EVLA Memo 151
EVLA Antenna Polarization at L, S, C, and X Bands

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Abstract

The method described in EVLA Memo #131 for determining absolute antenna cross-polarization was used in March 2011 to determine the cross-polarizations for all operational EVLA antennas at L, S, C, and X bands.

We find that the new wideband X-band receivers meet the EVLA 5% cross-polarization specification over most of the frequency range. The new-design quadrature hybrids installed on some L and S band antennas provide significantly lower cross-polarization than the original design, especially at the low frequency ends.

Comparison of the C-band cross-polarizations to those determined in April 2009 and January 2010 show that changes are less than 1% in nearly all cases. This stability should allow 'standard' polarization corrections to be made for most polarimetric imaging.

1 Introduction

EVLA Memo #131 describes a simple method for determining the absolute cross-polarizations of the antennas in an interferometric array. The method requires that an unresolved, unpolarized source be observed twice – once with all antennas in their normal orientations, and again with at least one antenna rotated by 90 degrees. The sums and differences of the cross-polarization visibilities obtained on those baselines for which one antenna is rotated on one of the observations provide a direct measure of the antenna cross-polarizations. This method of determining the cross-polarization is much preferred over the usual approach of solving the baseline-based cross products from data taken with all antennas in normal orientation, as these results must be be referenced to a fiducial value – the cross-polarizations derived this way are relative, not absolute. Absolute values are most useful when comparing astronomical observations to laboratory measurements. In practice, the EVLA antennas cannot be rotated by 90 degrees. However, the receivers – which are responsible for the great majority of the on-axis cross-polarization – can be rotated as they are bolted to the feeds with eight bolts equally spaced around the flanges.

This method was first applied to the seven EVLA antennas equipped with modern wide-band receivers at C-band in April 2009, and was repeated in January 2010, just prior to the shutdown of the VLA's correlator. These observations, reported in EVLA Memo#141, gave the first results for the new wideband L and S band receivers, and also provided good evidence for the long-term stability of the C-band polarizers. The L and S band polarizations were higher than desired, typically 5 to 10%, and higher towards the low frequency end of each band. Although disappointing, this finding was not too surprising, as the hybrids utilized were designed for room temperature applications, and their performance at cryogenic temperatures was expected to deteriorate. As described in the next section, a new-design hybrid is being deployed which is expected to have much less temperature sensitivity.

Many changes have taken place in the year since Memo #141 was released: the C-band receiver implementation has been completed (but with the old-design hybrids), many more S-band receivers are now available, the new design quadrature hybrid has been installed on some L and S band receivers, new wideband X-band receivers are installed on some antennas, and the WIDAR correlator can provide wide-band instantaneous coverage over a 2 GHz span. These dramatic expansions suggested another measurement campaign was due.

2 EVLA Polarizers at L, S, C, and X bands

The circular polarizers in the L, S, and C band receivers consist of a quadridge OMT which separates the orthogonal linear polarizations of the incoming signal, followed by a 90 degree quadrature hybrid which combines the two linear polarization signals with appropriate phase shifts to produce the two opposite circular polarization signals. The hybrids immediately follow the OMT, and are cooled to 15K in the receiver dewers. They hybrids are provided by MAC Technology. It was quickly learned that their excellent room-temperature performance changed notably upon cooling to cryogenic temperatures, so that the purity of the RCP and LCP signals was notably degraded, as reported in Memos 131 and 141. Bench measurements showed that the amplitude balance of the hybrids changed by nearly 1dB upon the temperature change.

The NRAO group working on ALMA noted the same problem with a similar wideband hybrid. John Effland worked with the vendor to modify their design by replacing the fiberglass substrate used in the original model with one made of Teflon and ceramic. Bench measurements of this new design indicated the change in amplitude balance upon cooling was reduced to 0.1 dB. On the basis of this, a program to outfit all new EVLA receivers with this new design hybrid was implemented. The receivers already in the field with the old design will be retrofitted with the new design once full implementation of the remaining receivers is completed.

The polarizer at X-band is a little different. The 90 degree phase shift between orthogonal linear components is implemented in advance of the OMT by a corrugated waveguide phaseshift, similar to that employed at the EVLA's high frequency bands. The compact wideband OMT design initiated by Paul Lilie and implemented at L, S and C bands is too small for easy implementation at X-band. The new X-band design by Gordon Coutts is a diagonal quadridge design, which is easier to fabricate than the convential design at this frequency. Because the necessary phase shifts are done prior to the OMT, the outputs of the orthogonal probes in the OMT now correspond directly to RCP and LCP.

There had not been any on-sky measurements of the polarization characteristics of the new style hybrids, nor of the new design X-band system, thus providing further impetus for the observations reported here.

3 Observations and Data Reduction

The observations were taken of the unresolved and unpolarized source 3C147[1] with the L, S, C and X band receivers in their normal positions on 9 and 11 March, 2011, and with the receivers on antenna 6 rotated by 90 degrees on 10 March. At this time, the available receivers were:

- 27 antennas with wide-band receivers at C-band;
- 5 antennas with wide-band receivers at X-band, with the rest outfitted with the old-style VLA narrow-band receivers;
- 12 antennas with wide-band receivers at S-band, of which three have the new quadrature hybrid design;
- 10 antennas with wide-band receivers at L-band, of which four have new quadrature hybrid design. The remaining 13 antennas retain the old narrow-band receivers, with old-design quadrature hybrids.

With the WIDAR correlator now available, the observations covered the entire frequency span offered by these receivers – 1 to 12 GHz.

The data were calibrated in AIPS, and the AIPS task 'TRUEP' employed to compute the cross-polarizations, following the method described in EVLA Memo#131. This task has been significantly upgraded to handle the WIDAR correlator's output of 16 subbands with 128 spectral channels per subband. The new version of the task now computes the cross-polarization for every channel in every subband across the entire frequency span.

4 Results

4.1 X-Band

At the time of the test, five antennas were outfitted with these new receivers. All the others retain the old narrowband systems installed in the 1980s in support of the Voyageur flyby of Neptune. These are traditional

[1] Independent observations show <0.02% linear polarization at L-band, <0.05% at S-band, 0.2 – 0.5% at Cband, and ~0.7% at X-band.

sloping septum polarizers, designed for good characteristics over a much narrower bandpass: 8.0 – 8.8 GHz.

The results are shown in the following figures. The antenna amplitude cross-polarizations for the five antennas outfitted with the new wide-band design are shown in the left panel of Figure 1. The polarizations are less then the goal of 5% over most of the band, although some antennas – notably antenna 7, are high at the edges of the band. The characteristic shape of the cross-polarization amplitude shown in the figure mirrors plots of the deviation of the phase shift from 90 degrees for the phase shifter. It thus seems likely the cause of the higher than expected cross- polarization is due to the deviations from orthogonality in the phase shifter.

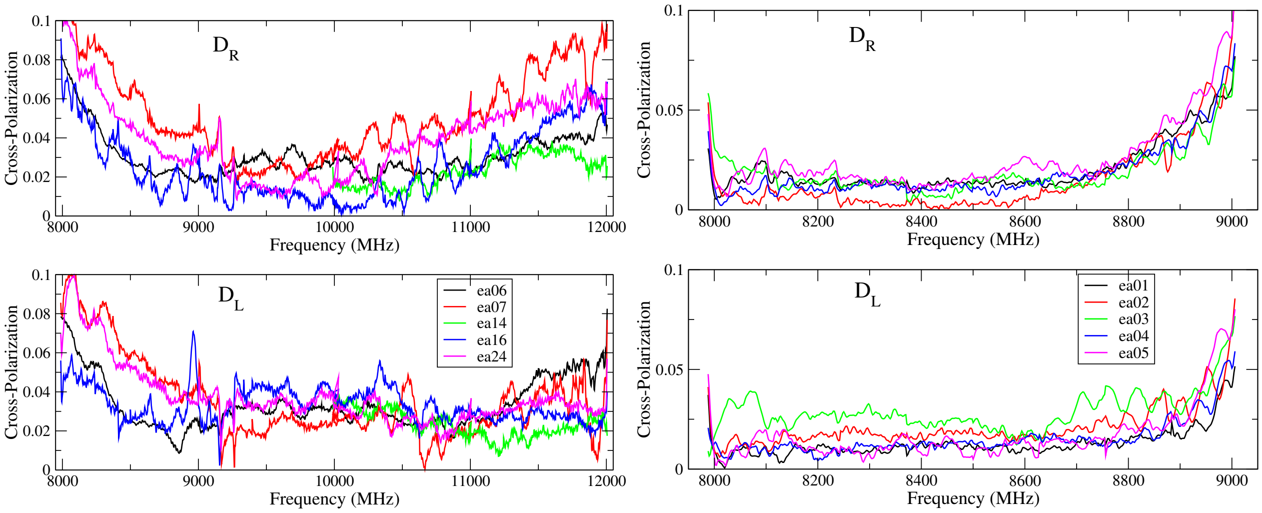

Figure 1: (Left)Cross-polarization amplitudes for the five antennas outfitted at X-band with the new wide-band polarizers. Most meet the 5% requirement over most of the band. (Right) The cross-polarization amplitudes for five of the old design polarizers. These narrow-band systems show much lower cross-polarization over their design bandwidth.

By contrast, the old-style narrowband receivers, shown in the right-hand side of the figure, show the expected very low cross-polarization.

4.2 S-Band

Four of the 12 antennas now equipped with S-band receivers have been retrofitted with the new design hybrids. The results for these antennas are shown in Fig. 2. It will be noted that the 5% goal is met by most antennas over most of the frequency range, and that a characteristic of these hybrids is a lower cross-polarization at the edges of the band than at the center.

4.3 L-Band

There were five antennas outfitted with new-style hybrids and five with old-style. The results are shown in Fig. 3

The characteristics of the old and new styles are the same as at S-band, with the new style providing considerably lower cross-polarization overall, especially at the edges of the band. All new L-band receivers going onto the array will have the new style installed, and a program to retrofit those antennas with the old style is being drawn up.

4.4 C-Band

At this band, we have only the old-style, low-temperature insensitive quadrature hybrids. The results for the seven antennas originally outfitted with wideband receivers, and reported on in Memos #131 and #141 are shown in Fig. 4. The characteristics of the remaining twenty antennas not shown in the figure are similar.

The general characteristics of the cross-polarization are the same as at C-band (with the old style): lowest near the center of the band, and higher at the edges, particularly the low frequency end. The cross-polarization is far higher than the 5% goal for most antennas over most of the band. It is expected that the new-design

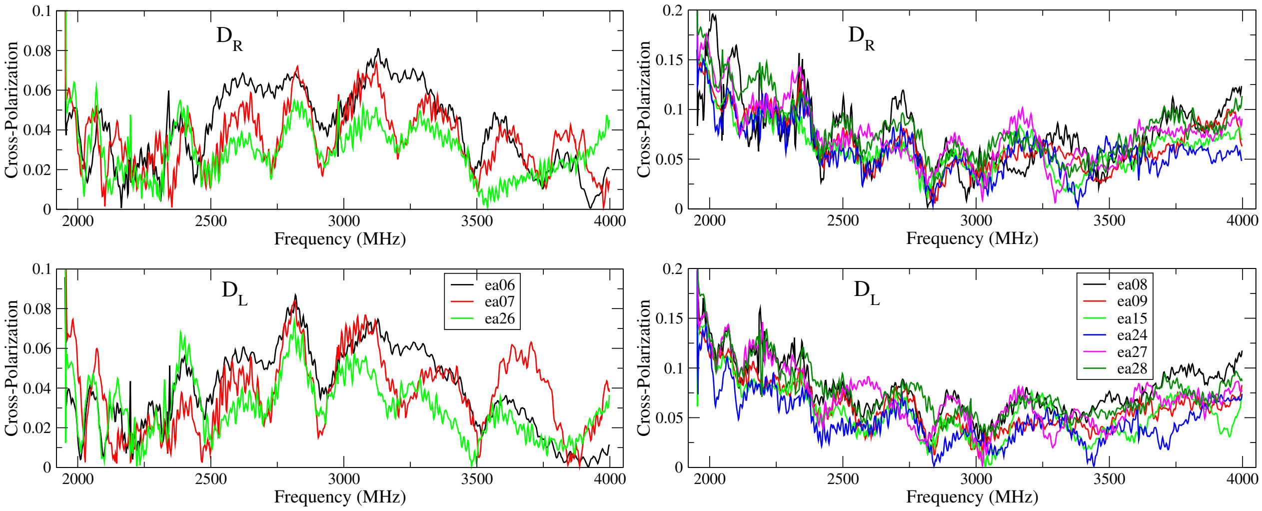

Figure 2: (Left) The cross-polarization amplitudes at S-band for three antennas outfitted with new design quadrature hybrids. (Right) The cross-polarization amplitudes for the old design hybrids. Note the change of scale – the old design is notably poorer than the new over the entire frequency range.

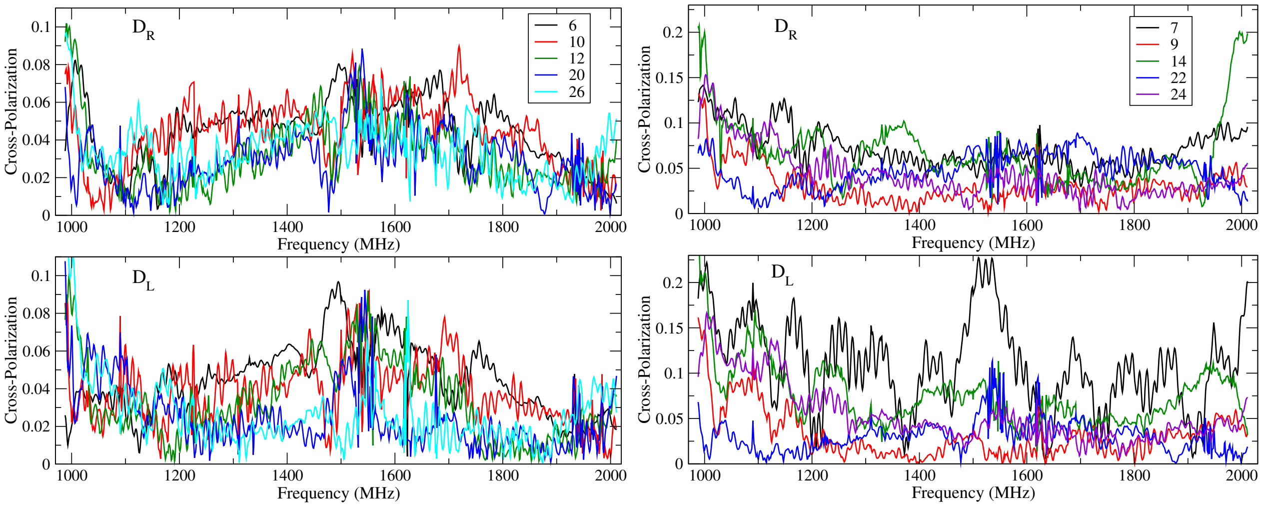

Figure 3: (Left) Cross-Polarization Amplitudes at L-band for five antennas outfitted with new design low-temperature quadrature hybrids. (Right) The results for five antennas with old-style. Note the change in scale. The new style provides better performance overall.

hybrids will perform much more satisfactorily. These new hybrids are arriving now, and will be retrofitted into the array as time permits.

5 Long-Term Polarimetric Stability

Although low cross-polarization is a desirable characteristic for the receivers, more important from the view of polarimetric imaging is the cross-polarization stability. In principle, any arbitrary cross-polarization can be corrected for in calibration, providing the value is known and is stable over the period of observation. EVLA Memo #134 presents an analysis of the necessary stability for accurate polarimetry. In short, for studies of bright objects, the memo shows that for 0.1% accuracy in determining linear polarization, a median stability of 1% in the antenna cross-polarization is all that is required. The requirements for polarimetry for weak objects in the field of a very strong source are much more stringent – refer to the memo for details.

The polarizers are metal waveguide or microstrip circuit passive devices which are immersed in a cryogenic environment – it is thus expected that their characteristics should should little change over long periods. Memo

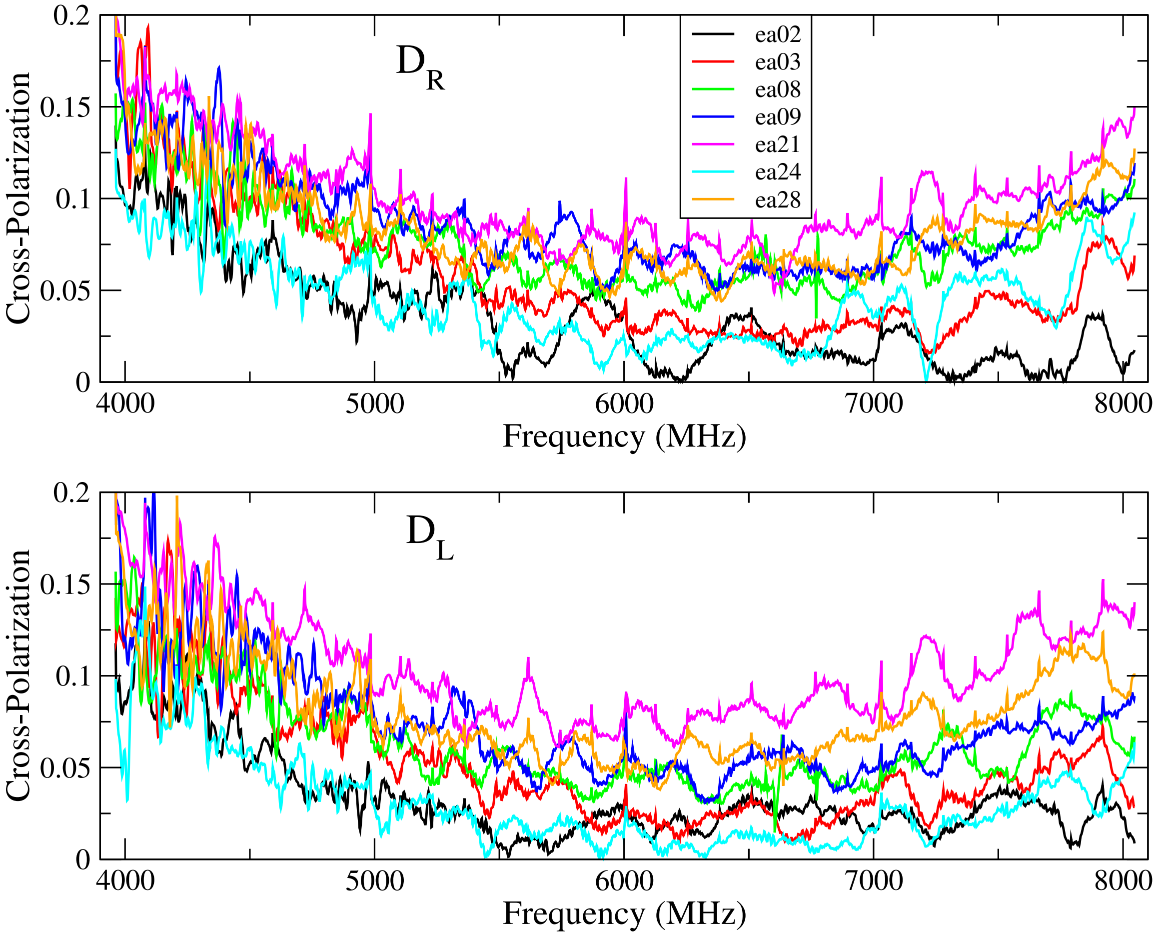

Figure 4: Cross-Polarization Amplitudes for seven antennas outfitted with the old quadrature hybrids at C-band.

#141 showed that the C-band polarization characteristics were indeed remarkably stable over a period exceeding a year. The new observations presented here have been analyzed to extend that time duration to the two year interval between April 2009 and March 2011. The results are shown in Fig. 5.

The stability of the polarizers is striking – with only a couple of exceptions, no polarizer has changed by more than 1% over a two year period.

6 Discussion and Conclusions

The key results are that the EVLA's low-frequency polarizers (covering L, S, C, and X bands) are, for the most part, within the 5% goal for cross-polarization. More importantly, there is strong evidence from the C-band results that the antenna polarizations are sufficiently stable over year-long periods that measurement of the cross-polarizations need only be done for only the highest-accuracy polarimetry experiments. This is especially valuable for short 'snap-shot' style observing, where there is in general insufficient time to determine the antenna polarizations.

The authors thank Eric Greison for generating the specialized AIPS task 'TRUEP', thus saving me many hours of laborious labor on my hand calculator! Thanks also are due to Chuck Kutz for arranging the coordinated activities required to rotate and re-rotate the receivers.

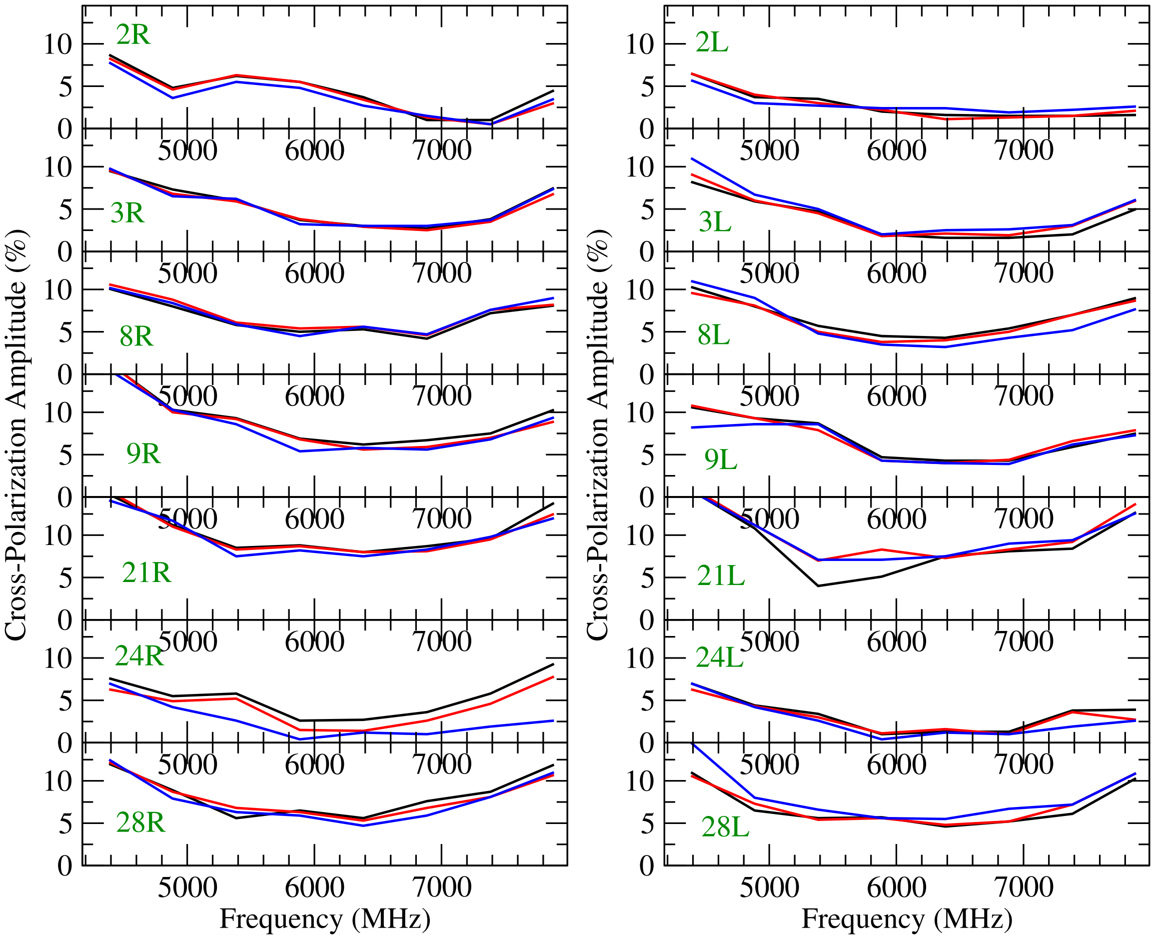

Figure 5: The change in C-Band cross-polarization for the seven antennas that have had wideband feeds since April 2009. The April 2009 results are shown in black, the January 2010 in red, and the new March 2011 in blue. For nearly all antennas, the change in cross-polarization over the two-year period is nor more than a few tenths of one percent.