EVLA Memo 141
EVLA Antenna Polarization at L, S, and C Bands

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Abstract

The method described in EVLA Memo#131 for determining absolute antenna cross-polarization was utilized in January 2010 to determine the cross-polarizations for all operational EVLA antennas outfitted with new receivers and polarizers at L, S, and C bands. Observations were made at eight frequencies within each band. The results show that the project goal of 5% cross-polarization is met for most antennas within the central 2/3 of each band. The low frequency end for each band shows the highest cross-polarization, in agreement with laboratory measurements. Comparison of the results at C-band to those determined in April 2009 shows that the cross-polarization is stable to better than 0.5% over the nine-month interval.

1 Introduction

EVLA Memo #131 describes a simple method for determining the absolute cross-polarization of the antennas in an interferometric array. In summary, the method requires that an unresolved, unpolarized source be observed twice – once with the antenna in its normal orientation, and again with the antenna rotated by 90 degrees. The sums and differences of the cross-polarization visibilities obtained in the two states 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, as this in general requires the solutions 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. Since that time, most of the rest of the EVLA antennas have been outfitted with these new receivers, and a few modern wideband L and S band receivers have been installed. The time was right in early January 2010 to repeat the method at all three bands[1].

2 Observations and Data Reduction

The observations were taken of the unresolved and unpolarized source 3C147 [2] with the L, S, and C band receivers on antenna 24 rotated by 90 degrees on January 7, and again with the receivers in their normal orientation on January 8. At this time, there were 16 available antennas equipped with wide-band C-band receivers, six with S-band receivers, and four with L-band receivers. For each band, observations were made at eight frequencies chosen to evenly span the available frequency span.

The data were calibrated in AIPS, and a special AIPS task 'TRUEP' employed to compute the cross-polarizations, following the method described in EVLA Memo#131. Although all antennas were included in the observations, the results shown here are only for those EVLA antennas with full band receivers and polarizers[3].

[1] The five high frequency bands were not included, as the X-band systems are not yet upgraded, and the four highest frequency band receivers cannot be conveniently rotated.

[2] Independent observations show ¡0.02% linear polarization at L-band, 0.1% at S-band, and 0.2 – 0.5% at Cband.

[3] Unsurprisingly, the non-wideband antennas showed very high cross-polarizations outside the frequency band in which their old-style polarizers were designed for.

3 Results

The antenna polarizations for all available antennas are shown in Figures 1, 2 and 3 for L, S, and C bands, respectively.

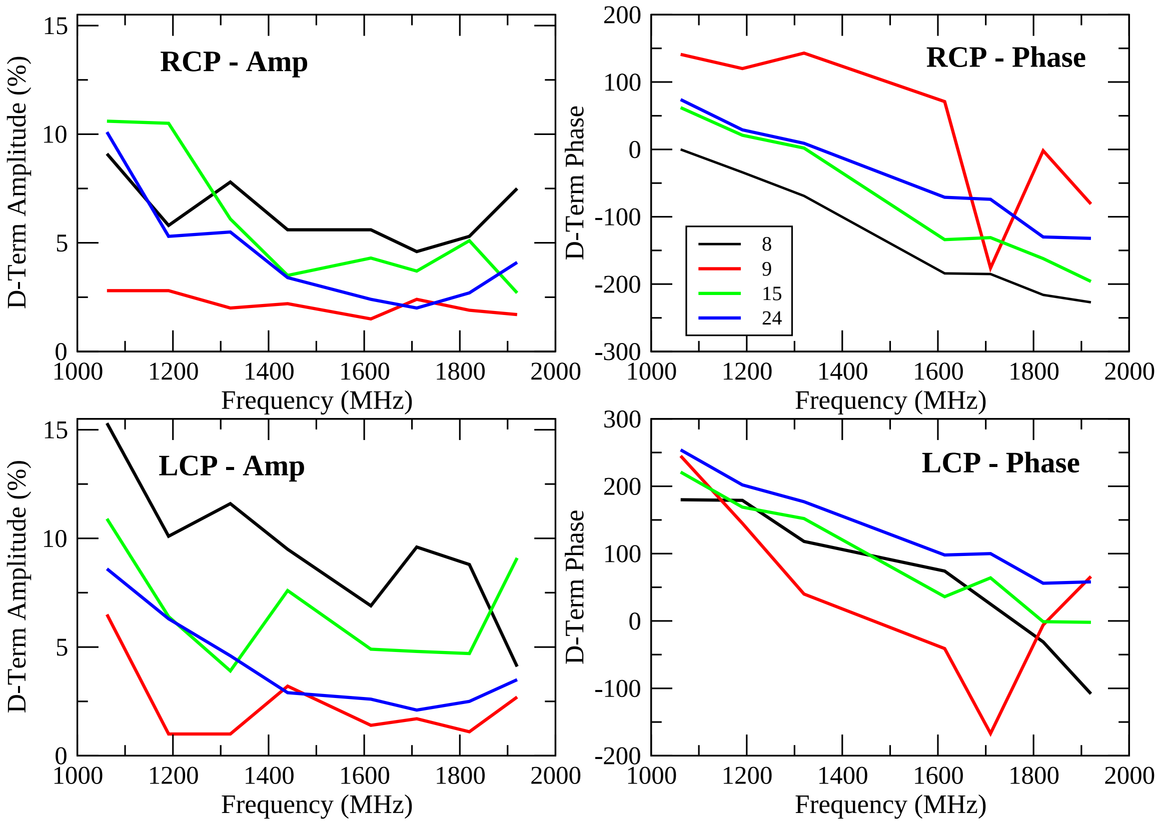

Figure 1: The L-band antenna cross-polarizations for the four EVLA antennas equipped with modern wideband receivers and polarizers. Note that the LCP-Phase plot has been negated, to permit easier comparison to the RCP-Phase.

In general, most antennas show cross-polarizations at or below the desired 5% level over most of their frequency spans. There are some notable exceptions – most of these also showed sub-par performance in bench tests. The origin of the high cross-polarization lies within the quadrature hybrid which combines the linearly-polarized output from the horn to provide the desired circular polarizations. Errors in the amplitude or phase matching within these commercial devices will generate the observed cross-polarization. Note that that these inexpensive devices are designed to operate at ambient temperatures, not in the cryogenic environment at which we utilize them. It is remarkable they work as well as they do in our application!

Although high cross-polarizations are undesirable, their effects can be completely managed in the calibration process provided they are known and stable through the length of time of an observation. In Memos EVLA Memos 134 and 135, Sault and Perley showed that the cross-polarizations are extremely stable over periods of a few days, as expected from devices which are operated in an extremely stable environment. Changes in the complex cross-polarization are at the 0.1% level, consistent with the measurement errors.

Although high stability over periods of months is certainly not required, demonstrating such long-term stability could simplify calibration processing for both default imaging and non-demanding polarimetric observations. Additionally, demonstration of stability over these long periods will lend confidence to our understanding of the processes involved. As the eight C-band frequencies utilized for the January observations are the same as for the earlier April 2009 observations, a direct comparison is possible. This is done in the following section.

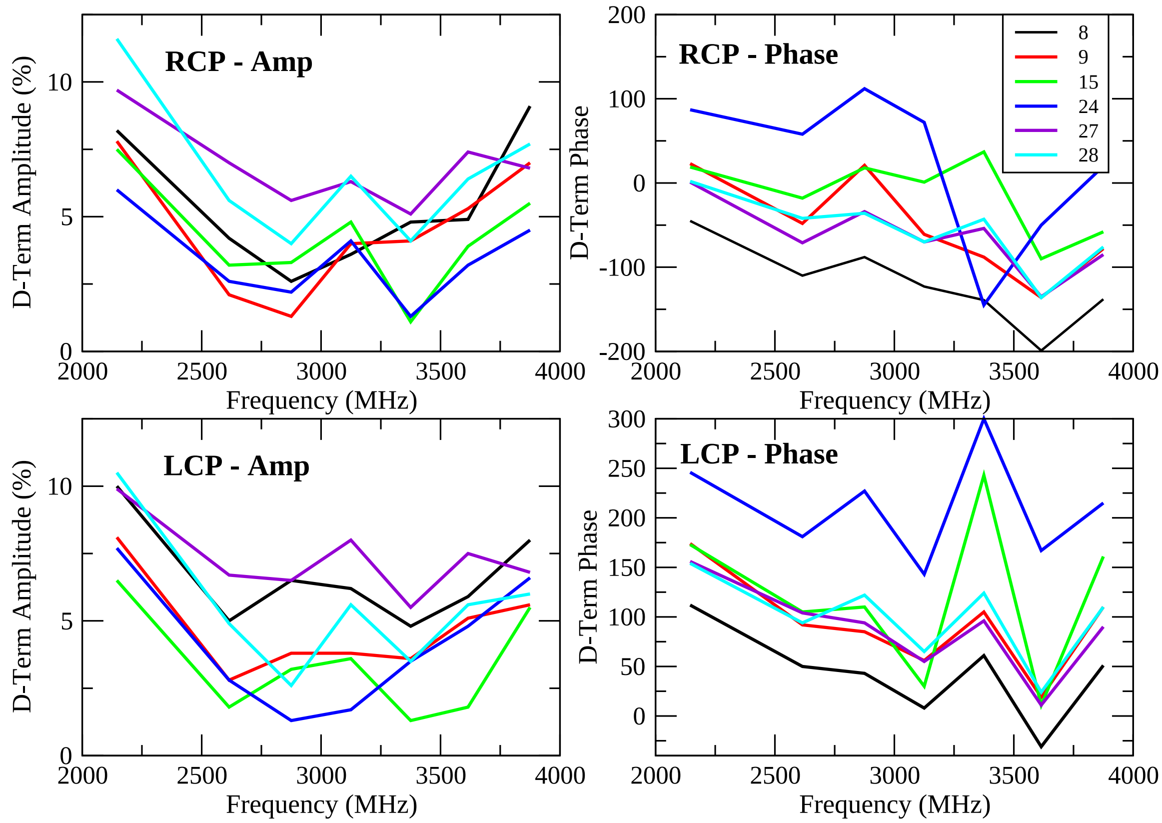

Figure 2: The S-band antenna cross-polarizations for the six EVLA antennas equipped with modern wideband receivers and polarizers. The LCP-Phase is negated.

4 Long-Term C-band Polarimetric Stability

The new results were compared to those from April 2009 for the seven antennas common to these two experiments. The results are shown in Figure 4.

It is immediately apparent that the amplitude of the cross polarizations have hardly changed – less than 0.5% in nearly all cases.

5 Orthogonality

This term refers to a desirable property wherein the antenna's polarization ellipses for the R and L feeds differ by 90 degrees. In terms of the complex cross-polarization factor 'D', orthogonality means that D_r and D_l^* have opposing phases. This is a useful property, since the cross-hand response of a complex interferometer is given by expressions like (ignoring second-order products)

$$V_{rl} = [Q + iU + (D_r + D_l^*)I] \tag{1}$$

The cross-hand response is a sum of the desired linear polarization with a leakage term proportional to the product of the (large) total intensity with the sum of the two leakage terms. If the antenna polarization ellipses are equal and orthogonal, the leakage term is exactly cancelled. Hence, an interferometer comprising antennas with high cross-polarization can be rendered insensitive to this first-order leakage.

Examination of the polarization leakages presented above shows that the cross-polarizations are indeed relatively close to orthogonal – especially (and conveniently) for those antennas with the largest cross-polarizations. This characteristic is not accidental – the desired property is clearly designed into the quadrature hybrids.

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

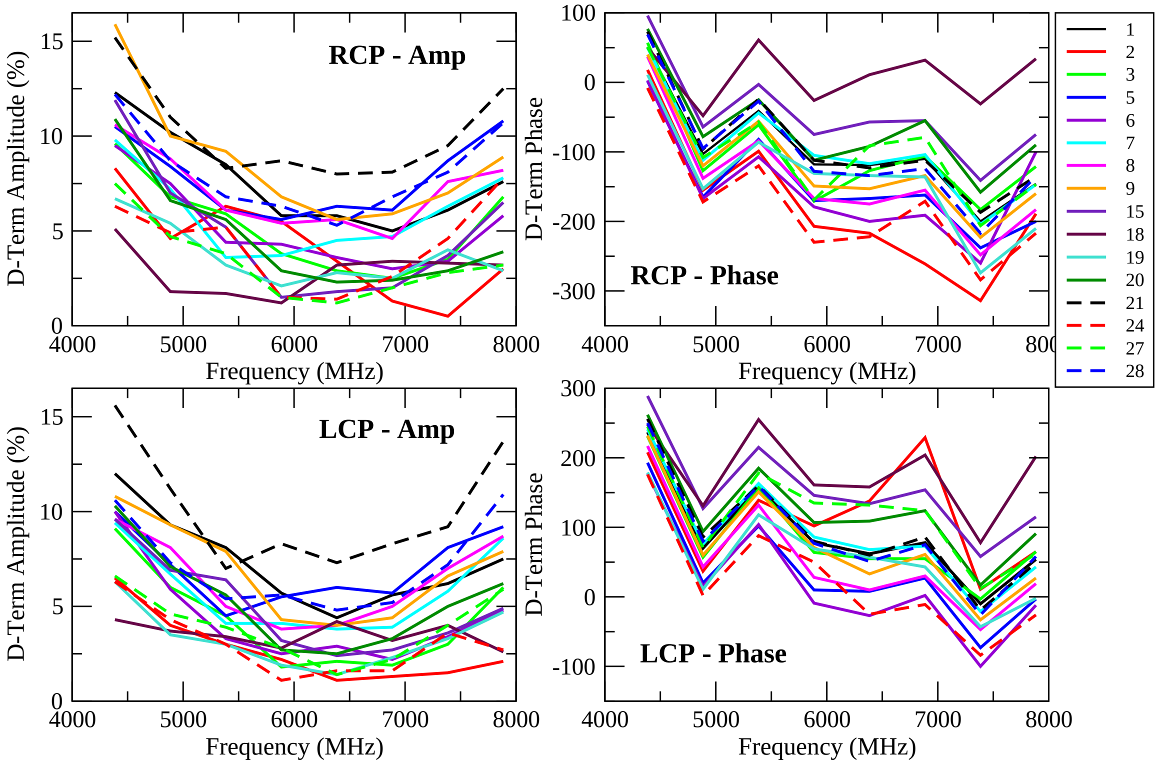

Figure 3: The C-band polarizations for the 16 EVLA antennas equipped with modern wideband receivers and polarizers. The LCP-Phase is negated.

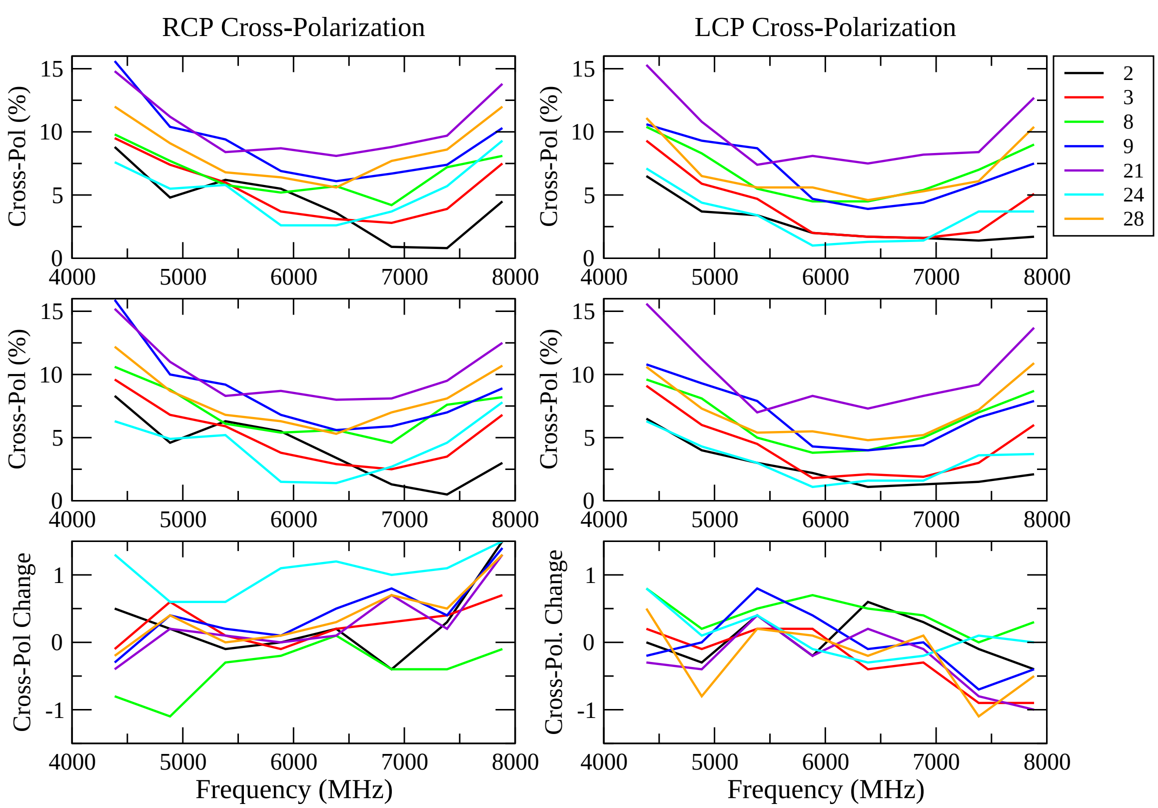

Figure 4: The C-band antenna polarizations $|D_r|$ (left)and $|D_l^*|$. The top row shows the cross-polarization in April 2009, the middle row in January 2010. The difference is shown in the bottom row.