ASTROMETRY USING BASIC MARK II VERY LONG BASELINE INTERFEROMETRY

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ABSTRACT

Two experiments have been performed in April and September 1976 to determine precise positions of radio sources using conventional Mark II very long baseline interferometry (VLBI) techniques. Four stations in the continental United States observed at a wavelength of 18 cm. The recording bandwidth was 2 MHz. The preliminary results using analyses of fringe rate and delay are discussed and the source positions compared with the results of other measurements.

In early 1976, the Naval Research Laboratory (NRL) undertook a program to use the North American Very Long Baseline Network to investigate its astrometric potential. New techniques for determining source positions and baselines were to be investigated. Little was known at that time about the astrometric properties of the Mark II processor in Charlottesville, Virginia. Objectives included (1) developing a grid of self-consistent baselines that could be used in this and other experiments, (2) testing ideas of how to produce a consistent source catalog of a large number of sources in a short time, and (3) developing a method for increased position accuracy by using phase comparison.

The method of using relative phase between sources previously had been limited to separations of 10^{-2} rad (Wittels, 1975).* If an adequate source catalog could be used as a starting point with well-known baselines, a low observing frequency might provide a long enough coherence time to switch between distant sources enough times to track the phase and determine lobe ambiguities. In practice, we compared closely-spaced pairs with other closely-spaced pairs. The 2 MHz bandwidth of the Mark II system would be needed to obtain a good signal-to-noise ratio even for extremely short scans. The concept leads to accuracies at the level of absolute phase when relative phase is maintained for a day.

By using an array of baselines, fringe rates would be used to determine initial source positions to ~0.″05 using the longest baselines. Relative phase from the shortest baseline, Maryland Point to Green Bank, would then establish an improved position catalog using its 0.″15 spacing. Then the longest baselines, spacing ~0.″01, would again be used to determine the final catalog, one with errors at the few milliarcsecond level.

Two observing sessions of 48 hours each were used for this program. In April 1976, data were obtained from the Owens Valley and Maryland Point observatories. In September 1976, all baselines between Green Bank, Haystack, Maryland Point, and Owens Valley have produced valuable data. The observations were taken at 18 cm, the lowest standard frequency of the network, to provide a long coherence time. Hydrogen maser frequency standards were used at all sites. The data were correlated on the National Radio Astronomy Observatory (NRAO) processor in Charlottesville and reduced using programs developed at NRL. In this paper, we will discuss the fringe rate source catalog based on our September data set.

Application of basic Mark II techniques, as was done here, could investigate large numbers of survey sources to eliminate from further study those that show too much structure to be of astrometric interest. These techniques should be used at several frequencies to study the frequency dependency of the centroids of the source emission. As has been shown by Perley and Johnston (1979) from their VLA maps, the size and spectral index of 3C371 depends on frequency. At low frequencies, an extended nonthermal component 3 arcseconds northwest of the compact component biases the position found for this source. Measurements of 3C371 by Elsmore and Ryle (1976) made at 5 GHz

*J. J. Wittels; Ph.D. thesis: Mass. Inst. of Technol., Cambridge, 1975.

with a resolution of 3″ and by Wade and Johnston (1977) at 2.7 GHz with a resolution of 0.″6 have a discrepancy of 0.ˢ1 in right ascension. Readhead et al. (1978) discuss systematic changes in structure and position angle with frequency such as found in 3C273 and 3C345. Structural differences such as these can be expected to lead to discrepancies in positions that can be resolved by a more complete study of the spatial and spectral characteristics of radio sources.

Both the delay and fringe rate properties of our data were used to determine source position catalogs and baselines. Because only the 2 MHz bandwidth of the Mark II system was used (no synthetic bandwidth), delay solutions that were precise enough to be of interest could not be established. The period of the 4 MHz clock (250 nanoseconds) limits solutions to about 25 nanoseconds. For a 3500 km baseline, this is an error of almost 0.″5 in source position or 5 to 8 meters in baseline.

The fringe rate depends on source position, baseline and instrumental clock in the basic form

$$\phi = \Omega\, B_e \cos h \cos \delta + R \qquad (1)$$

where Ω is related to the earth rotation rate, B_e is the equatorial component of the baseline, h is the source angle from the meridian of the baseline, δ is the source declination, and R is a functional for the oscillator frequency offsets between the independent oscillators at each station. For our data, R was a constant to within the error of measurement.

It is important to note that in equation (1), a small change in the magnitude of the baseline B_e is inseparable from a change of opposite sign in $\cos \delta$. This is because in this analysis $\Omega\, B_e \cos \delta$ are each individually time independent, only their product is determined. Outside constraints (such as limiting $\cos \delta$ over the range $0 \leq \cos \delta \leq 1$) must be used to factor this measured product. Observing a large number of sources over the sky will establish a source catalog with the same error in $\cos \delta$, but will not remove it (Shapiro, 1976). Similarly, a grid of baselines can be established using many stations. Baseline direction vectors and relative lengths can be found, but the scale of length cannot be separated from $\cos \delta$ without outside information. Likewise, the zero of right ascension cannot be determined from the observable data alone.

It is difficult for radio astronomers to establish a right ascension for a catalog. Clark et al. (1976) and Wade and Johnston (1977) established their zero point in right ascension by adopting the position of 3C273B determined by Hazard et al. (1971) from lunar occultation timings. Elsmore and Ryle (1976) established their zero point relative to the FK4 position of β Persei. Fanslow (1978)* chose the position of NRAO140 as the zero point. The position of NRAO140 was established such that it minimized the difference between the optical and radio positions for those sources in the catalog having optical counterparts. In this paper, 3C273B was used to set the zero point of right ascension.

*J. Fanslow, private communication, 1978.

A variety of techniques has been examined to establish the zero of declination. We have tried holding the Owens Valley to Haystack baseline fixed to the value provided by Knight (1979) and Thomas et al. (1979). This value should be good to a few centimeters. Fixing one baseline provides a scale length and establishes the other baselines, thus the source positions.

One could fix a single source position and thus force the others and the baseline scale to follow. This approach was considered but not used because the declination of no one source is known well enough to grant it this favored status.

Instead, the fringe rate catalog of table 1 has its declinations fixed by a statistical average of the 10 best sources that also appear in the catalog of Wade and Johnston (1977). We did not select a weighted mean catalog of all the above mentioned catalogs (see Johnston et al. 1979, and Elsmore 1978), because a systematic error found later in one of the component catalogs could be too hard to remove. The root mean square of the residual of the solution is 0.4 MHz or 0."05. A comparison of the solution obtained by fixing a baseline to the solution of table 1 shows that there are no significant differences to the source catalog.

In table 2, the average differences in position for sources common in the above catalogs versus Wade and Johnston (1977) are displayed. As stated above, our average declination difference is defined to be zero. Also, fringe rate positions must degrade near the equator because the error in declination goes as $1/\cos\delta$.

The conclusion is that fringe rate techniques and Mark II VLBI can be readily used at a large number of stations to establish baselines to ~1 meter and source catalogs. Certain errors became known or cancelled because of the grid of baselines, and we were able to get a satisfactory solution using only 48 hours of data. This technique may become important in studying the spatial, spectral, and temporal characteristics of large numbers of sources.

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Table 1
Fringe Rate Catalog

Source	α	δ
0224+671	$02^h24^m41^s.1695$±.0022	67°07'39".690±.006
3C84	03 16 29.5637±.0005	41 19 51.883±.005
NRAO140	03 33 22.4055±.0008	32 08 36.618±.011
CTA26	03 36 58.9568±.0030	-01 56 15.755±.445
3C120	04 30 31.5945±.0018	05 14 59.180±.089
OJ287	08 51 57.2544±.0008	20 17 58.346±.014
DA267	09 23 55.3204±.0010	39 15 23.549±.007
3C274	12 28 17.5750±.0060	12 40 01.250±.200
3C273	12 36 33.2460	02 19 41.667±.380
3C279	12 53 35.9278±.0161	-05 31 05.406±.940
OQ208	14 04 45.6167±.0043	28 41 29.205±.046
OQ172	14 42 50.4260±.0130	10 11 12.000±.300
1546+027	15 46 58.2900±.0080	02 46 05.300±.400
1548+056	15 48 06.8870±.0110	05 36 11.800±.300
1555+001	15 55 17.6837±.0054	00 05 08.544±24.7
NRAO512	16 38 48.1733±.0023	39 52 30.116±.028
3C345	16 41 17.6053±.0009	39 54 10.797±.010
3C418	20 37 07.4628±.0022	51 08 35.727±.010
2134+004	21 34 05.2353±.0075	00 28 00.795±3.27
BL Lac	22 00 39.3635±.007	42 02 08.569±.006
CTA102	22 30 07.7833±.0091	11 28 22.531±.155
3C454.3	22 51 29.5102±.0023	15 52 54.150±.040

Table 2
Weighted Mean Differences. Wade and Johnston (1977) - Other Catalogs

Catalog	Sources in Common	Δα	Δδ
Clark et al. (1976)	17	$-0^{s}.0001\pm0.0006$	$0''.002\pm0.009$
Elsmore & Ryle (1976)	17	-0.0060 ± 0.0015	0.049 ± 0.016
Fanslow (1978)	10	-0.0032 ± 0.0026	0.012 ± 0.017
This paper	10	0.0002 ± 0.0020	0.000 ± 0.016

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