VLA Test Memorandum #172

Report on VLA Technical Issues Seminar #1 held on July 28, 1993

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VLA observations of polarized signals

The discussion was led by F. Owen and M. Holdaway and what follows is my summary of it.

First, F. Owen presented an overview of the subject:

Observations of polarized signals have to deal with two main issues:

1) Measure the delay between RCP and LCP sides. This can, in principle, be done with one observation of a known polarized source.

2) Measure the instrumental polarization. There is leakage which produces a signal in the absence of a polarized sky signal. This can be dealt with by observing a source over a range of parallactic angles which results on a sinusoidal perturbation superimposed on the constant term. It can be fitted and removed on an antenna basis.

A number of assumptions are usually made:

1) All data are perfectly calibrated.

2) There is no Faraday rotation.

3) The instrumental parameters are constant in time.

4) The off-axis polarization is the same as the on-axis one.

5) The polarization calibrators are point sources.

The net instrumental polarization is usually small ($\leq 1\%$).

However, it is often the case that attempts at calibration of the instrumental parameters result in no net difference and sometimes make things even worse.

Discussion:

B. Clark indicated that if one has sufficient data, deviations from the sinusoidal modulation describe the instrumental variation.

F. Owen recommends to look at several sources with known polarization (which should be found first) and use them to solve for the instrumental terms.

P. Napier noted that one has to differentiate delay and phase, i.e. delay errors result in reduced RL and LR coherence if they are large whereas phase errors induce errors in the polarization angles. Delays are measured every few months but not at all frequencies.

The round-trip phase correction is done through the 2-4 GHz LO and is normally corrected for the A and D IFs in hardware and subsequently corrected for the residual (systematic) difference for the conjugate IFs in the on-line software (this is done in the array processor to the output of the correlator but it is not done when observing in spectral mode). If phase changes result from the actual hardware they can be different for the different IFs and would not be, in principle, corrected. Such correction must be done in the data-reduction stage.

Next, M. Holdaway discussed in some detail the effect of the instrumental polarization on the images. What follows is an outline of the discussion; details should be found in VLA test memo # 163 and VLA scientific memo # 163.

The instrumental polarization terms can be expressed in a straightforward way in the visibility domain using the so-called D-terms. If the polarization signal is weak it is possible to linearize the expressions but that looses the absolute D-terms which are needed to correct the parallel-hand data for the instrumental terms.

It is worth noting that:

a) The systematic components of the D-terms cause leakage from total intensity signals to the polarization images. These show ghosts at the positions of the strongest sources in the I image.

b) The effect of the random components is to scatter flux through the image.

c) The random components of the D-terms are comparable to the systematic ones.

A discussion of the time dependence of the D-terms followed. It is not necessary to spend 8 hours to estimate them if a model of the polarized emission is available. Moreover, there is a systematic and repetitive behaviour of the combination $\langle D_R + D_L^* \rangle$ for all antennas with a period of a few minutes (see the memos noted above).

P. Napier asked whether the fringe rotation could be different for IFs A and C. B. Clark said that was not the case but noted that delay "cogging" (stepping), is different for all IFs and indicated that the effect described by Holdaway could be due to a beat between that and the fringe rotation. Holdaway said that the actual pattern of time-dependence changes during the observation (so that it could depend on hour angle). D. Bagri noted that if the fringe-rotation correction were in error it would be the same for IFs A and C but the delay correction would not be. He asked to check for correlation between the periodicity of these errors ($\sim$ 3 min. in Holdaway's example) and the size of the corresponding baselines.

Polarization "self-calibration" can be done in SDE which makes it cumbersome for spectral-line data; it would be desirable to be able to do it in AIPS

Outstanding problems:

1) What causes the fluctuations in the D-terms?

2) How to correct for the effect of the absolute D-terms in total intensity images? (This will limit the dynamic range of I-images in the presence of polarized emission).

3) Does the "self-calibration" determination of the D-terms converge? When does it not?

M. Holdaway discussed as well the topic of wide-field polarization imaging:

It is observed that the leakage is position-dependent. Observations of NGC253 by M. Holdaway and C. Carilli seem to show that the off-axis terms are mostly constant among antennas as they produce spurious sources in the images rather than simply scattering power. This is not due to the beam squint. It is worth noting that:

1) The sum $D_R + D_L^*$ is largely coherent across the array.

2) In the absence of bright point sources, it should be possible to get fractional polarization error below 1% through mosaic observations as:

a) The primary-beam attenuation downweights the worse D-term leakage.

b) The change in the parallactic angle throughout the observation rotates the $D_R + D_L^*$ "beam" on the sky.

c) Adjacent beams will average and lower the errors somewhat.

3) Problems can be dealt with through specific ad-hoc procedures.

Polarization wish-list

What follows is a preliminary wish-list detailing specific areas where we need to improve our procedures with some suggestions as to what to do. Please send other wishes or comments to me.

1) All-sky calibration for instrumental terms and Faraday rotation.

If we could observe close in time a few sources with known polarization properties and located at different positions in the sky we would be able to determine simultaneously the instrumental parameters and the Faraday rotation.

In order to do this, we need to observe a list of candidate sources at a single frequency like 6 cm (candidates might be drawn using R. Perley's lists) and look for sources which have not changed over several years. We will subsequently need a calibration program to use these results.

2. Ionospheric correction using the GPS satellites.

JPL currently determines a global ionospheric model using the GPS. We might have access to these data and eventually generate similar models from the VLBA station GPS receivers.

We would need to write (or obtain somehow) a program to determine an all-sky ionospheric model from the VLBA GPS data from different VLBA sites.

Meanwhile, the model might be obtainable from JPL.

In any case, some software effort is needed in order to read the model into AIPS in a format suitable for use by the AIPS task "FARAD."

Explore the possibility of using self-calibration to determine the small angular scale correction.

3. Determine if the instrumental polarization parameters can be determined/monitored from test signals generated inside the VLA, e.g. using the existing calibration noise sources and looking at the single-dish RL correlations.

4. It would also be desirable to determine if the off-axis pattern can be measured.

5. Implement self-cal/wide-field polarization procedures for the community.

It would be useful to write down a set of practical procedures (i.e., a recipe) for each process (for wide-field polarization it may just be an estimate of when it is necessary to do something special). Then identify missing steps in the process (like software) and decide on the best/quickest path to achieve access by the community to the full process. Eventually, it would seem desirable to do this in AIPS/AIPS++ or whatever package the observatory would support.

6. Produce models of total intensity and polarization for the standard polarization calibrators at each frequency to avoid baseline limitations in calibration programs.

7. Study the time, position, and frequency dependence of the instrumental polarization in hopes of finding its origin. Can the holography measurements shed some light on the cross-polarization of the antenna beam-pattern?

8. Explore the possibility of using pulsars for polarization calibration at low frequency (i.e., P-band).

9. Establish a working group to keep track of developments in these areas, coordinate activity and plan long term strategy given the limited manpower.