VLA Test Memo 196
Spectral Line Phase Calibration with the Continuum Phase at the VLA

M.A. Holdaway
National Radio Astronomy Observatory
Socorro, NM 87801

October 19, 1995

Abstract

We have observed the bright calibrator 0923+392 switching quickly between continuum and spectral line modes. After removing an apparently constant antenna based phase offset between continuum and spectral line modes, we find that the differences between the continuum and spectral line phases are consistent with the expected atmospheric fluctuations. A new AIPS task should be written for observers to easilly take advantage of this technique.

1 Introduction

VLA observations at Q band (40-50 GHz) will often be limited by phase fluctuations, especially on the longer baselines. However, fast switching phase calibration with cycle time $t \simeq 80$ s can remove phase fluctuations on spatial scales larger than $vt/2$, resulting in phase stability in all arrays which is comparable to the intrinsic phase stability of the D array. Fast switching requires that the calibrator be detected at high SNR over the 10-20 s in which it is observed, a requirement which can be met for a 0.25 Jy source when observing in continuum with two IFs, but which is seldom met when observing in spectral line mode with narrow channels. I demonstrate here that it is possible to observe the calibrator in continuum mode and transfer the phases to the target source spectral line data after solving for a time independent phase offset between the continuum and spectral line antenna based phases.

2 Data

On 24 December 1994, I observed the 10 Jy quasar 0923+392 at 22 GHz in the VLA's C array for one hour. I cycled between continuum, 2IF spectral line mode with 16 channels and 12.5 MHz total bandwidth, and 2IF spectral line mode with 32 channels and 6.25 MHz total bandwidth, each with 10 s integration time. The entire cycle time for the three different modes was usually 150 s, but the interaction between the schedule created by the observe program and the on-line system was not perfectly clean, resulting in varying cycle times and between 10 and 40 s on source per cycle in each of the modes. The on-line system required 20 s of set-up time when changing between continuum and spectral line or vise versa, but required 30 s of set-up time

Mode	Theoretical rms $\theta_R - \theta_L$	Measured rms $\theta_R - \theta_L$
Continuum	0°.17	3°.3
Line (12.5 MHz)	0°.40	1°.2
Line (6.25 MHz)	0°.56	0°.8

Table 1: Gauging the data quality: we report the rms difference between the Stokes R and Stokes L antenna based phase after a systematic offset has been removed, averaged over all antennas, for the three correlator modes we used. The measured R-L rms is higher than the theoretical due to non-closing errors, presumably caused by bandpass mismatches which are more severe for larger total bandwidth.

when changing between the two spectral line modes. For comparison, the minimum set-up time, the time between two continuum scans when no antenna motion is required, is 20 s.

2.1 Data Quality

Antenna based gains where derived from the continuum data and the "channel 0" data derived from the spectral line data. The quality of the data for each mode and each antenna was gauged by the rms of the Stokes R gain phase minus the Stokes L gain phase after correcting for the mean R-L offset. The R-L offset is roughly calibrated on-line for the continuum data, resulting in R-L offsets close to zero. The spectral line data has very large R-L offsets, but the two different spectral line modes had offsets which differed by only a few degrees. The calculated and theoretical rms gain differences after correcting for the offset are shown in Table 1 for the three observing modes. The higher than expected measured rms gain differences are presumed due to amplitude and phase bandpass mismatches between antennas which become smaller with smaller bandwidths (no bandpass calibration was performed). Since the spectral line phases are so much better than the wide band continuum phases, the spectral line system should be used for future atmospheric studies.

Antenna 4 had a single 50° phase shift which affected data in both Stokes, both IF's, and both continuum and spectral line modes.

2.2 Comparing the Continuum and Spectral Line Phases

The hope is that the antenna based phase solutions obtained in continuum mode track the phase solutions in spectral line mode. Three affects may limit the agreement of the agreement of the two phases after determining a mean offset:

- each continuum phase solution has an error of about $3^\circ.3/\sqrt{2}$, as determined by the R-L gain phase differences.
- each spectral line phase solution has an error of about $1^\circ/\sqrt{2}$, as determined by the R-L gain phase differences.
- the spectral line and continuum phases were calculated at different times, and the atmosphere could have changed between the observations. The phase structure function allows us to predict how much the phase changes over this short time delay.

- the phase offset between the continuum and spectral line data may drift with time.

We solved for an antenna based offset between the spectral line antenna phase time series and the continuum antenna phase time series interpolated onto the spectral line solution times, using the full hour of data. After removing the constant offset, the rms difference between the spectral line and continuum time series, averaged over all antennas, was $6.^\circ0$ for both R and L Stokes for the 16 channel data, and $5.^\circ0$ for both R and L Stokes for the 32 channel data. It is not understood why these numbers are different, suggesting that there may be a non-atmospheric contribution. Figure 1 shows an example of how the gain solutions in continuum and spectral line mode track one another.

Now we must determine if the rms difference between the continuum and spectral line phase time series is consistent with the expected contributions from the atmosphere and the errors in the phases as determined from the rms R-L differences. Unfortunately, the SNR of the individual phase time series was not sufficient to accurately determine the temporal structure functions on individual baselines. However, the spectral line data from all baselines allows us to determine the spatial structure function, which was:

$$\sigma_\phi(\rho) = 1.^\circ38\rho^{0.27},$$

where ρ is the baseline length. The power law exponent of 0.27 is below the Kolmogorov thin-atmosphere exponent of 0.33, which could be caused by the phase being dominated by LO noise on the shortest baselines. The phase structure function evaluated at $vt/3 = 10\ m/s \cdot 150\ s/3 = 500\ m$ is about $7.^\circ4$, which is somewhat *larger* than the rms phase differences we found between the continuum and spectral line data. A lower number would be obtained if we used a lower wind velocity, or if the phase structure function power law exponent were a bit steeper. (The noisy data do not permit an accurate determination of the velocity from the standard methods.) Hence, it appears that the difference between the continuum and spectral line antennas based phases are consistent with being due to the change in the atmosphere during the time between the continuum and spectral line observations.

3 Future Work

This test demonstrates that continuum phase calibration of spectral line data should work well. The $3.^\circ3/\sqrt{2} = 2.^\circ3$ phase errors presumably due to the bandpass errors in continuum mode will not be very important for most spectral line observations. Since the R and L Stokes for both continuum IF's can be phase aligned, there is potentially a very large gain in sensitivity on the calibrator source, which translates into a modest reduction of the calibration cycle time, which would be especially attractive for long baseline, narrow channel spectral line observations at K and Q bands. An astronomically interesting test of this observing mode in concert with fast switching would be the next step. The observe program must be robust enough to accurately predict the behavior of the on-line system for very short times on source (10 or 20 s). Before this mode of observing can be used by the casual VLA observer, new software is required in AIPS to solve for the phase offsets and to average the phases in the different continuum Stokes and IFs.

Special thanks to Claire Chandler for a critical reading of this memo.

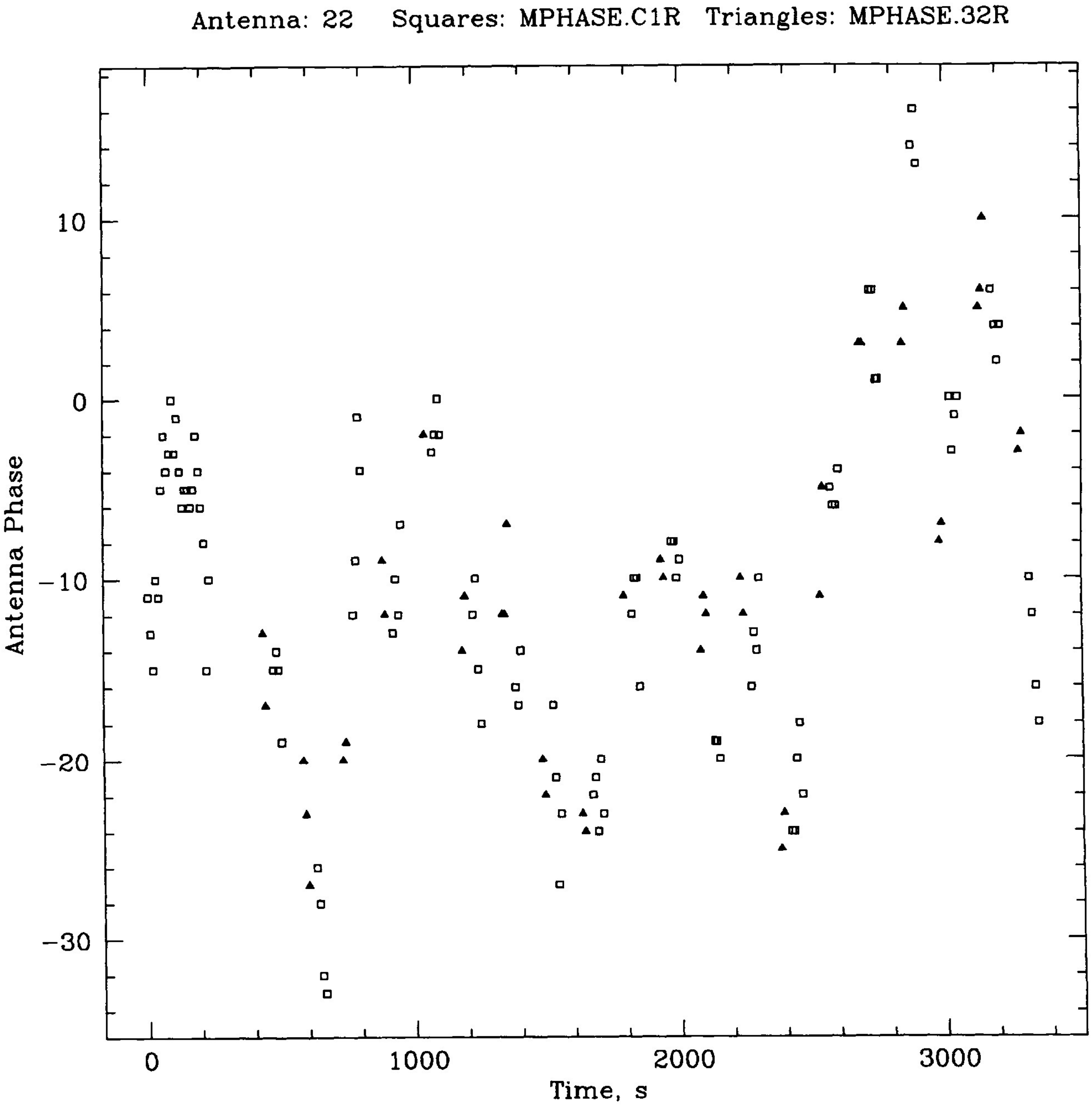

Figure 1: Time series of the antenna phase solutions for antenna 22. The open squares are the phase from continuum mode, IF1, Stokes R. The filled triangles are the phase from spectral line mode, 32 channels, 6 MHz bandwidth, Stokes R. In this case, a constant offset of 0.°7 was applied to minimize the mean difference between the interpolated phase time series. After the offset was removed, the rms difference between the spectral line phase and the interpolated continuum phase was 4.°4.