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RDV Analysis and Mark 4/VLBA Comparison Results

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Abstract

The processing of the RDV sessions and problems encountered in their analysis are briefly discussed. Results of a VLBA/Mark 4 correlator comparison are presented. Comparison of group delays in session RDV22 processed by two different correlating/fringing systems shows good agreement, with an RMS of ~12 psec. Group delay formal errors may be underestimated in the RDV processing.

1. RDV Sessions

The RDVs, a joint VLBI program of NASA/GSFC, USNO, and NRAO scientists, use the 10 VLBA antennas and up to 10 additional Mark 4 antennas. Six RDVs experiments have been observed per year since 1997. Correlation is done on NRAO's VLBA correlator in Socorro, New Mexico, which produces cross-spectral visibility data. Further processing, to produce group delays, phases, and phase delay rates has been done at the GSFC Analysis Center using the NRAO analysis package AIPS. This processing involves phase calibration, fringing, computation of total delays and rates, conversion of observables from geocentric to reference station time tags, and reformatting the data into the Calc/Solve analysis system.

VLBA antennas are equipped with decoders which extract the phase calibration phases at two tones in each base band converter (BBC). These phases, interpolated to the middle frequency of each BBC, as well as a phase cal group delay for each BBC, have been used in the AIPS fringing and have been found to improve the results by a small amount (~10 psec in an RSS sense) compared to the use of manual phase (constant offset) calibration. The VLBA correlator itself cannot extract phase cal phases, therefore phase cal information at the Mark 4 stations is lost since they have no phase cal extraction capability. For this reason manual phase calibration has been applied for all the Mark 4 antennas in all the RDVs. Table 1 summarizes the major differences between the RDV sessions and Mark 4 sessions.

Some peculiarities were noticed early on in the analysis of the RDVs, although it was never fully understood what the problems were. The Solve solutions did not "look" the same as sessions processed through the Mark 3/4 correlators. There seemed to be a problem with excess noise for southern sources, and this phenomena came to be known as the "southern source" problem. The ratio of the square of a partial weighted sum of residuals for each source to its mathematical expectation exceeds 1 predominately for sources with southern declinations. This effect also shows a strong seasonal pattern, being greatest in the warm, humid (northern hemisphere) months, and almost non-existent in the colder, drier months. Such a pattern though is typical in geodetic VLBI.

The performance of the RDVs and the VLBA sites have been studied in several ways. Source positions obtained from the RDVs alone agree well with those obtained from Mark 3/4 sessions. Baselines with a VLBA site (coming primarily from the RDVs and earlier VLBA correlated sessions) show the best baseline length repeatability of all baselines (Figure 1). However, the chi-

Table 1. Differences in VLBA and Mark 4 Geodetic VLBI

VLBA	**Mark 4**
4 X, 4 S band channels, 8 MHz bandwidth	8 X, 6 S band channels, 2 to 8 MHz bandwidth
FX correlator, produces cross-spectral data	XF correlator, produces lag data
Correlated data processed by AIPS	Correlated data processed by Fourfit
Phase cals extracted by a VLBA decoder at VLBA stations, lost for Mark 4 stations	Phase cals extracted by Mark 4 correlator for all stations
Uses two phase cal tones at 10 and 7010 kHz and BBC single band delays	Uses one phase cal tone at 10kHz

square per degree of freedom of the residual baseline lengths show the largest values of all baselines (Figure 2), implying that the formal uncertainties of the baseline lengths derived from RDV experiments are systematically underestimated.

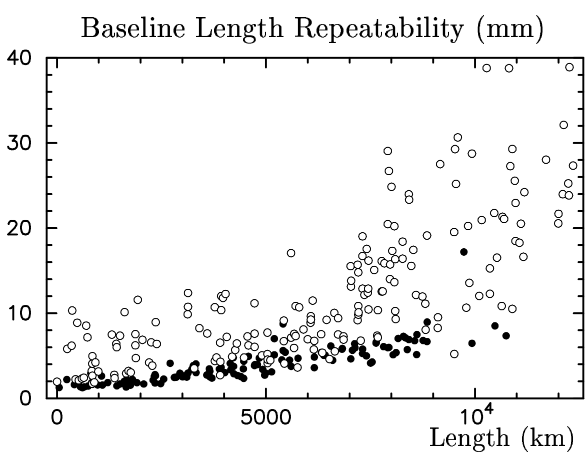

Fig. 1

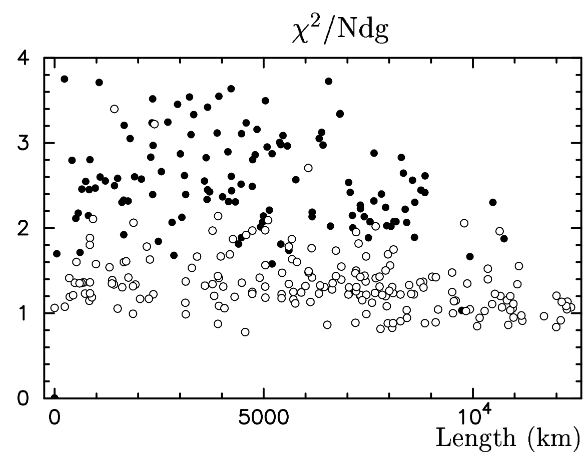

Fig. 2

Solid circles - baseline with a VLBA station at one or both ends.
Open circles - baselines with Mark3/Mark4 stations at both ends.

Baseline length evolution plots combining Mark 3/4 data with RDV data show no significant biases for the RDV points, except on Onsala baselines. The explanation for this seems to be a strong azimuthal dependence of the Onsala phase cals and cable cals, which introduces a bias when manual phase cals are used. Modeling and correcting for this effect seems to be possible though.

In order to address the problems seen in the RDVs, a partial correlator comparison was planned for the RDV22 session (2000 July 6). Tapes from 8 stations (LA, PT, KP, BR, MK, OV, GC, and KK) were forwarded to Haystack Observatory and, after considerable software enhancements, were correlated on the Mark 4 correlator and fringed with Fourfit. Two fringings were made, using extracted phase cals and manual phase cals. These were compared to AIPS fringings, both with manual and measured phase cals. A third type of processing was also made, a hybrid of the Mark 4 and AIPS. The Mark 4 correlator output was input into AIPS using program MK4IN (recently developed by Walter Alef et al. at Bonn), which converts the Mark 4 lag data into cross-spectral data. The resulting AIPS file was fringed using manual phase cals.

2. RDV22 Comparisons Using Measured Phase Cals

The first Mark 4 fringing of RDV22 was made to match the standard AIPS processing. Extracted phase cals at 10 kHz (plus additive phases as needed) were applied to the six VLBA sites, and manual phase cals to the two Mark 4 sites. The same 8 stations in the VLBA/AIPS version were refringed, also using the measured phase cals at the VLBA sites and manual phase cals at the two Mark 4 sites. The two tones, at 10 and 7010 kHz, were linearly combined to give a value at the BBC mid-frequency (4000 kHz). Time tags were made to match those of the Mark 4/Fourfit version. Direct comparisons of the observed group delays were then made, after subtracting out average differences for each baseline. These comparisons show group delay differences that are systematic with elevation, at levels of typically 10-30 psec. These systematic effects were found to be the result of elevation dependent differences in the two sets of measured phase cals. The 10 and 7010 kHz tones show group delay differences that are systematic with elevation, in patterns that vary by station, by up to 50 psec or so. Unless due to some spurious signals, this effect presumably represents an elevation dependence of the instrumental single band delays. As a test, the full RDV22 (18 stations) was reprocessed through AIPS using only the 10 kHz tone. This 10 kHz version was found to give a slightly noiser Solve solution, and the reprocessing had no effect on the scatter of residuals for southern sources. Thus, the indication is that this phase cal elevation dependence is real and should be calibrated for by using the two tones. But because of the uncertainty, a change, at least temporarily, has been made for future RDVs, to record the 10 and 5010 kHz tones instead. Another suggestion that may be tried is to increase the observing frequencies by 0.5 MHz and record the phase cal tones at 510 and 7510 kHz.

3. RDV22 Comparisons Using Manual Phase Cals

Next, a set of comparisons were made in which the data were reprocessed using manual phase cal offsets at all 8 stations. Manual phase calibrations, being constant offsets, cannot impose any systematic differences on the delays. Three data sets were created for this study. The three versions were:

1) VLBA correlated/AIPS fringed (aips)
2) Mark 4 correlated/Fourfit fringed (mk4)
3) Mark 4 correlated/AIPS fringed (hy)

Version 3, as mentioned earlier, is a Mark 4/AIPS hybrid, made by fringing the Mark 4 correlated data with AIPS. Versions 2 and 3 (same correlator) used identical manual phase cals, whereas version 1 used a different set. Group delays and rates were differenced between pairs of these three versions, with average baseline differences subtracted out. The remaining delay differences appear completely random, i.e. no systematic dependence on time, elevation angle, or azimuth is apparent. The RMSs of the differences compare very well, if not better than, those of recent Mark 3/Mark 4 comparisons. In Table 2 we summarize the RMSs of the delay and rate differences, sorted by baseline length. Comparison of group delay formal errors also shows good agreement, with AIPS computed formal errors averaging ~1% larger than those from Fourfit.

The numbered RMS columns in Table 2 can be described briefly as: (1) same correlator (Mark 4), different fringing software; (2) different correlators, same fringing software (AIPS); and (3) different correlators, different fringing software. It is not possible to determine how correlated the different processings are, or how much of the delay differences are due to random noise-like effects versus systematic effects. Comparison (1), which should have no contribution from correlating differences, shows the least scatter, as expected, with an average RMS of 8.7 psec, and with values as little as 3.1 psec on short baselines. Between comparison (2) and (3), the largest RMSs occur when the two correlations are both fringed through AIPS. While not absolutely conclusive, this is an indication that the data emerging from AIPS is noisier than the data emerging from Fourfit, and that this excess noise in unnaccounted for in the AIPS delay formal errors.

There are additional reasons to suspect the accuracy of the delay formal errors computed by AIPS. AIPS fringing is spread between three different programs, and the computation of group delays and rates can be followed fairly clearly between these three programs. However, the computation of correlated fringe amplitudes and the accounting for total integrated observing time is computed separately from the delays and rates, and is very obscure in the AIPS code. As such, it is not clear whether the fringe amplitudes and coherence coefficients are defined and/or scaled similarly to those in Fourfit. Also, the number of bits used per observation may be maximum estimates, and thus may be overestimated in some cases. AIPS determines single band delays and phases, and then makes a least squares fit to the phases to determine group delays. The computation of formal errors does not account for uncertainties in the least squares fits, nor for differences in the number of bits used per channel. Thus, there are numerous reasons to suspect the AIPS delay formal errors of being underestimated.

4. Conclusions

Though this study is not absolutely definitive, a few general conclusions can be made:

- Though there is some uncertainty about how phase cals should be used for the VLBA sites, this uncertainty cannot explain the VLBA problem and apears to be unrelated to it.
- The AIPS determined group delays have no significant biases with respect to Mark 4 processed data, and there is no indication of any problem with the VLBA Correlator.
- The AIPS determined delay formal errors may be underestimated.

Table 2. Summary of RV22 Delay and Rate Differences

Baseline	Length (km)	RMS's of delay differences (psec) mk4-hy (1)	aips-hy (2)	mk4-aips (3)	RMS's of rate differences (fsec/sec) mk4-hy (1)	aips-hy (2)	mk4-aips (3)
LA-PT	236	5.4	5.2	6.4	10.4	20.6	41.0
KP-PT	417	4.7	8.1	6.3	12.2	37.0	44.3
KK-MK	508	11.1	15.8	13.8	35.1	76.4	73.2
KP-LA	652	3.2	6.9	6.6	12.7	35.4	38.3
KP-OV	845	4.7	8.1	7.6	10.7	34.6	37.1
OV-PT	973	4.7	7.4	7.2	19.5	34.7	45.9
LA-OV	1088	4.8	7.1	7.2	14.5	29.7	36.7
BR-OV	1215	5.9	13.8	9.6	18.9	39.9	73.9
BR-LA	1757	6.1	7.8	7.7	11.2	29.3	29.4
BR-PT	1806	6.5	11.3	11.0	28.6	51.9	69.5
BR-KP	1914	8.0	10.3	9.9	15.2	49.1	56.1
BR-GC	2482	9.1	14.9	11.5	16.6	47.6	51.8
GC-OV	3584	9.3	17.3	13.7	18.0	57.1	56.7
MK-OV	4015	8.8	16.1	13.5	26.2	33.6	40.2
KK-OV	4220	13.0	17.2	16.1	26.5	80.1	75.3
GC-PT	4225	10.0	12.5	10.8	17.1	49.1	50.7
GC-KP	4323	8.9	15.3	10.5	13.0	33.7	32.6
BR-MK	4399	13.8	22.6	28.2	18.3	38.6	61.0
KP-MK	4467	8.8	15.6	9.4	19.0	46.8	31.3
BR-KK	4469	13.1	18.4	16.9	41.5	83.4	77.1
GC-KK	4728	13.6	19.9	17.7	39.3	82.9	75.4
KK-KP	4736	11.4	16.0	12.1	34.1	65.4	65.0
GC-MK	4923	13.7	19.0	16.1	19.5	51.9	82.3
LA-MK	4970	7.3	11.0	10.8	22.2	43.3	38.2
KK-PT	5040	11.7	14.6	12.0	55.2	59.6	67.4
	average:	8.7	13.3	11.7	20.0	48.5	54.0