PROGRESS REPORT ON THE USNO/NRL GREEN BANK INTERFEROMETER PROGRAM

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INTRODUCTION

The connected-element radio interferometer of the National Radio Astronomy Observatory (NRAO) in Green Bank, West Virginia, is being used by the U.S. Naval Observatory (USNO) and the Naval Research Laboratory (NRL) in a joint program to apply radio interferometric techniques to the determination of improved source coordinates, astronomical constants, and variations in Earth rotation parameters. This is the first time that a radio interferometer has been applied to astrometric work on a full-time, continuous basis.

Radio interferometry was first used for the determination of Earth rotation parameters by Elsmore (1973) and by Shapiro, et al. (1974) with accuracies approaching 3 ms. Observations by Wade and Johnston (1977) indicated that the Green Bank interferometer also could be used effectively in this pursuit. With the construction of the very large array (VLA) by NRAO, the Green Bank interferometer became available for continuous use for astrometric work in October 1978. It was decided to initiate a series of observations to evaluate connected-element radio interferometry for the above purposes.

The primary observables and operational aspects of this program are described elsewhere (Johnston, et al., 1978).

The Green Bank Interferometer

The Green Bank instrument has been described by Hogg, et al. (1969). This instrument consists of three 26-meter antennas which are located along an azimuth of 242°. In the present operational mode, the two movable antennas are separated by 1.5 and 2.4 km from the fixed antenna. A 14-meter antenna is located approximately 35 km from the fixed antenna at an azimuth of 204°. The operating frequencies are 2695 and 8085 MHz with an IF bandwidth of 30 MHz and a total system temperature of about 125 K. The IF signals from the remote antenna are transmitted to the Green Bank site via a phase-stable microwave link.

In the initial phase of the program, two radio sources which pass close to the zenith at Green Bank were observed extensively over a large range of hour angles. These two sources (NRAO 150 and 3C345) were the primary sources for the determination of UT0 until July 1979. Another 19 sources distributed over a declination range of -30° to +70° were used primarily to determine polar motion. These sources were observed at least five times daily at various hour angles, with each observation being at least 5 minutes long. From October 1978 through mid-March 1979, the observations were made only at 2695 MHz. After this time, all observations were made at both observing frequencies in order to eliminate the ionospheric contribution to the interferometer phase noise.

The data, in the form of 30-second averages of fringe amplitude and phase, are recorded on magnetic tape and sent to the USNO daily. They are reduced using a set of programs which apply a correction for differential path delay in the atmosphere that is based upon a standard model atmosphere and ground-level weather data, along with corrections for relativistic effects, and drifts in the local oscillator. The phases also are rotated to correspond to the apparent places of the sources observed, computed using the adopted IAU values for precession and the nutation series. No corrections were applied for ionospheric effects, differential solid Earth tides, source structure effects, or for errors in the nutation series.

Source Positions

The list of sources observed in the Universal Time/Polar Motion (UT/PM) program is derived from the catalog of Wade and Johnston (1977), with a few additional sources at high and low declinations. Updated positions were obtained for most of the sources from S-band (2695 MHz) observations which were made during several weeks of excellent observing weather in October and November 1978. At this point, several sources which showed exceptionally large postfit residuals were eliminated from the observing schedule. (See table 1.)

Because of a degradation in the quality of the observations during the winter of 1978-79, several tests on equipment and of observing procedures were begun in February 1979. It was found that ionospheric effects contributed to the short-term (~0.5 hour to ~4 hours) phase drifts at S-band. Dual frequency observations were begun in mid-March 1979. A set of observations, obtained by using the S- and X-band observations to eliminate the effect of the ionosphere, produced interferometer phases with about half the intrinsic scatter of the pure S-band phases. This result implied, that, at the current solar maximum, the differential ionosphere over our 35-km baseline is important at S-band at the 0.5-cm level, with significant variations occurring over time spans as short as several minutes.

Therefore, it seems apparent that dual-frequency observations are necessary in order to achieve angular measurements with accuracies approaching the $0\overset{''}{.}01$ level. However, the data reduction procedure for combining the S- and X-band data is laborious because of the many lobe ambiguities in the X-band data which must be resolved. Because of current manpower constraints, less than a month of dual-frequency data has been fully reduced at this time, but this relatively small data set has permitted further position improvements for a number of sources.

Table 1

Source Position Catalog

Source	α(1950.0)		δ(1950.0)	
1519–273	$15^h19^m37^s.230$	±0.020	$-27^\circ 19' 29''.60$	$\pm0''.30$
0237–234	02 37 52.780	0.020	–23 22 06.15	30
1245–197	12 45 45.225	010	–19 42 57.80	20
0336–019	03 36 58.957	008	–01 56 16.94	07
1226+023	12 26 33.246	–	02 19 43.26	03
0742+103	07 42 48.470	005	10 18 32.60	05
1502+106	15 02 00.159	004	10 41 17.64	04
2251+158	22 51 29.521	005	15 52 54.29	03
0851+203	08 51 57.255	003	20 17 58.39	03
1328+254	13 28 15.924	003	25 24 37.46	03
1901+319	19 01 02.312	004	31 55 13.88	03
0923+392	09 23 55.322	006	39 15 23.54	03
1641+399	16 41 17.607	003	39 54 10.78	02
2200+420	22 00 39.365	005	42 02 08.57	03
0355+508	03 55 45.261	004	50 49 20.28	02
2037+511	20 37 07.459	003	51 08 35.75	02
0954+658	09 54 57.855	007	65 48 15.52	03
0224+671	02 24 41.166	007	67 07 39.70	02
1749+701	17 49 03.395	008	70 06 39.61	02

Figure 1 gives an indication of the sensitivity of the 35-km baseline to errors in source position. The figure shows the error in source position (either E-W or N-S) that is needed to produce a 30° phase error at S-band at some time during the observing day, as a function of source declination. The limits of the observing day are determined by two conditions: (1) the source must be at an altitude of 20° or more and (2) the source must be less than 6 hours from the local meridian. It can be seen that the interferometer's sensitivity to source position errors deteriorates rapidly below the equator, especially in the N-S direction (declination). The situation below the equator is a little worse that the figure indicates since right ascension and declination errors become increasingly correlated as the hour-angle coverage decreases.

Earth Rotation Parameters

It is to be emphasized that the results and data presented below on Earth rotation parameters have not yet been corrected for the effects of the ionosphere, source structure, or solid Earth tides. Figure 2 shows the components (Bx, By, and Bz) of the baseline vector as determined from 2-day averages of interferometer data for the representative period from April 11 to May 30, 1979. The width of each curve represents twice the probable error of its determination, which ranges from 4

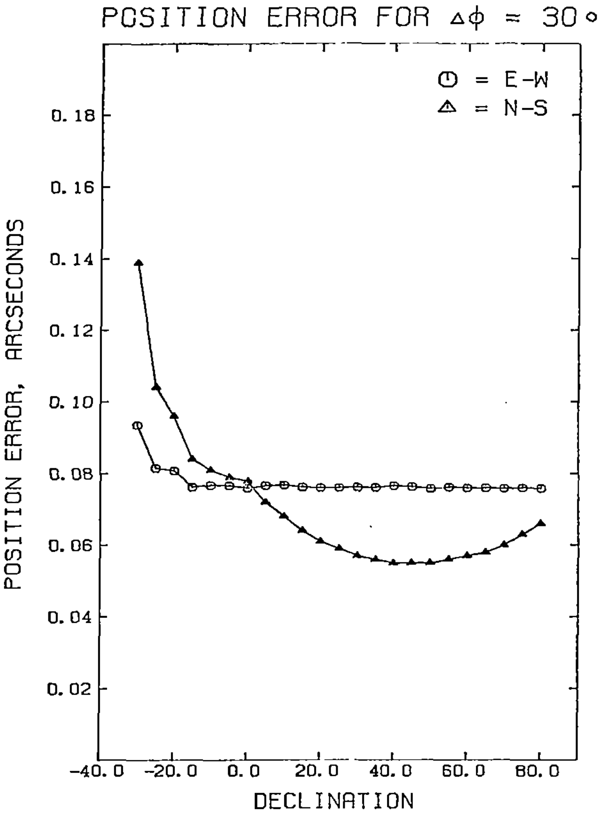

Figure 1. Sensitivity of the 35-km baseline to errors in source position. Source position error (ordinate) needed to produce a 30° phase error at S-band as a function of source declination (abscissa).

to 24 ps, corresponding to 1.2 to 7.2 mm. The top curve represents the length of the baseline which should be invariant under a rotation of the baseline vector. To achieve a goal of a precision of 2 ms in time, the baseline must be determined with a precision of approximately 5 ps which corresponds to about 2 mm in baseline length.

The components of the baseline vector (Bx, By, and Bz) are expected to vary due to the motion of the instantaneous axis of rotation with respect to some reference point and to variations in the Earth's rate of rotation. In order to insure the accuracy of the delay tracking of the interferometer, the sidereal time used in controlling the telescope is derived by using values of UT1-UTC, provided by the Rapid Service of the Bureau International de l'Heure (BIH). Thus, the baseline components shown in figure 2 have the effects of a first approximation to variations in the Earth's rotation rate removed from them but are not corrected for the effects of polar motion.

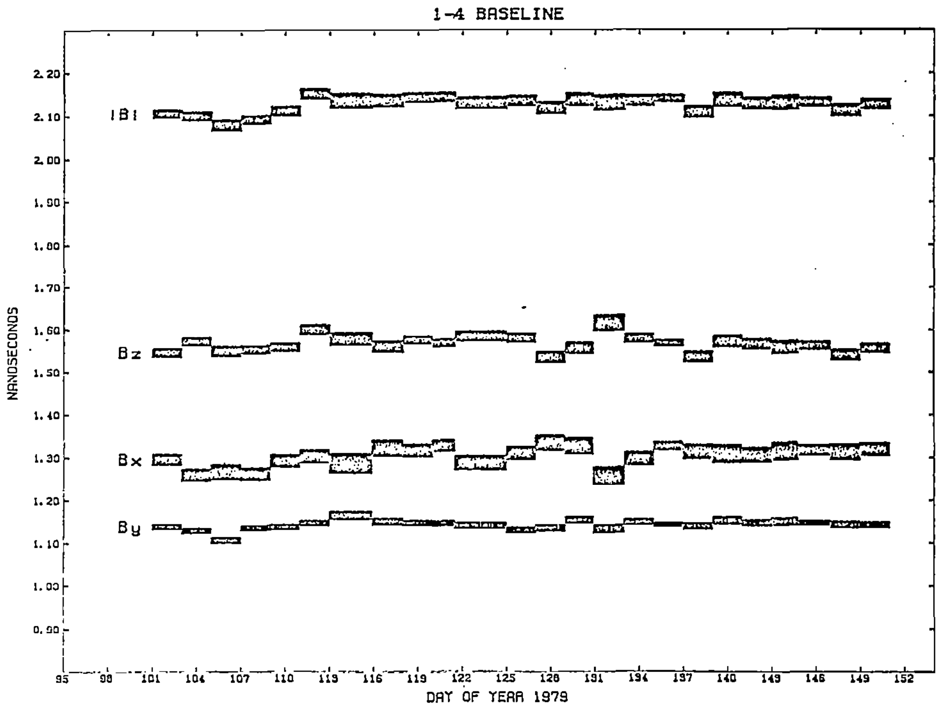

Figure 2. Normalized changes in the baseline components (Bx, By, Bz) for the period April 11 to May 30. Width of the curves is twice the formal probable error. The top curve represents the change in baseline length (|B|).

For the current configuration of the Green Bank interferometer, the equations relating changes in baseline components to the motion of the pole and changes in the Earth's rate of rotation are:

$$\begin{bmatrix} \Delta B_x \\ \Delta B_y \\ \Delta B_z \end{bmatrix} = \begin{bmatrix} -B_z \cos \lambda & -B_z \sin \lambda & B_y \\ B_z \sin \lambda & -B_z \cos \lambda & -B_x \\ (B_x \cos \lambda - B_y \sin \lambda) & (B_x \sin \lambda + B_y \cos \lambda) & 0 \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \\ T \end{bmatrix}$$

where

Bx, By, Bz are the components of the reference baseline in a local left-handed system;

ΔB_x, ΔB_y, ΔB_z are observed changes in the baseline components;

Δx, Δy are changes in the polar coordinates from those of the reference data;

T is the change in UT1-UTC from the value assumed in the observations;

λ is the adopted longitude of the interferometer (5h 19m 20$^{\mathrm{s}}$000).

Since the determinant of the matrix formed by the coefficients of the right-hand side of these equations is zero, the matrix cannot be inverted. In other words, the single baseline can only be used to determine two combinations of the three quantities of interest. In the future, it is hoped, with the cooperation of the National Science Foundation (NSF) and NRAO, to establish a second long baseline nearly orthogonal to the current one to overcome this difficulty. Until that time, it has been decided to publish values of UT0-UTC and variations in the component of polar motion determined from variations in the component of the interferometer baseline (McCarthy, et al., 1979). Table 2 lists the values of UT0-UTC obtained for the more recent period of observations preceding this conference (April 11 to May 30) and their probable errors. The formal probable errors for the quantity UT0-UTC are about 2 ms for 2-day averages and, in some instances, approach 1 ms.

Table 2
Values of UT0-UTC as Determined
by the 35-km Interferometer

Date	MJD	UT0-UTC
79 412	43975.000	0$^{\mathrm{s}}$2819 0.0015
79 414	43977.000	0.2791 0.0016
79 416	43979.000	0.2687 0.0019
79 418	43981.000	0.2662 0.0017
79 420	43983.000	0.2560 0.0017
79 422	43985.000	0.2492 0.0018
79 425	43987.500	0.2449 0.0026
79 427	43990.000	0.2302 0.0023
79 429	43992.000	0.2234 0.0018
79 5 1	43994.000	0.2419 0.0017
79 5 4	43997.000	0.2085 0.0019
79 5 6	43999.000	0.1991 0.0018
79 5 8	44001.000	0.1905 0.0021
79 510	44003.000	0.1874 0.0022
79 512	44005.000	0.1888 0.0024
79 514	44007.000	0.1805 0.0020
79 516	44009.000	0.1712 0.0013
79 518	44011.000	0.1664 0.0020
79 520	44013.000	0.1629 0.0008
79 522	44015.000	0.1571 0.0021
79 524	44017.000	0.1495 0.0024
79 526	44019.000	0.1450 0.0017
79 526	44021.000	0.1396 0.0020
79 530	44023.000	0.1334 0.0018

In order to test the accuracy of our UT0-UTC data, they may be compared with the values derived from the Earth rotation parameters of the BIH Rapid Service. Using the values for Δx, Δy, and UT1-UTC from the BIH Rapid Service, values for UT0-UTC are computed for the dates listed in table 2. The differences between the computed values for UT0-UTC and those determined by the interferometer are shown in figure 3. The values are given in the BIH 1979 System and have been adjusted by a constant so that there is no difference between the observed and computed values on the first date. Figure 4 shows the same comparison but for a period covering the initial months of operation from October 19 to December 12, 1978. These data were computed in the BIH 1968 System and also adjusted to make the difference between observed and computed values on the first day equal to zero. Because of the brevity and discontinuity of the data presented here, no reliable conclusions regarding the accuracy of the data can be drawn.

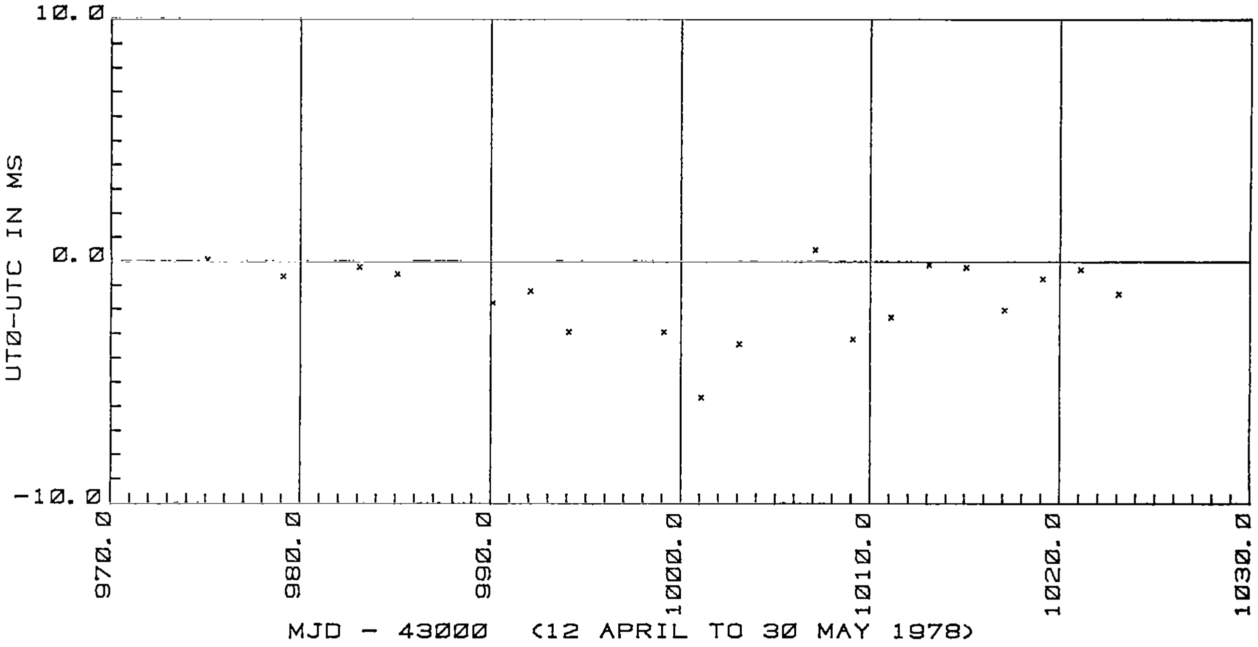

Figure 3. The difference in UT0-UTC between that observed and that computed from the BIH Rapid Service data (referred to the BIH 1979 System), for the period April 12 to May 30.

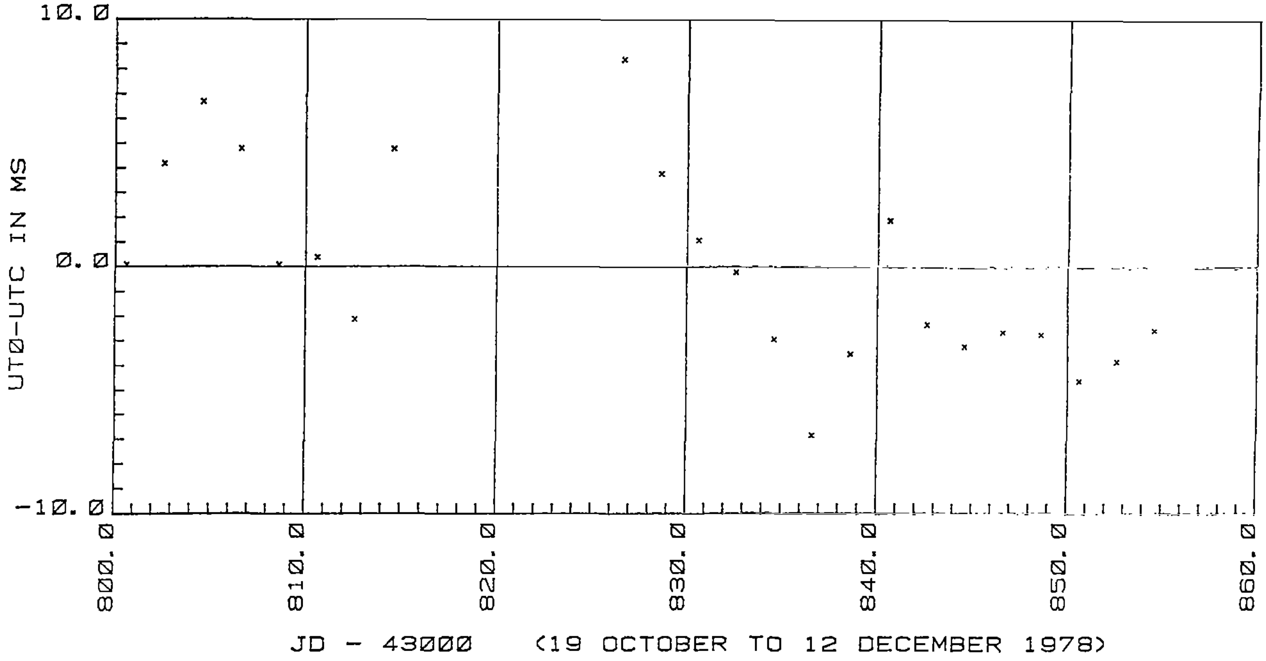

Figure 4. The difference in UT0-UTC between that observed and that computed from the BIH Rapid Service data (referred to the BIH 1968 System), for the period October 19 to December 12.

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