VLBA TEST MEMO NO. 20

Report on Pie Town in ATD-5

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1989 February 24

Summary:

The first use by the CDP of the new VLBA antenna at Pie Town, NM, was in the experiment ATD-5 on 1988 September 08. Non-standard frequency sequences were required at Pie Town because of the availability of only eight, rather than the usual 14, video converters there. This perturbation did not appear to cause any significant degradation of the geodetic quality of the experiment. The intrinsic quality of the Pie Town data seems fine in the sense of instrumental stability and sensitivity, although many non-detections occurred due to problems with the station control software. The system equivalent flux density for the Pie Town antenna is estimated to be 370 Jy at S-band and 380 Jy at X-band, within the range quoted by NRAO albeit at the weak end. In geodetic terms, the Pie Town data fit very well and produce formally good determinations of the station position, when allowance is made for the adjustment of the axis offset parameter. Henceforth, the measured axis offset of 213.5 cm (reported by Lee King) will be fixed in future analyses. The geodetic solutions indicate that the Pie Town clock performance is acceptable but could probably be improved somewhat. The result is, however, tentative because no cable cal was available for this study; with calibration, the clock performance could well improve.

Experiment Schedule:

The ATD experiments (for Analysis and Technique Development) are a series of CDP measurement sessions designed for research and development purposes. The objectives include studying systematic effects that limit the accuracy of VLBI results by: incorporating a high density of observations, utilizing the full range of elevations available at each station, using sensitive stations, and repeating the measurements at regular intervals. During 1987, the ATDs were run monthly and in 1988, every other month, for a total of 18 experiments. The standard ATD network uses Mojave (12-m dish), Fairbanks (26-m), Westford (18.3-m), and Ft. Davis (26-m). For ATD-5, the 25-m Pie Town antenna was tagged along to the standard schedule.

The original experiment schedule was written by Arthur Niell at Haystack Observatory. In order to observe the lowest possible elevation angles as sources rise and set, a significant amount of subnetting was used in the scheduling. The fast Westford, Fairbanks, and Mojave antennas record about 280 scans per day whereas the comparatively slow Ft. Davis gets about 100 scans fewer. Because Pie Town is relatively fast, it is able to make about 85% of the existing scans.

Special Procedures:

The availability of only eight video converters in the standard VLBA terminal configuration, versus 14 for the CDP Mark III terminals, required special frequency sequences for Pie Town. The sequences used at Pie Town were based on a recommendation by D. Shaffer (memo of 04 April 1988) with a subset of five out of the standard eight CDP X-band channels and three out of six S-band channels. The frequencies are listed below. Mojave, Westford, Ft. Davis, and Fairbanks used the standard CDP sequences.

As previously noted by Shaffer, the Pie Town sequences represent a compromise between widest possible spanned bandwidth, lowest sidelobes, and widest ambiguity spacing subject to the constraint of selecting frequencies from the standard CDP sets. The chosen subsets give rms spanned bandwidths close to the usual values (or slightly greater at X-band) and produce tolerable sidelobes provided that SNR values are kept above about 10. However, the S-band ambiguity spacing of only 40 ns (versus the usual 200-ns spacing) could cause problems for group delay ambiguity resolution on long baselines, especially under conditions of high ionospheric electron content and large disturbances. This was not a problem for ATD-5, but the Pie Town sequences are not recommended for arbitrary geodetic networks.

sky frequency	stations
8210.99 MHz	all
8220.99	all except Pie Town
8250.99	all
8310.99	all
8420.99	all except Pie Town
8500.99	all except Pie Town
8550.99	all
8570.99	all
2217.99 MHz	all
2222.99	all except Pie Town
2237.99	all except Pie Town
2267.99	all
2292.99	all
2302.99	all except Pie Town

A special test was performed at the end of ATD-5 to check the polarization purity of the feed. For this test, the standard polarization sense was reversed at Pie Town for the fifth X-band channel and the third S-band channel. Examination of the FRNGE plots for one test scan (with a quality code of 2) confirms a large reduction in the amplitudes of the affected channels, by up to a factor of 10. A thorough report of this test will be prepared by Alan Rogers at a later time.

Data Quality:

The most severe problem with the ATD-5 data was the complete loss of observations involving Fairbanks because of the failure of the narrow-track tape recorder heads there; the heads were replaced following this experiment. The quality codes for the remaining six baselines are shown in the table below. It can be seen that a significant fraction of the scans involving Westford fall into the "o" (for "other") column. There is no documentation to explain why these observations could not be processed, but it is likely that the correlator had difficulty reading certain passes on at least one of the Westford narrow-track tapes.

As for the quality of the Pie Town data, the most glaring problem seen below is the large number of 0 quality codes (that is, no fringes). These non-detections are attributed to two difficulties: more importantly, the formatter time was reset frequently and, because of a bug in the station computer software, the epoch was sometimes set incorrectly by an integral number of seconds (although the time was probably correct at the microsecond level); less frequently, the antenna control computer sometimes chose the wrong cable wrap (that is, the long slew was chosen) and occasionally mispointed altogether, causing some scans to be missed or late. In principle, the former difficulty could have been overcome at the processor given sufficient time and persistence to find the proper epoch for each scan affected. Manual intervention by the operators was attempted to mitigate the second difficulty, although not always successfully. The other main problem with the quality of the Pie Town data, the very poor narrow-track tape recordings, is not apparent from the examination of the quality codes below. However, this did greatly complicate the processing of ATD-5 and necessitated extensive modification of the recorders at the Haystack Correlator.

Examination of FRNGE plots does not reveal any problems with the Pie Town data not already mentioned above. There are, however, many scans with only a few accumulation periods, as few as one; each accumulation period represents 6 s of data. The poor tape recording quality presumably explains these occurrences. In particular, the FRNGE plots do not show any phase instabilities that can be attributed to system deficiencies at Pie Town.

		quality codes												
baseline		0	1	2	3	4	5	6	7	8	9	D	o	Tot
Wes-Moj	X	1	0	2	0	0	1	3	7	21	103	9	34	181
	S	7	0	3	0	0	0	0	5	9	109	14	34	181
FtD-Moj	X	0	0	2	0	0	3	4	5	19	68	12	9	122
	S	1	0	0	0	0	0	1	8	10	84	8	10	122
Moj-Pie	X	55	0	2	0	0	1	3	3	8	86	7	26	191
	S	53	0	3	0	0	0	3	2	3	87	15	25	191
Wes-Pie	X	41	0	1	0	0	1	1	7	12	69	5	43	180
	S	41	0	1	0	0	0	1	3	3	78	9	44	180
Wes-FtD	X	2	0	1	0	0	1	2	9	15	71	12	32	145
	S	1	0	2	0	1	4	6	7	9	78	3	34	145
FtD-Pie	X	24	0	1	0	0	3	0	2	3	69	9	13	124
	S	25	0	1	0	2	1	1	2	2	74	4	12	124
totals	X	123	0	9	0	0	10	13	33	78	466	54	157	943
	S	128	0	10	0	3	5	12	27	36	510	53	159	943

Key to quality codes:
- 0 = no fringes (SNR < 7)
- 1 = one or more channels with low phase cal amplitude
- 2 = one or more channesl with low correlated amplitude
- 3-9 = increasing value implies better quality
- D = no data recovered in one or more channels (tape problem)
- o = other

Antenna Sensitivity:

The sensitivity of Pie Town has been derived with respect to Mojave, assuming a value of 3000 Jy for the SEFD (system equivalent flux density) for Mojave at both S- and X-band. The sensitivity of Mojave is well determined. From the ATD-5 data, the fringe amplitude ratios for the baselines Westford–Pie Town and Westford–Mojave are

$$\frac{\text{Westford–Pie Town}}{\text{Westford–Mojave}} = 2.8 \text{ to } 2.9 \quad \text{at S–band}$$

$$= 2.8 \quad \text{at X–band}$$

with an error of about 0.2 and 0.1 for S– and X–band, respectively.

The scan–to–scan amplitude consistency is not very good in ATD–5, especially for Pie Town, and there are a fair number of scans for which Pie Town gave no fringes. The station problems which could give rise to this are discussed in the previous section on data quality.

The inverse square of the fringe amplitude ratios gives the relative SEFD for Pie Town and Mojave. Thus, SEFD(Pie Town) is 370 Jy at S–band (using an amplitude ratio of 2.85) and 380 Jy at X–band. These values are at the high end of the range expected by NRAO, 200–400 Jy.

Geodetic Analysis:

The standard SOLVE geodetic solution fits very well, giving a weighted rms postfit residual of 26 ps overall. The fits for the individual baselines using both SOLVE and Tom Herring's Kalman filter are listed below. The two solution types were parameterized similarly, estimating deterministically the three coordinates of each site relative to Westford fixed, two nutation offset parameters, and the axis offset for the Pie Town antenna. In addition, clock variations (relative to Ft. Davis fixed) and "wet" atmospheric path delays were modelled stochastically with the filter and quasi–stochastically with SOLVE (using piecewise linear, continuous, constrained segments of one–hour duration) after the fitting of deterministic quadratic and offset models, respectively. The a priori values for the station and source coordinates were taken from a recent global solution using all fixed–station VLBI data through 1987. The earth orientation values were taken from the IERS Bulletin–B series. The a priori calibrations applied were: cable cal (except Pie Town, for which logs are not yet available); ionospheric corrections based on the S/X differences; tropospheric path delay corrections for the "dry" atmosphere based on surface meteorological data and using the CfA–2.2 model (except Pie Town). Only group delay observables were used in the geodetic analysis and some manual editting was applied, especially to eliminate obvious source structure effects.

SOLVE gives formal one–sigma uncertainties for the reference point of the Pie Town antenna of 6, 16, and 12 mm for X, Y, and Z, respectively, or 3, 4, and 20 mm for local north, east, and up components. The baseline length errors range from 1.8 mm for Pie Town–Ft. Davis to 5.5 for Pie Town–Westford. The comparable uncertainties from the Kalman filter are 50–75% larger. The estimation of the Pie Town axis offset greatly increases the formal uncertainty of the local vertical component of the station position (by a factor of two) because of the high correlation between these two parameters. Heretofore, the value of the axis offset was given as 2 m, with no quoted tolerance, which required that an adjustment be included in the analysis. However, according to Lee King (telephone conversation on 1989 Feb. 17) the axis offset for Pie Town has been measured as 84.06 inches with an uncertainty of 1/8 inch, or 213.5 +/– 0.3 cm. The two solutions estimated the offset to be 206.9 +/- 1.4 cm for SOLVE and 217.2 +/- 2.1 cm for the filter. The geodetic solutions will be significantly strengthened when the axis offset is fixed at the value from Lee King.

Byproducts of geodetic analysis include estimates for the atmospheric and clock variations at the stations. Interpretation of these estimates for Pie Town are limited by the current lack of field logs containing surface met data needed to calibrate the "dry" troposphere and cable cal variations needed to remove gross clock-like effects. Nonetheless, it is apparent that the performance of the Pie Town clock (that is, the sum effect of all station-dependent clock-like variations including the maser, cabling, and defects in the instrumental calibration) is at least fair, even without cable calibration. There is a peak-to-peak variation, after removing a quadratic fit, of about 600 ps over the one-day interval, relative to Ft. Davis. The character of the residual variation is roughly sinusoidal and may reflect inadequate thermal isolation of the maser or the absence of cable calibration. The observed rate changes are somewhat larger than we like to see, up to about 4 x 10↑-14 s/s over a 4-hr period, but well within the range of the analysis software to handle adequately. Mojave and Ft. Davis show better performance, by at least 50%. The same cannot be said for Westford, whose clock shows large variations on long time-scales as well as short-term instabilities within individual scans.

When different frequency sequences are used for different stations within the same experiment, as was the case with Pie Town in ATD-5, there is a potential for delay misclosures due to instrumental offsets. Often, baseline-dependent clock offset parameters are needed in SOLVE analyses to account for these biases. A test solution was made to check for this effect in ATD-5. It was found that the estimated offsets are 1-2 ps with formal uncertainties of 6-7 ps. The total absence of instrumental delay closure errors here despite the rather non-standard frequency sequences used at Pie Town implies negligible dispersive effects within the combined Mark III/VLBA systems.

baseline	# obs. used/total	wrms delay residual (ps) SOLVE	Kalman filter
Wes - Moj	112/138	59	42
FtD - Moj	92/101	38	24
Moj - Pie	93/158	44	15
Wes - Pie	80/132	38	21
Wes - FtD	83/101	19	23
FtD - Pie	72/102	13	9
total	532/732	26	21

End of CDP Report.

Postscript by Craig Walker

The reader may have noticed that the actual coordinates of Pie Town were not included in the above report. Since this is one of the pieces of information that we wanted from the CDP observations, I called C. Ma to get them. The reason that they were not included is that they are very model dependent, especially at the centimeter level. To interpret them properly, one needs to know what is treated as the reference for many variable quantities such as pole position, Earth tides, axis offsets ... With those disclaimers, the following coordinates were given to me from the "GLB468Y" list. Haystack and OVRO are included to help put Pie Town into the context of other lists.

Pie Town	X =	-1640951.83 m
	Y =	-5014816.88
	Z =	3575412.31
Haystack	X =	1492406.55 m
	Y =	-4457267.36
	Z =	4296882.14
OVRO 130'	X =	-2409599.00 m
	Y =	-4478350.59
	Z =	3838603.72

I have asked about the "very poor narrow-track tape recordings" from Pie Town. It is still not entirely clear to me what is meant since I thought that our recordings were supposed to be as good or better than any other Mark IIIa recordings. It does seem that the poor playback during processing of this experiment was at least partly responsible for the considerable work that Alan Rogers did recently to improve the performance of the playback drives on the Haystack processor and to improve the consistency of Mark IIIa recordings. According to Art Neill, the Pie Towns tapes for the CDP observations that followed those reported here were no worse than any of the other recordings from that experiment.