VLBA Memo No. 671

POSITIONS OF KP AND LA FROM MKII VLBI

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1. Introduction

A significant amount of astronomical interferometry is being done with the VLBA during its construction phase. Existing VLBI processors require precise VLBA station coordinates to correlate VLBA data. Wade (1989) used survey methods to determine the coordinates of all VLBA station sites, with a precision of several tens of meters. Ray *et al.* (1989) have used sophisticated MkIII VLBI methods to obtain the position of PT precise to centimeter levels. Such methods will eventually provide similarly precise positions for other VLBA antennas, but cannot be used until those antennas are outfitted for MkIII VLBI. In the meantime, it is possible to use MkII VLBI to measure the baseline vector between PT and another VLBA antenna. This baseline vector can be used to derive an interim antenna position. This memo reports the results of test time observations at 6 cm on 1990 February 16 UT designed to measure the baseline vector between PT and each of the other two VLBA antennas then able to do MkII VLBI (KP and LA).

2. The Method

For a VLBI interferometer, 2 observables are available, each of which depends on a source's position and the baseline vector. These observables are the group delay and the fringe rate. During the processing of MkII VLBI data, the best *a priori* values are assumed for the source positions and the baseline vector. Because these *a priori* values can be imprecisely known and because the observables can be affected by prevailing atmospheric conditions, the processed data will show residual group delays and residual fringe rates. If the source positions are known with enough precision (see below) and if the atmospheric effects can be adequately modelled, then the residual group delays and residual fringe rates can be used to solve for errors in the assumed baseline vector (Cohen and Shaffer 1971; Thompson, Moran, and Swenson 1986 [TMS], chapter 12). It is common practice to decompose the baseline vector along 3 mutually orthogonal directions, with the z axis aligned with the Earth's mean pole. In such a system, residual fringe rates are insensitive to the z or polar component of the baseline vector, while residual group delays are sensitive to all 3 baseline components.

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3. Observations and Correlation

PT, KP, and LA were scheduled for 14 hours to observe 8 sources with J2000 positions with milliarcsecond precision (Ma *et al.* 1990). The schedule was divided into 7 two-hour sections. Each section involved 8 sources giving good enough elevation and azimuth coverage that it alone could yield a reasonable baseline solution. This strategy paid off, as KP started late by 1 hour and broke after operating for only 5 hours, so the observations were ended early. A total of 8 sources were observed, all at elevations above about 20 degrees to minimize atmospheric effects. Table 1 gives their J2000 positions. Each antenna recorded LCP MkII data with a bandwidth of 2 MHz and 4990.99 MHz converted to 0 MHz. No frequency switching was attempted, so delays are based on only 2 MHz bandwidth. Correlation was done on the NRAO MkII processor shortly before it was moved to Socorro. This processor requires B1950 positions for correlation. Table 1 gives the B1950 positions calculated by Craig Walker's Caltech VLBI package program SCHED and assumed for the processing. SCHED's J2000 to B1950 conversion assumes that the J2000 positions were measured on 1985 January 1.

4. Analysis

The correlated data were fringe fitted in 2-minute intervals and delivered as lists of sources, residual group delays, and residual fringe rates as a function of time for the baselines KP-PT, LA-PT, and LA-KP. Obviously spurious points were edited. Figures 1 and 2 show plots of the edited residual group delays and residual fringe rates, repsectively, as a function of UT *prior to baseline fitting*. Sources are coded with the plot symbols described in Table 1.

For parameters typical of the MkII observations reported here, the fringe rates should provide more precise equatorial baseline information than the group delays (TMS, equation 12.21). The observed fringe rate for a given source shows an rms about the mean of σ_f $\sim$ 1 milliHz, part of which probably arises because no fractional bit shift corrections were applied to the data. For equatorial projections of the baselines examined here ($D_E \sim$ 200 – 500 km or 3 – 9 million wavelengths) typical fringe rates are $f \sim 200 - 600$ Hz, and the observed fringe rate errors should result in baseline errors $D_E\ \sigma_f\ /\ f \sim 1$ m and position errors $\sigma_f\ /\ f \sim 0.4 - 1.0$ arcsecond. Parameters derived from group delays will be less precise. Source positions known to be uncertain by less than a few tenths of an arcsecond can safely be held constant rather than treated as unknowns.

The MkII VLBI observables were analysed using a VAX Fortran program SPOOKG written by Jim Moran and modified by JMB. The program fits residual group delays or residual fringe rates separately to yield 3 or 2 baseline components, respectively, for a given antenna pair. Source positions were held constant. A simple atmospheric model was used to determine the effects of the atmosphere above each antenna on the measured residual group delays and residual fringe rates (TMS, chapter 13). This model assumes a spherical Earth and exponentially distributed refractivity with scale heights of 8.5 km and 2.2 km for the dry and wet components, respectively. For each antenna, the model requires the antenna site's elevation, total atmospheric pressure p, and partial pressure of water vapor e. (In principle, SPOOKG could derive the site elevation from station coordinates.) VLBA site elevations were taken from Wade (1989). VLBA weather data provided p. e is the product of the relative humidity rh and the saturation vapor pressure e_s. VLBA weather data provided the dew point and temperature t needed to derive rh, or an upper limit to it, using the table on page E-44 of the CRC Handbook 58th edition. Values of KP's dew point and temperature seemed suspect, so LA's values were substituted. For a given t, e_s was estimated from the table starting on page 350 of the Smithsonian Meteorlogical Tables. We found that either $e = 3$ millibar or the upper limit to e was less than 3 millibar. Given the crudeness of these e estimations, we chose to run SPOOKG with a value of 3 millibar for each antenna. Test runs on the KP–PT baseline with $e = 30$ millibar gave baseline components within 1/3 m of those derived assuming $e = 3$ millibar. This indicates insensitivity to the wet atmosphere parameters for these dry conditions and for the baseline precisions expected.

5. VLBA Baselines from MkII VLBI

Fitted baseline components B_x, B_y, and B_z are given in Table 2, along with baseline components derived from the VLBA station coordinates x, y, and z measured by Wade (1989) with survey techniques. The sign of B_y as reported by SPOOKG was reversed to conform to the survey convention. Table 3 gives the rms deviations in the residual group delays and residual fringe rates *after baseline fitting.*

How precise are the baseline components derived from MkII VLBI? In section 4 the observed rms fringe rate errors were predicted to result in baseline errors of about 1 m, with larger errors expected for baseline components derived from group delays. Can these error predictions be tested empirically? A simple way of doing this is to note that the sum of each of B_x, B_y, and B_z around the 3 independently measured baselines should be zero. Call this sum a closure baseline (CB). For the baseline components derived from group delays, $CB_x = 5$ m, $CB_y = 12$ m, and $CB_z = -11$ m. For the baseline components derived from fringe rates, $CB_x = 3$ m and $CB_y = -2$ m. Thus the baseline components derived from MkII fringe rates are about as precise as predicted and are indeed inherently more precise that those derived from MkII group delays. For this reason, the final values for B_x, B_y, and B_z adopted are from measurements of fringe rates, fringe rates, and group delays, respectively; and should be in error by about 3 m, 3 m, and 10 m, respectively.

Given the close proximity of PT, KP, and LA, all sources were observed at about the same elevation and azimuth at each antenna. Consequently, the baseline measurements reported here are insensitive to the axis offsets at the antennas, which are about 2 m. Future observations involving longer baselines will need to take these axes offsets into account.

The adopted MkII baseline components differ in magnitude from the survey-derived baseline components by up to 11 m in B_x, 8 m in B_y, and 6 m in B_z.

6. VLBA Station Coordinates from MkII VLBI

Using the precise position for PT from Ray *et al.* (1989), MkII-derived station coordinates can be calculated for KP using the KP-PT baseline and for LA using the LA-PT baseline. These coordinates are given in Table 4, along with the survey-derived station coordinates for all three antennas. The MkII-derived station coordinates should be as precise as the MkII-derived baselines, meaning the uncertainties in x, y, and z are 3 m, 3 m, and 10 m, respectively.

References

Cohen, M.H., and Shaffer, D.B. 1971, Astronomical Journal, 76, 91.
Ma, C., Shaffer, D.B., de Vegt, C., Johnston, K.J., and Russel, J.L. 1990, Astronomical Journal, 99, 1284.
Ray, J., Ryan, J., Ma, C., and Shaffer, D. 1989, VLBA Test Memo No. 20.
Thompson, A.R., Moran, J.M., and Swenson, G.W., Jr. 1986, Interferometry and Synthesis in Radio Astronomy, John Wiley and Sons, New York.
Wade, C.M. 1989, VLBA Memo No. 644.

Table 1. Sources Observed

Source	B1950 RA/Decl	J2000 RA/Decl	Plot Symbol
0106+013	01h06m04.517s	01h08m38.771s	star
	01d19'01.16"	01d35'00.32'	
0212+735	02 12 49.925	02 17 30.814	square
	73 35 40.10	73 49 32.62	
0355+508	03 55 45.263	03 59 29.748	plus
	50 49 20.30	50 57 50.16	
1641+399	16 41 17.604	16 42 58.810	cross
	39 54 10.81	39 48 37.00	
1803+784	18 03 39.185	18 00 45.684	circle
	78 27 54.30	78 28 04.02	
2134+004	21 34 05.207	21 36 38.587	triangle
	00 28 25.10	00 41 54.22	
2200+420	22 00 39.361	22 02 43.292	lozenge
	42 02 08.61	42 16 39.98	
2251+158	22 51 29.519	22 53 57.748	diamond
	15 52 54.37	16 08 53.56	

Table 2. VLBA Baselines

Baseline	B_x(m)	B_y(m)	B_z(m)	Method	Reference
KP-PT	−354716	−22520	−218086	survey	Wade 1989
KP-PT	−354721	−22508	−218092	MkII delays	This work
KP-PT	−354723	−22518	...	MkII rates	This work
LA-PT	+191209	+39518	+133711	survey	Wade 1989
LA-PT	+191199	+39522	+133716	MkII delays	This work
LA-PT	+191198	+39526	...	MkII rates	This work
LA-KP	+545925	+62038	+351797	survey	Wade 1989
LA-KP	+545925	+62042	+351797	MkII delays	This work
LA-KP	+545924	+62042	...	MkII rates	This work

Table 3. RMS Deviations After Baseline Fitting

Baseline	Residual Group Delay (microseconds)	Residual Fringe Rate (milliHz)
KP-PT	0.0203	1.62
LA-PT	0.0209	1.53
LA-KP	0.0152	1.50

Table 4. VLBA Station Coordinates

Station	x(m)	y(m)	z(m)	Method	Reference
PT	−1640917	−5014857	3575419	survey	Wade 1989
PT	−1640951.83	−5014816.88	3575412.31	MkIII	Ray *et al.* 1989
KP	−1995633	−5037377	3357333	survey	Wade 1989
KP	−1995675	−5037335	3357320	MkII[a]	This work
LA	−1449708	−4975339	3709130	survey	Wade 1989
LA	−1449754	−4975291	3709128	MkII[a]	This work

Note – [a] x and y from fringe rates. z from group delays.

VLBA MkII 6cm Data Prior to Baseline Fitting

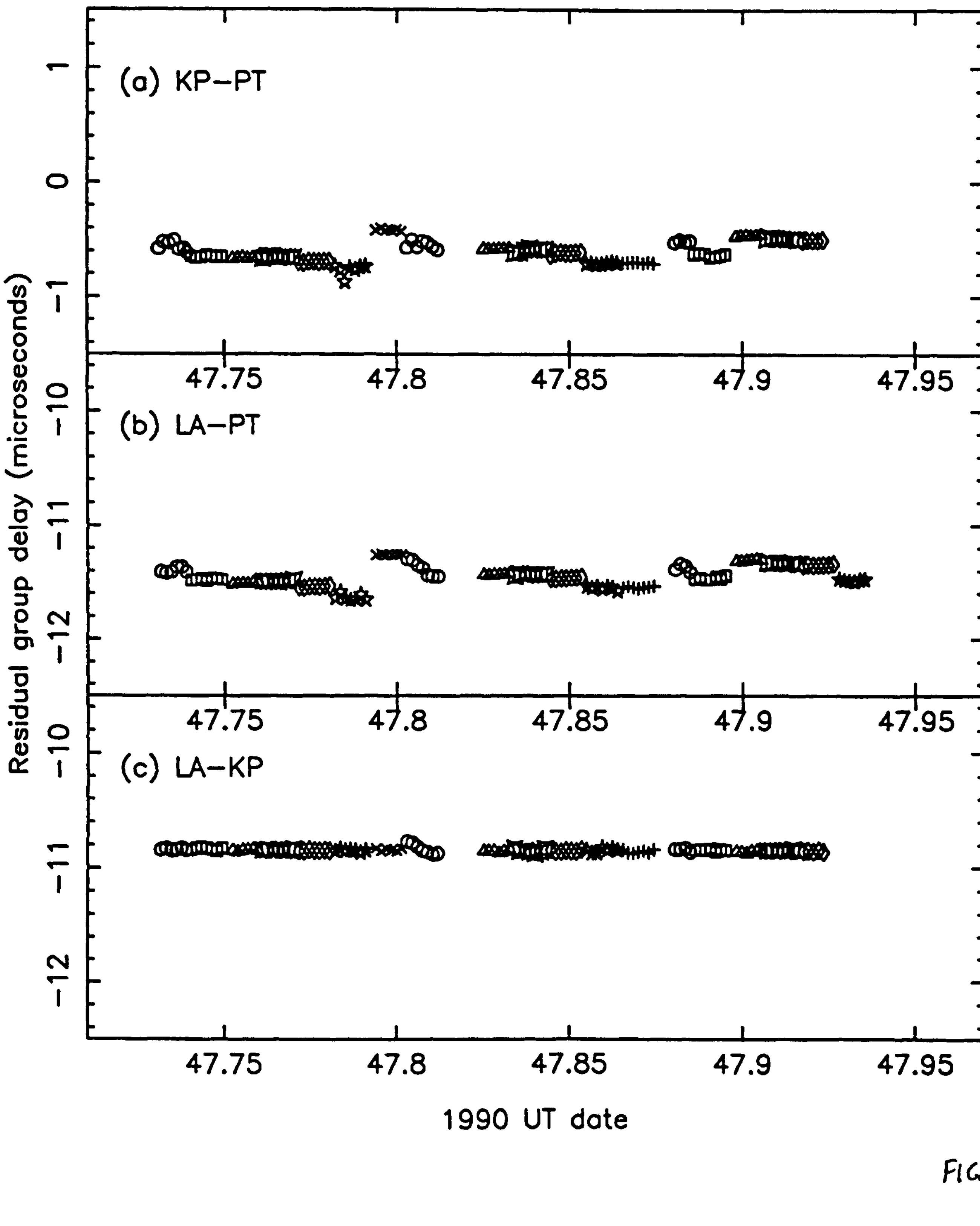

FIG. 1

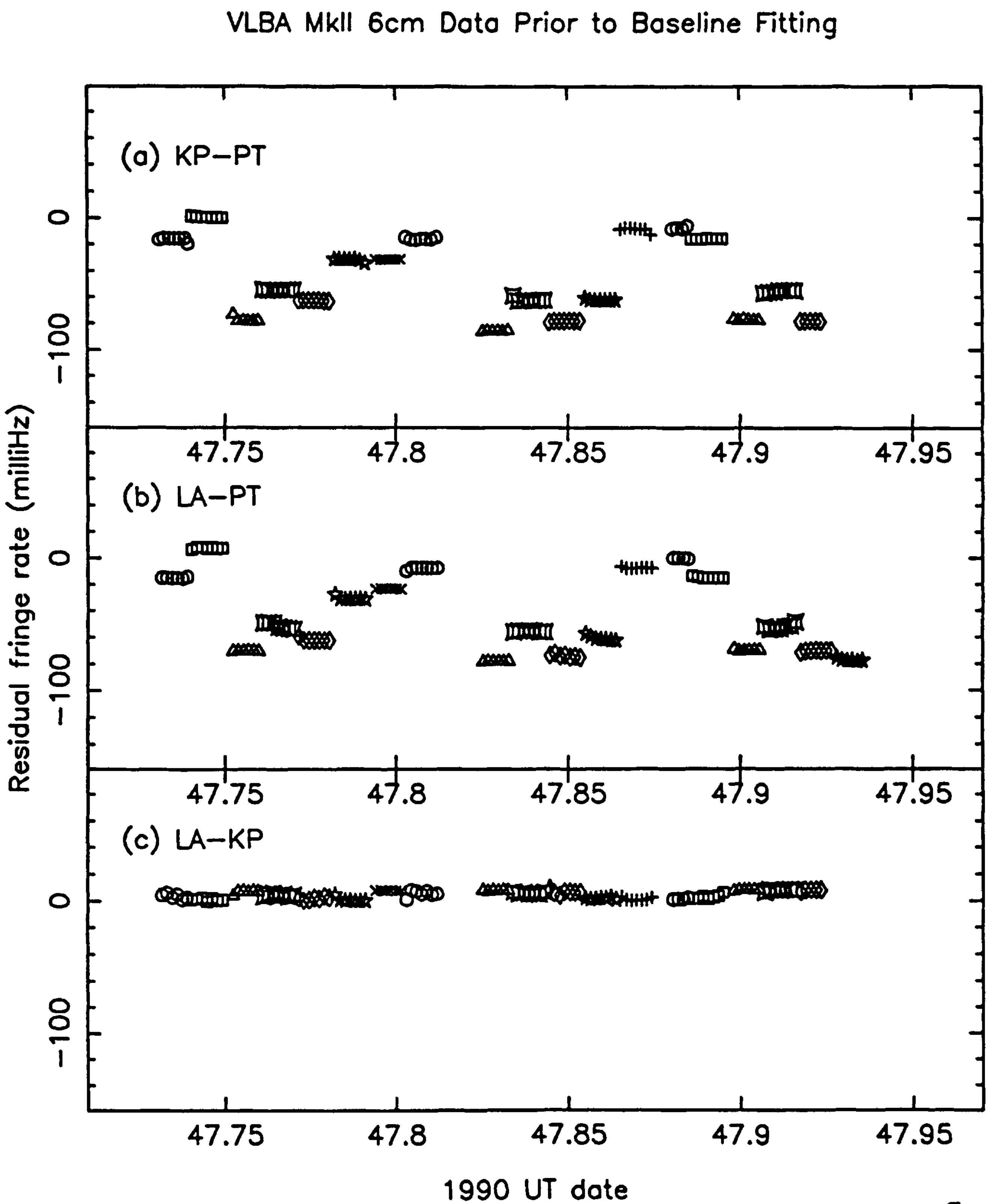
VLBA MkII 6cm Data Prior to Baseline Fitting
(a) KP–PT
(b) LA–PT
(c) LA–KP
0
−100
Residual fringe rate (milliHz)
47.75
47.8
47.85
47.9
47.95
1990 UT date

FIG. 2