VLB ARRAY MEMO No. 470

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To: VLBA Project
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Subject: Closure errors.

It is clear that closure errors are limiting the dynamic range achieved with the VLA on relatively simple sources. By closure errors, I mean instrumental offsets in amplitude and phase that cannot be removed with antenna dependent corrections. Some possible sources of the errors are missmatched bandpasses, correlator errors, improper corrections to slow fringe rate or delay rate data, pointing errors on large sources etc. The maximum ratio of peak to off-source rms that can be reached on VLA maps is about 10,000 without correcting for closure errors. With corrections, peak-to-rms values of close to 100,000 have been reached recently on 3C 273. There is a serious effort in progress to find and correct the sources of the closure errors. Typical closure errors seen in current VLA data have an RMS of between 0.5 and 1.0 percent, evenly distributed in amplitude and phase. The dynamic range of maps of simple sources is predicted to be limited to about the rms of the closure offsets times the rms sidelobe level of the beam (Clark, VLA Scientific Memo 137) and this value is about what is observed.

In the past, we have thought that the VLBA should meet the same closure specification that is met by the VLA, ie closure errors of about 1 percent (0.5 degree). The rms sidelobes for the VLBA beams are 2 to 3 percent. The maximum peak-to-rms with 2.5 percent sidelobes and 1 percent closure errors would be about 4000. As the VLA is now demonstrating, we should be able to do much better, especially on relatively simple, strong sources (a typical VLBI case). In the ideal situation, the dynamic range of maps of simple sources, for which the limit is not imposed by uv coverage, would be set by the ratio of the peak flux density to the thermal noise. The thermal noise for VLBA observations can be as less than 40 micro Jy per beam while some sources have peak flux densities in excess of 20 Jy. This suggests that a peak/rms dynamic range would need to be in excess of 500,000 before being thermally limited. With 2.5 percent sidelobes, this requires that the rms closure errors be smaller than 0.01 percent. This is probably not possible but it demonstrates the importance of doing as well as we can. Note that the VLA has about 1 percent sidelobes so closure errors on the VLBA would have to be calibrated 2 to 3 times better than on the VLA to achieve equivalent dynamic range.

Closure errors that are constant in time can be calibrated using measurements of point sources or sources whose structure is known. Therefore it is more important to keep the closure errors constant than to reduce them to zero. For example, filters need not be so closely matched that they produce tiny closure offsets, but they should be very stable. Note, however, that the smaller the closure errors, the smaller the time variable components are likely to be. There is one possible problem with relying on calibration - it is not clear how well closure errors in the cross-hand polarization data can be calibrated. The dynamic range in the cross-hands does not need to be as high as in the parallel hands because the peak polarized intensity is usually well below the peak total intensity. However it would be unfortunate to have the noise level in the polarized maps well above the noise in the total intensity maps.

As the discussion above indicates, closure errors that are smaller than may be possible to achieve would be useful, so the choice of a specification is somewhat arbitrary. I encourage the designers to attempt to achieve the lowest possible closure errors. But to provide a number, I suggest that we try to keep rms of the non-constant portion of the total closure errors produced by the system to below 0.1 percent. Note that there are several possible sources of errors so each one should be kept well below this value. With 2.5 percent sidelobes and 0.1 percent closure errors, a peak-to-rms dynamic range of about 40,000 should be possible.