

(4) With the antenna pointed at boresight, use a step attenuator in the S-band line to the ZDD on the collimation tower and step the attenuator so that the signal drops 2, 4, 6, 8, 10, and 12 dB from that obtained at boresight. Record AGC and range values corrected by suitable number of DRVIDs. This step is required for correcting range versus signal level changes for the tests performed above.

If a step attenuator at the collimation tower is not practical, then use the dish-mounted ZDD to obtain a received signal level versus range calibration curve at approximately the same signal levels as the collimation tower measurements.

III. Test Results

The test procedure described in the previous section was capably carried out by DSS 42 personnel and the results are shown in Figs. 1 and 2. The test results shown in the upper half of the figures indicate that when the target was within the 3-dB points of the 26-m antenna, the range changes were less than 0.25 m peak-to-peak for either elevation or azimuth angle offsets. At the larger angle offsets, most of the larger range changes could be explained by the fact that the signal level becomes weak and data becomes increasingly corrupted by noise. For example, ranging power-to-noise ratio was about 15 dB at -160 dBm AGC signal level as compared to 35 dB at -140 dBm.

Specific test parameters of importance to note for the plots of Figs. 1 and 2 were RCP polarization, 3-dB carrier suppression, and test frequencies of Channel 11 (2112.4 MHz uplink and 2294.0 MHz downlink). The test was done at these frequencies because the collimation tower ZDD local oscillator had already been set up for Channel 11.

The boresight coordinates of the DSS 42 collimation tower antenna for the test were assumed to be AZ = 312.324 deg and EL = 3.857 deg, which corresponds to HA = 59.028 deg and DEC = 30.566 deg. However, as may be seen in the AGC boresight curves in the figures, these coordinates were in error by about 0.032 degree in elevation and 0.050 degree in azimuth.

Further discussion should be given at this time concerning the AGC boresight curves. The AGC curves show the signal level change to be twice as large as the antenna pattern gain change as a function of offset angle. This result can be explained by the fact that the test was done for a round-trip measurement. In this particular test setup, there is a signal loss on the uplink frequency signal when mispointing the 26-m antenna at the collimation tower at a look angle off the peak of the main beam, and if the downlink frequency is close to the uplink frequency, then the same loss occurs when the translated signal returns from the collimation tower to the 26-m antenna at the same offset angle. Since the uplink frequency (2112.4 MHz) and downlink frequency (2294.0 MHz) were sufficiently close to each other, the 6-dB points on the AGC received signal level versus offset curves were assumed to be the approximate 3-dB points of the 26-m antenna pattern.

IV. Discussion of Data Reduction and Error Limits

Some of the specific details of test and data reduction will now be discussed. The Mu-II Ranging System (Ref. 1) was fortuitously available at DSS 42 at the time of this test and, therefore, was used in place of the Planetary Ranging Assembly. In the Mu-II System, the doppler can easily be disabled with a switch and, therefore, the DRVID data becomes range (group delay) change only. The Mu-II ranging machine was programmed to provide a DRVID integration time of 16 seconds. Typically, 9 to 10 DRVID values were then obtained and averaged at each offset angle. The average DRVID was then added to the acquisition range (obtained only one time at the start of test) to arrive at a delay value at each offset angle for the range measurements to the collimation tower. Then corrections were made for range changes due to signal level changes in the receiver. This was accomplished with the calibration data obtained from Step 4 of the test procedure and shown in Fig. 3.[1] A weighted least square method was used to compute the best fit curve as well as to determine calibration errors. The corrected range values were then converted from ns to meters and a constant was subtracted from the result to provide the final range change values shown on the plots in Figs. 1 and 2. Within the limitations imposed by noise, these plots represent best achievable accuracies on the measurement of range changes as a function of antenna pointing angle when using a ranging system. The error bars are plus and minus one standard error (Refs. 2 and 3) bars due to (1) measurement scatter, and (2) errors on the calibration corrections for signal level changes. The error limits do not include estimate of other possible sources of errors such as ground multipath or near-field effects.

---

[1] The range correction for a signal level change from −140 dBm to −160 dBm turned out to be only about 0.3 m for the particular receiver used for the test (see Fig. 3).

Possible causes of time delay changes occurring when the antenna pointing goes from boresight (on target) to off boresight are (1) geometric time delay changes with respect to the antenna center of rotation, (2) differences in antenna phase versus frequency responses at different look angles (Cha, Ref. 4) and, (3) near-field effects. The magnitude of contributions from these error sources are presently not known, but will be studied in the near future.

The described collimation tower tests were necessarily performed at this time because the 26-m antenna at DSS 42 will be updated to the 34-m-diameter size at the end of September, 1979. After the update, the DSS 42 antenna will be more in the near-field of the collimation tower at S-band. It is likely that future time delay experiments with a collimation tower technique can be done easily only at DSS 13.

V. Concluding Remarks

The results of this article indicate that if the target is within the 3-dB points of the antenna beam, the range change will be less than 0.25 meters. A portion of this change is attributed to noise and possible measurement errors, but there still appears to be some small residual effects. Although these residuals are negligibly small for ranging, they could be significant for VLBI.

The test results presented in this article should be analyzed further and compared to the results of a theoretical antenna study. The theoretical study should consist of (1) finding out if group delay changes actually occur through different parts of the antenna pattern, and (2) finding out what errors occur due to the fact that the collimation tower is not in the far-field of the 26-m antenna. To investigate the magnitude of errors of antenna mispointing on VLBI time delays, antenna pointing error tests should be performed with VLBI radio sources and use of VLBI measurement techniques.

Acknowledgments

References

1. Martin, W. L., and Zygielbaum, A., *Mu-II Ranging*, Technical Memorandum 33-768, Jet Propulsion Laboratory, Pasadena, Calif., May 15, 1977.

2. Eisenhart, C., "Expression of the Uncertainties of Final Results", *Science*, Vol. 160, June 14, 1968, pp. 1201-1204.

3. Ku, H. H., "Notes on the Use of Propagation of Error Formulas", *Journal of Research of the National Bureau of Standards – C. Engineering and Instrumentation*, Vol. 70C, No. 4, Oct.–Dec. 1966, pp. 263-273.

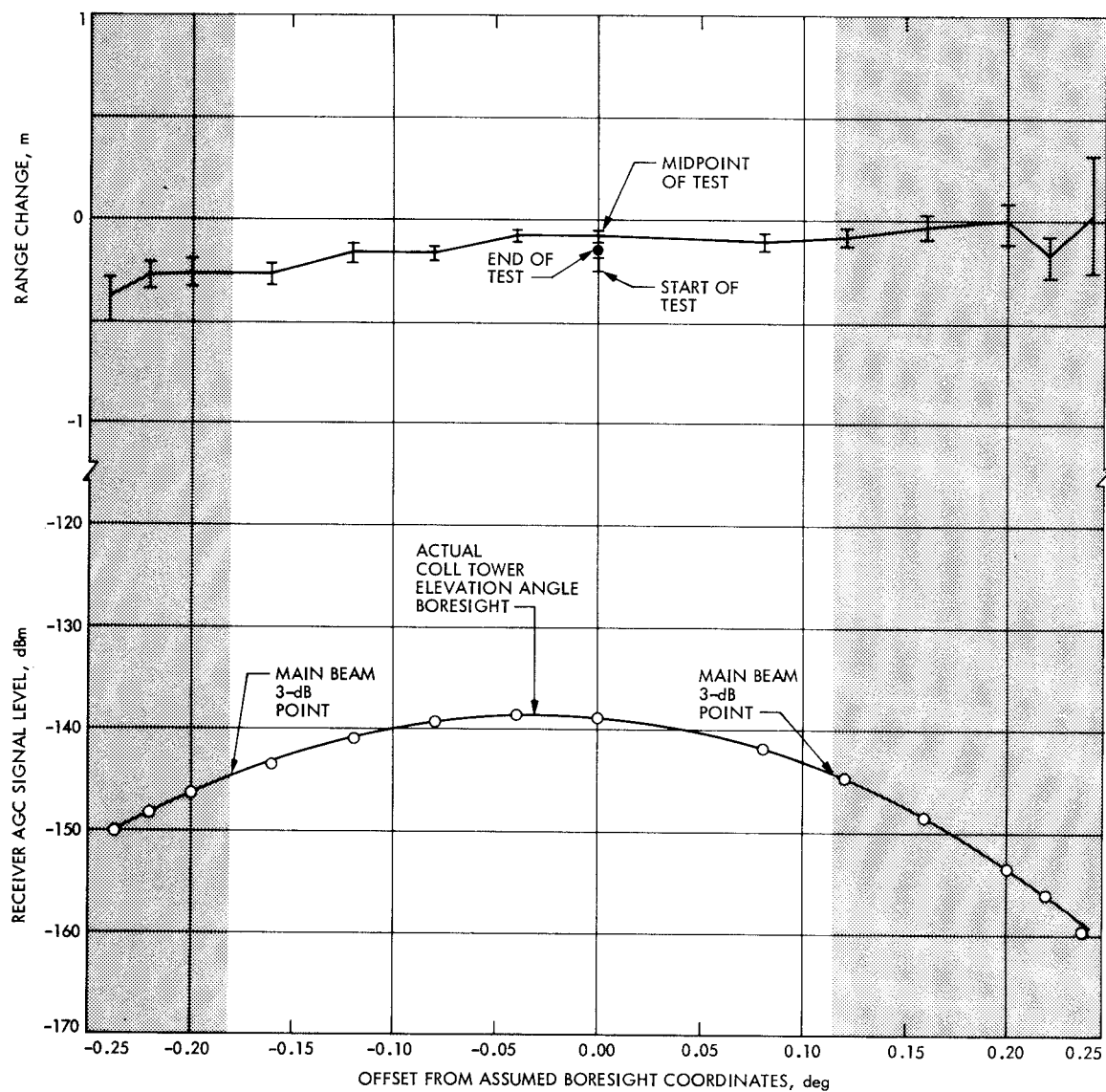4. Cha, A. G., private communication, January, 1979.

Fig. 1. Range delay change versus elevation angle offsets from boresight. Tests were performed with 26-m antenna and collimation tower at DSS 42 on 1979 Day of Year 50
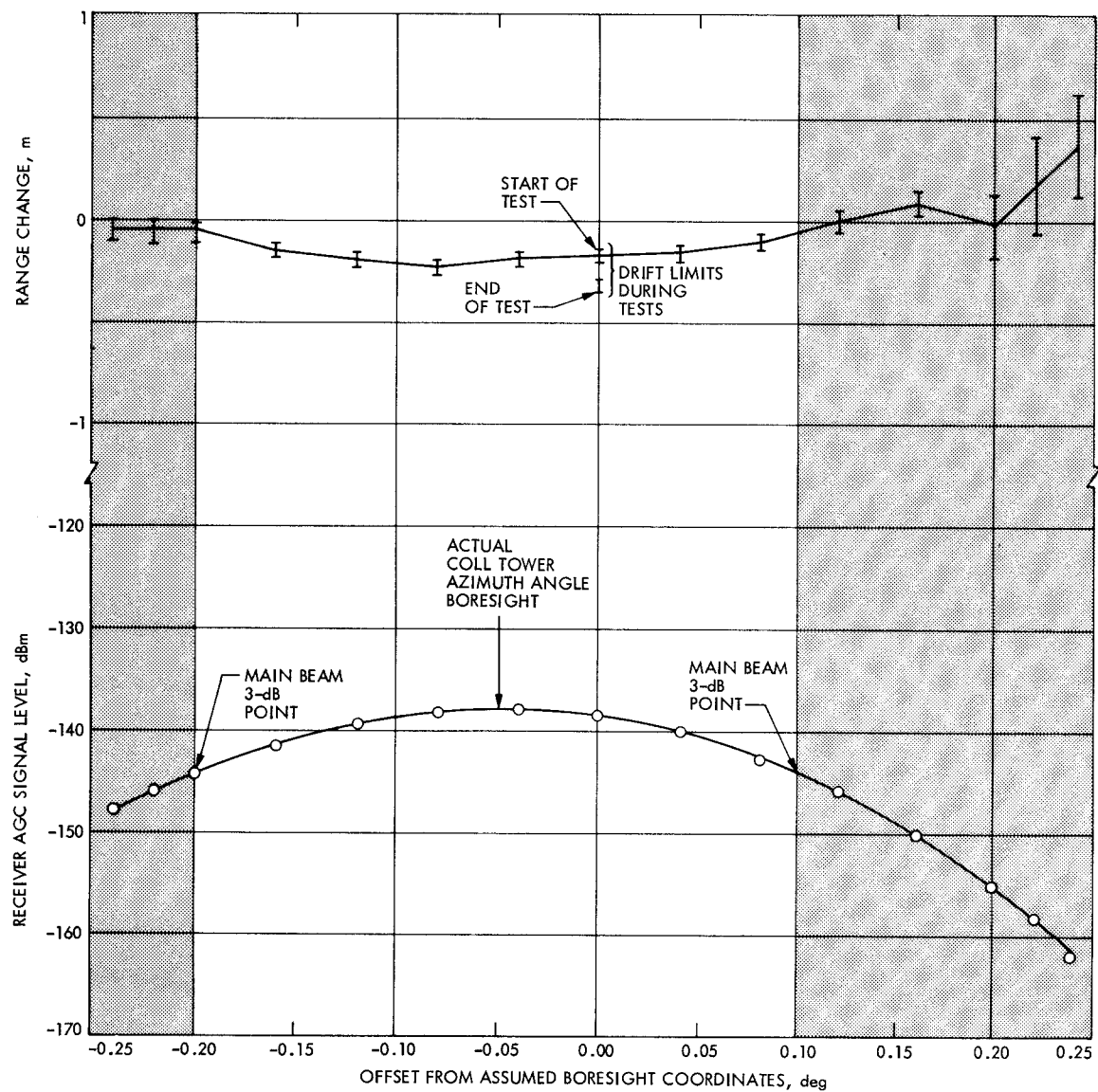
Fig. 2. Range delay change versus azimuth angle offsets from boresight. Tests were performed with 26-m antenna and collimation tower at DSS 42 on 1979 Day of Year 50
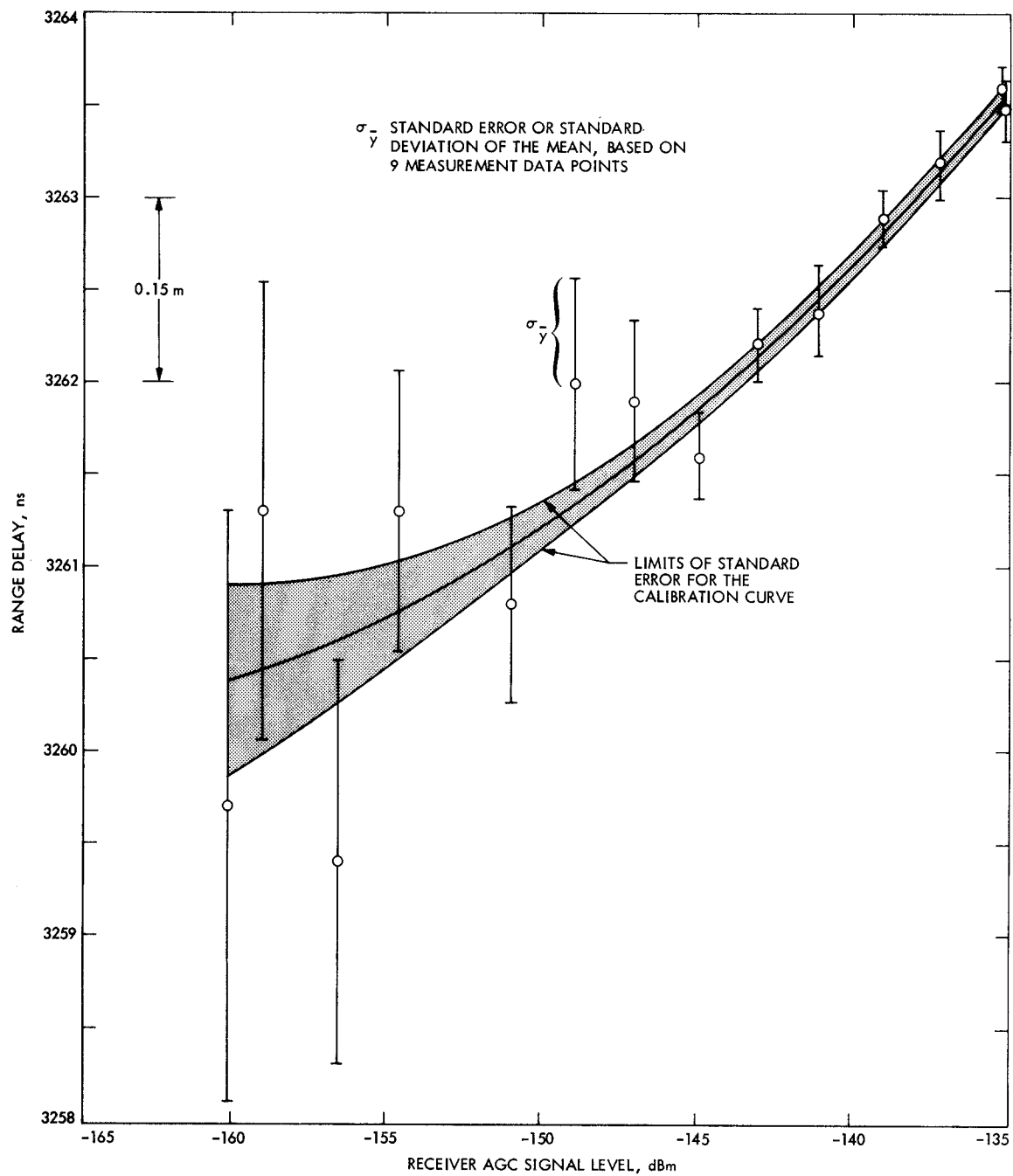
Fig. 3. Weighted least squares calibration curve of station range delay versus signal level characteristics for ZDD mounted on 26-m antenna at DSS 42