EVLA Memo 123
The Effect of the 4-Band Dipoles on L, C, and X Band Performance

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Abstract

Test observations show that the deployable 4-band dipoles degrade VLA antenna sensitivity by approximately 7% at L-band, 8% at C-band, and 6% at X-band. The loss at higher frequencies is unknown, but is expected to be less. The dipoles also introduce a variability of $1-3\%$ in the antenna cross-polarization at L-band only. This variability will degrade L-band polarimetry capabilities, limiting its accuracy to $\sim$1%.

1 Introduction

Tests made in the 1990s indicated that the deployable 4-band dipoles degraded L-band sensitivity (as judged by the antenna SEFD) by approximately 7%. Tests at higher frequency bands were inconclusive, but seemed to indicate that the losses were less severe. On the basis of the L-band loss, it was decided then that subsequent observations at 4-band will be grouped, and the dipoles deployed for a limited time, sufficient to cover these proposals.

In September and October of 2007, careful tests of the polarization performance of the EVLA antennas at L-band demonstrated a significant time-variable antenna cross-polarization, visible on both EVLA and VLA antennas. These observations were taken when the 4-band dipoles were deployed on the array. This variability disappeared following the removal of the dipoles, providing strong, but circumstantial, evidence that the 4-band dipoles were responsible. As it was felt necessary to more directly demonstrate that the dipoles were responsible, a test was fashioned for the purpose. This memo details the results of these tests.

2 The Observations

Variations in the antenna cross-polarization are most easily diagnosed through examination of the normalized cross-hand visibilities, preferably for a source with very low intrinsic polarization. For calibrated data, the normalized cross-hand visibility for any given baseline can be written

$$\frac{V_{r1l2}}{V_{r1r2}} = D_{r1} + D^*_{l2} + Pe^{-2i\Psi_p} \qquad (1)$$

where P = Q/I is the fractional linear polarization, and I have assumed that the Stokes visibilities U and V are both negligible[1]. The two complex D terms represent the antenna pair cross-polarizations, or 'leakage' of LCP into RCP, for antenna 1, and *vice versa* for antenna 2. The rotation of the sky in the frame of the antenna is described by the parallactic angle Ψ_p. The observed complex visibility is the sum of the antenna contribution and the source fractional polarization whose phase is rotated by twice the parallactic angle.

[1]These assumptions do not limit the analysis, as V is certainly negligible, and the sky reference frame can always be rotated such that U = 0 for a point source.

As we are interested in determining the characteristics of the cross-polarization terms, it is clearly advantageous to observe a source with minimal linear polarization. In this case, the normalized output will reflect only the variations in the antenna cross-polarization, and the need for decoupling the source and antenna terms can be avoided.

Because we are interested in the possible variations in the antenna polarization as a function of time and elevation, it is advantageous to use a source which transits near the zenith. The object selected was 1924+334, whose flux and linear polarization are shown in Table 1. The negligibly low linear polarization of this source at L-band makes analysis of the cross-polarization very simple. The source's fractional linear polarization at C and X bands is comparable to the antenna cross-polarization, complicating somewhat the analysis.

1924+334			
Band	I	Q	P
L	3.88	.008	0.6%
C	1.75	.036	2.1%
X	1.18	.047	4.0%

Table 1: The total and linearly polarized flux densities, in Jy, of 1924+334. The right-most column shows the fractional linear polarization.

Two sets of observations were made. The first, with the dipoles off, was from 16:30 through 22:30 IAT on the morning of 29 April. The target source transited within one degree of the zenith exactly in the middle of this observation. One-minute durations of the target source were made sequentially at L, C, and X bands. Following this observation, the 4-band dipoles were mounted on four EVLA antennas: #1, 21, 23, and 26. The second set of observations, using exactly the same file and IAT range, was taken the following morning. The data were filled as correlation coefficients, and calibrated using the known flux density values. Use of correlation coefficients is preferred for estimation of antenna sensitivity, as they are direct measures of the sensitivity, and avoid the application of system temperature measurements, which are subject to various errors.

Calibration followed well-established techniques. A 'closure-correction' was added to remove the coherence losses on VLA-EVLA baselines due to the differing bandpass shapes. Self-calibration was utilized to remove all residual temporal amplitude and phase fluctuations – the resulting Stokes I images appear to be noise limited.

Polarization calibration was done, although not utilized in the results shown in the next section.

3 Polarization Results

The effects of the 4-band dipoles on the polarization response is best shown by examination of the normalized cross-hand data, uncorrected for the cross-polarization. The following sets of figures shows these data for each of the bands. For all figures, the left side shows data from the first observation, taken without the dipoles, and right side shows data taken on the second night, when the dipoles were mounted.

3.1 L-Band

The effect of the dipoles on cross-polarization correlation is dramatic at L-band. Figure 1 shows the effect on the amplitude on baseline 1-24. Figure 2 shows the effect on the phase for baseline 4-23. In each figure, the upper plots show the response without the dipoles (left panel) and with the dipoles (right panel). The lower plots show that the cross-polarized response on a baseline without dipoles did not change on the two days. For the two examples shown, the modulation roughly follows the change in elevation, likely indicating that the sag of the dipoles is a major contributor to the time variability.

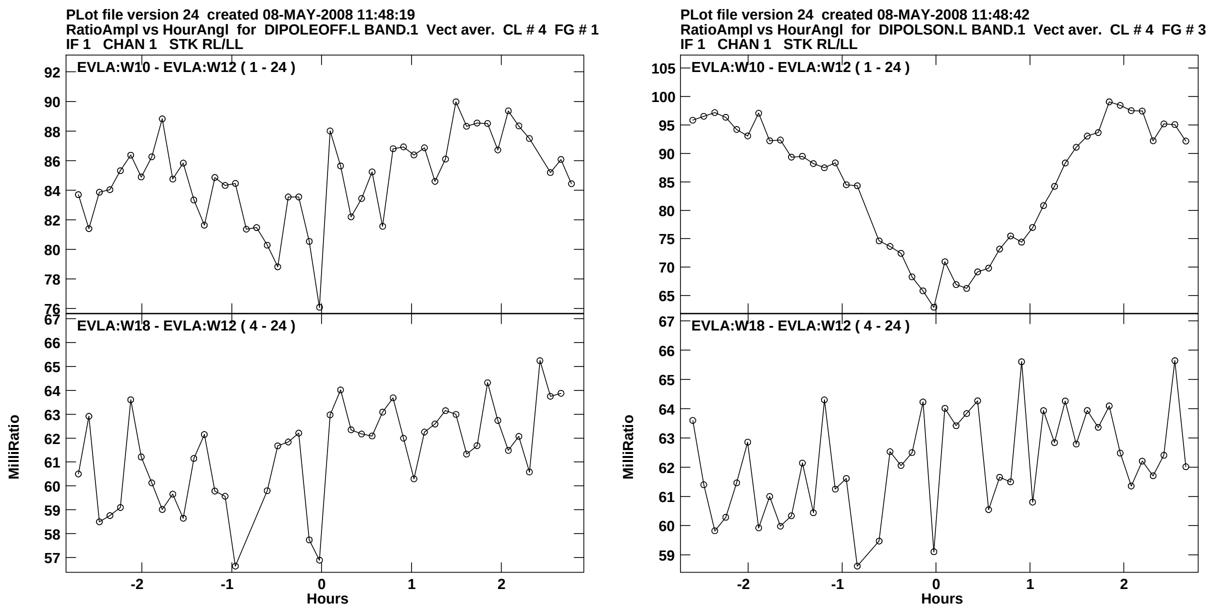

Figure 1: The observed fractional cross-polarization amplitude, RL/LL, for two baselines over a 6-hour period during which the source elevation rose from 55 through 90, then declined to 55 degrees. The left side panels show the first day observations, on which both baselines demonstrate excellent stability, with variations of a few tenths of one percent. The right side panels show how the dipole deployed on antenna #1 has induced an elevation-dependent variation of $\sim$3% in its polarization, while the baseline 4x24, which was not modified, is the same as the previous day.

The results for the other modified antennas are the same in general as those shown above. In summary, the cross-polarization is stable to within a few tenths of 1% on all baselines comprising

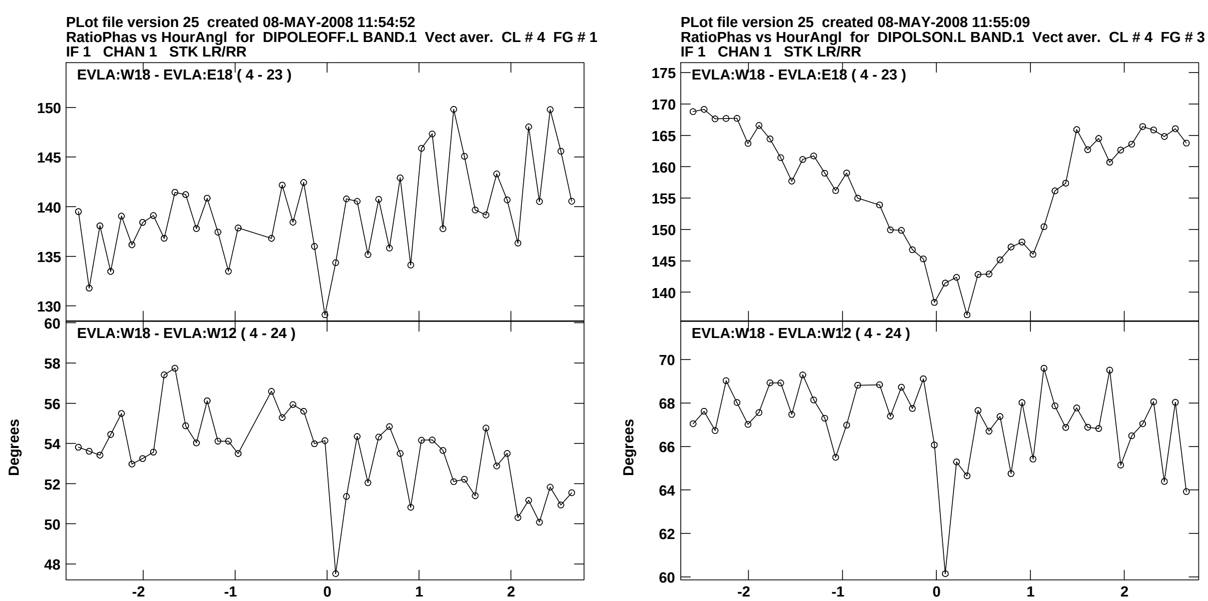

Figure 2: The same as in Fig. 1, but showing the phase of the fractional polarization of LR/RR for the baseline 4 x 23 (top) and 4 x 24 (bottom). Antenna 23 had the dipoles attached for the second day. The baseline 4 x 23 has an extraordinarily high fractional polarization of $\sim$14%.

antennas without the 4-band dipoles. Deployment of the 4-band dipoles induces a variation in the cross-polarization of typically one to three percent. The September 2007 observations (which first demonstrated the effect) suggested that the variation is roughly proportional to the magnitude of the cross-polarization, so that for the EVLA, which has (at this time) a higher cross-polarization in general, the absolute varibility is higher.

3.2 C and X Bands

Figures 3, 4, 5, and 6 show the cross polarization effects of the dipoles at C and X bands. In short, there is no discernible degradation of polarization on any of the four modified antennas at these bands.

In viewing these figures, the reader should note that at these bands the source fractional polarization is comparable to the leakage terms, so that the visibility vector sum will be sharply dependent on the relative phases of these contributions. The test source transits only 0.6 degrees from zenith, resulting in a parallactic angle 'flip' of about 160 degrees within a few minutes surrounding meridian transit. Before, and after this 'flip' there is very little change in parallactic angle over the range of the observations. Because of the $2\Psi_p$ dependency, the 'before' and 'after' transit visibilities will be very similar in both amplitude and phase, as observed. The fact that the amplitudes are nearly the same before and after transit (and the phases change by about 40 degrees) indicates that for the examples shown in the figures, the antenna cross-polarization leakage vector and source polarization vector signals are nearly aligned.

The variations seen in the cross-polarization at these bands for all antennas are very well fitted by the PCAL program, and the resulting polarization images are noise limited.

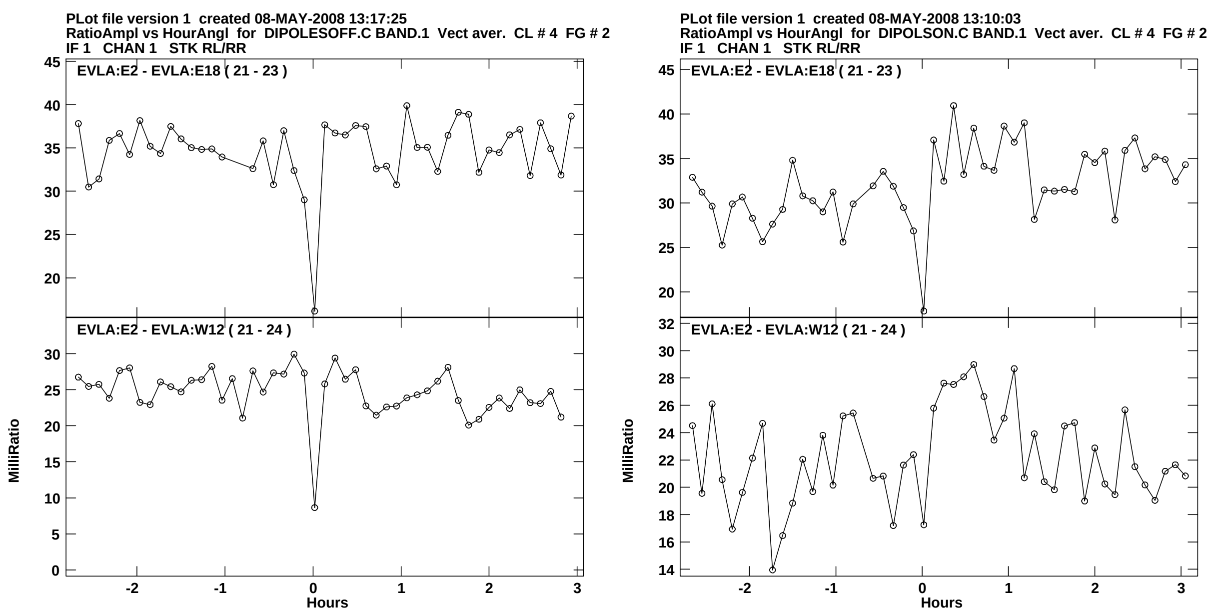

Figure 3: The normalized cross-polarization amplitude at C band, with dipoles off (left), and on (right) for two baselines. The modified antennas are #21 and #23.

4 Effect on G/T

The effect of the dipoles on antenna sensitivity was determined through analysis of the correlation coefficients. The `AIPS` program `CALIB` resolves the $N(N-1)/2$ cross-product amplitudes into N amplitude gains via least squares analysis. The resulting gain amplitudes can be converted to

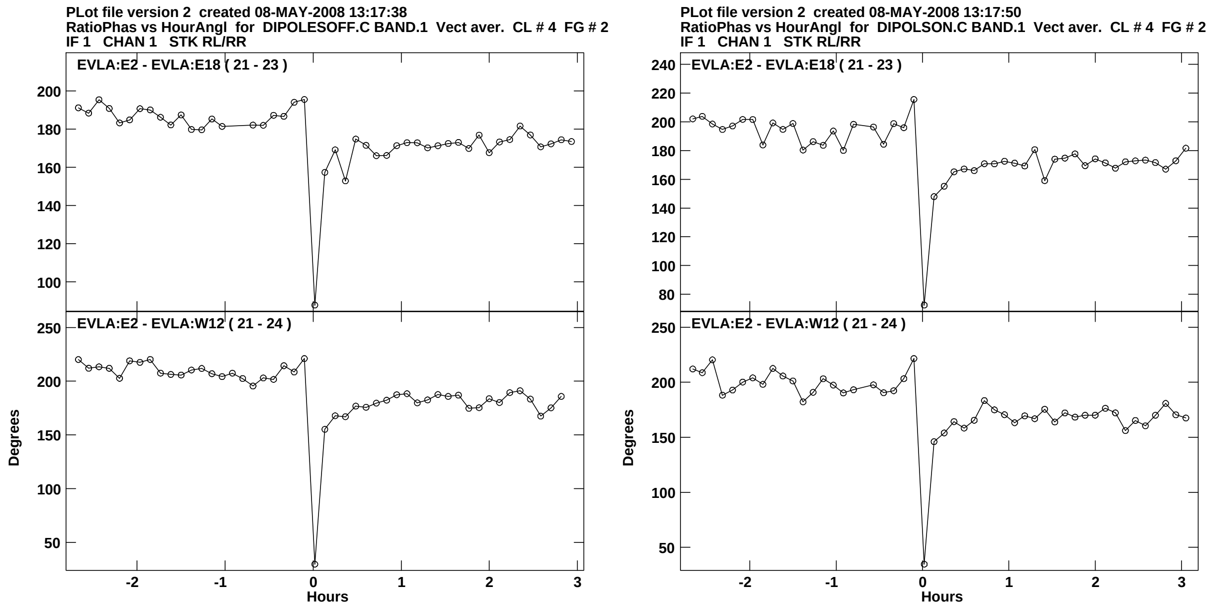

Figure 4: The same as for Fig. 3, but showing the phase of the fractional polarization.

System Equivalent Flux Density by the method described by Perley and Hayward in EVLA Memo #119, providing the source flux density is known.

The SEFDs were derived for each observation at each band. The values at the beginning, at transit, and at the end (where the elevations were 55, 90, and 55 degrees respectively) were recorded, as shown in Table 2.

L-Band SEFD									
	Dipoles Off			**Dipoles On**			**Off/On Ratios**		
Ant.	-3	0	-3	-3	0	-3	-3	0	3
1	475	455	470	515	520	514	1.08	1.14	1.09
21	540	523	540	568	583	565	1.05	1.11	1.05
23	375	373	380	410	433	421	1.09	1.16	1.11
26	411	415	420	450	470	455	1.09	1.13	1.08
4	430	422	429	442	436	440	1.03	1.03	1.03
24	362	351	363	370	362	370	1.02	1.03	1.02
6	390	367	386	387	365	385	.99	.99	1.00
15	380	340	375	373	340	370	.98	1.00	.99
3	450	418	450	440	411	442	.98	.98	.98
9	405	379	405	400	380	407	.99	1.00	1.00
8	370	342	364	362	340	360	.98	.99	.99

Table 2: The SEFDs for the L-band observations, at three hour angles: HA = -3, 0, and +3. The first four lines show EVLA antennas which had dipoles mounted. The next two are EVLA antennas which did not have dipoles mounted. The last five are VLA antennas adjacent to the modified EVLA antennas.

The righthandmost three columns show the On/Off SEFD sensitivity ratios. A value larger than 1.0 indicates a decreased sensitivity with the dipoles on. Review of these ratios shows the following:

- There was no change in VLA sensitivity between the two days.
- All modified EVLA antennas declined notably in sensitivity with the dipoles on. For the 55

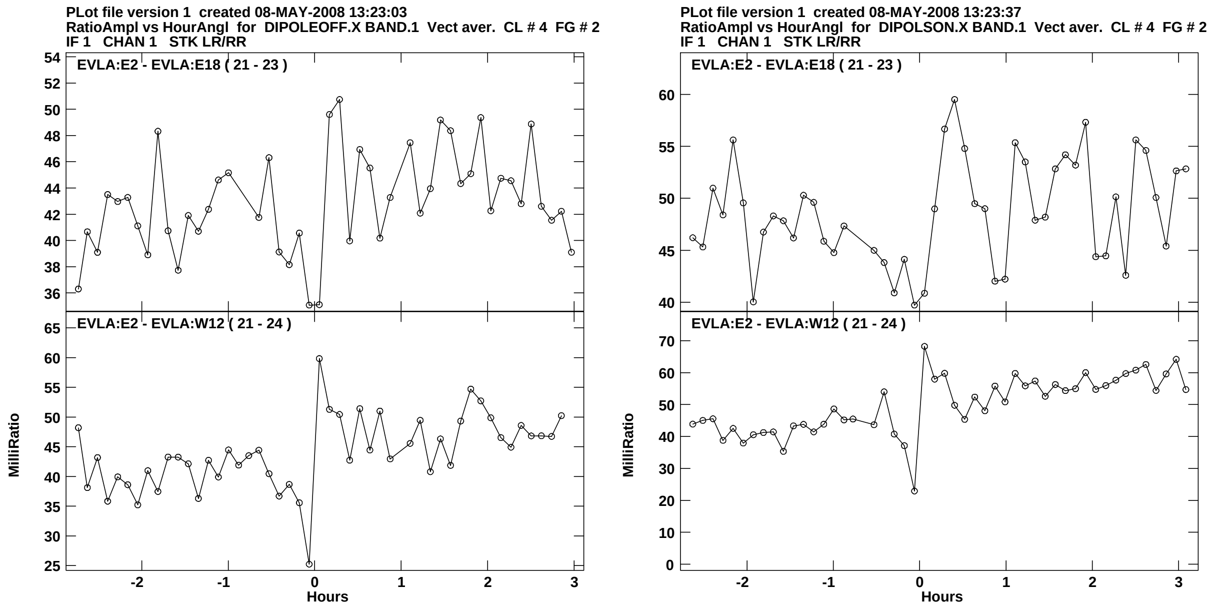

Figure 5: The same as in Fig. 3, but for X-band.

degree elevation, the decline was by 8%, for the 90 degree elevation, it is 13%.

- Curiously, the two unmodifed EVLA antennas also showed a decrease in sensitivity, by 3%. Presuming the (unknown) cause for this also affects the modified EVLA antennas, the adjusted loss due to the dipoles is reduced to 5% at 55 degree elevation, and 10% at the zenith.

Examination of the recorded system temperatures showed no significant change between the two days for any antenna. We must then conclude that the loss of sensitivity is due to a reduction in gain, presumably due to scattering of the incoming radiation cone off the 4-band crossed dipoles.

The corresponding values for C and X bands are given in Table 3 and 4. The analysis and results are similar to that at L-band, except that there is no clear elevation dependence for sensitivity loss

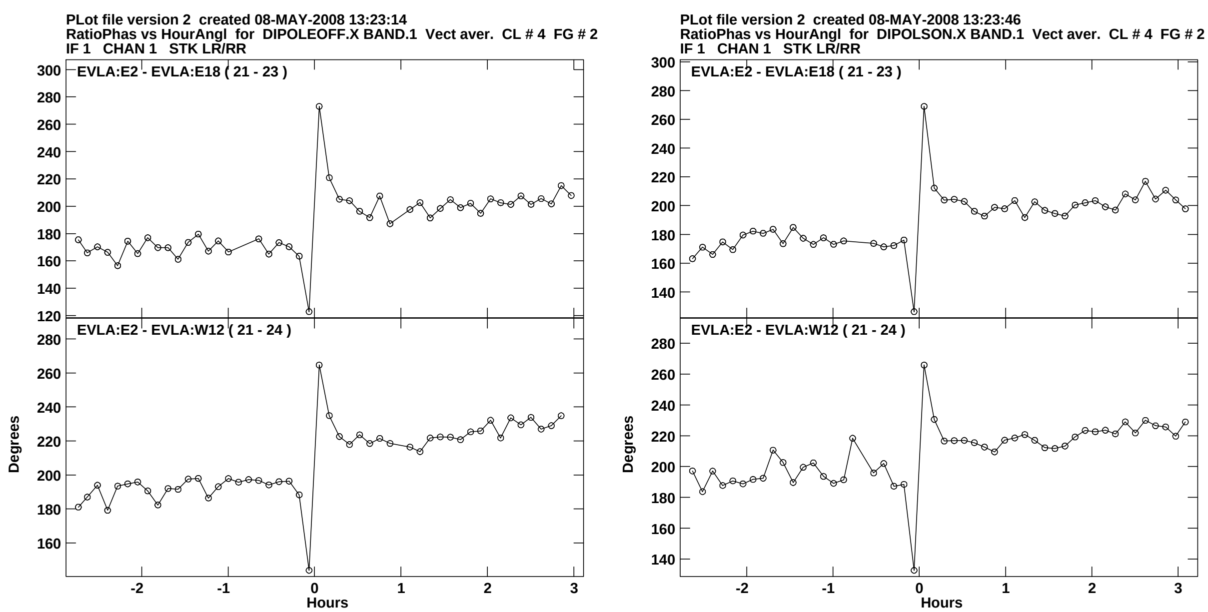

Figure 6: The same as for Fig. 5, but showing the phase of the fractional polarization.

at either band. The apparent C-band loss is by 8%, and at X-band, 6%. As at L-band, there is no evidence that system temperatures were higher on the second day. Hence, the probable cause for the sensitivity loss is scattering of the astronomical radiation off the dipoles – despite the location of these dipoles under the feed legs. We also note the same peculiar loss of sensitivity for the two non-modified EVLA antennas on the second day is also seen at these higher frequency bands, leading us to suspect some systematic origin. However, we have no idea of the origin of this. Unfortunately, the seven EVLA antennas numbered 11 through 19 were not available on the second day, so the reality of this peculiar gain loss is based on only two antennas.

C-Band SEFD									
	Dipoles Off			**Dipoles On**			**Off/On Ratios**		
Ant.	-3	0	-3	-3	0	-3	-3	0	3
1	319	308	317	348	340	359	1.09	1.10	1.13
21	303	300	308	340	342	345	1.12	1.14	1.12
23	287	280	288	317	325	324	1.10	1.16	1.13
26	308	303	314	346	350	355	1.12	1.16	1.13
4	343	340	342	350	360	353	1.02	1.06	1.03
24	283	279	284	290	295	294	1.02	1.06	1.04
6	550	550	565	554	542	547	1.01	.99	.97
15	550	610	550	542	585	540	.99	.96	.98
3	450	450	455	445	440	440	.99	.98	.97
9	428	425	424	435	430	430	1.02	1.01	1.01
8	530	535	541	537	530	520	1.01	.99	.96

Table 3: The SEFDs for the C-band observations. The first four lines show EVLA antennas which had dipoles mounted. The next two are EVLA antennas which did not have dipoles mounted. The last five are VLA antennas adjacent to the modified EVLA antennas.

X-Band SEFD									
	Dipoles Off			**Dipoles On**			**Off/On Ratios**		
Ant.	-3	0	-3	-3	0	-3	-3	0	3
1	370	338	379	395	359	397	1.07	1.06	1.05
21	318	310	315	346	345	350	1.09	1.11	1.11
23	380	362	385	414	410	420	1.09	1.13	1.09
26	292	280	308	330	310	325	1.13	1.11	1.06
4	310	309	309	320	325	322	1.03	1.05	1.04
24	311	309	318	322	320	318	1.04	1.04	1.00
6	325	327	340	328	331	331	1.01	1.01	.97
15	284	278	285	280	270	282	.99	.97	.99
3	360	344	372	365	350	363	1.01	1.02	.98
9	320	311	330	330	315	318	1.03	1.01	.96
8	350	312	350	360	335	348	1.05	1.07	.99

Table 4: The SEFDs for the X-band observations. The first four lines show EVLA antennas which had dipoles mounted. The next two are EVLA antennas which did not have dipoles mounted. The last five are VLA antennas adjacent to the modified EVLA antennas.

5 Discussion

The loss of sensitivity due to the dipoles must surely be due to scattering of radiation, as there is no measureable increase in system temperature between the two days. It is easier to think of this in the transmission case. Radiation emanating from the feed passes the dipoles on the way to the subreflector. Some fraction of this will be scattered away, leading to the observed loss of gain. It was thought that the placement of the dipoles under the quadrapod legs would not introduce any additional loss, as the scattered radiation would have been lost anyway due to the quadrapod leg blockage. Evidently, this simple model is not correct at the longer wavelengths, and diffractive effects provide an additional loss. Nevertheless, at higher frequencies yet, the non-diffractive model must apply, and we still expect that at the highest frequencies, the additional loss due to the dipoles must become negligible. Regrettably, we did not attempt to measure this at K or Q bands.

The variable cross-polarization seen only at L-band must be due to a reflected radiation. Peter Napier in Chapter 3 of 'Synthesis Imaging in Radio Astronomy' identifies four sources of on-axis instrumental polarization. Of these, the third – 'Front-End Mismatch-Subreflector Reflection' could be applied to our observation. In this model, a mismatch at the front-end causes a reflected signal to be re-radiated with the same polarization as the incoming signal. This is reflected, with reversed polarization by the subreflector, and hence masquerades as the opposite polarization, and adds vectorially with the other components of the cross-polarization. In our application, the reflection is from the dipolese, and because the pathlength of the reflected signal varies with elevation due to the sag, the amplitude and phase of the net cross-polarization will vary with elevation. According to Napier, a 2% change in cross polarization will occur with a -10dB return-loss reflection (1%), and a -25 dB (0.3%) return reflection from the dipole. Bench tests of the L-band horn indicate the return loss to be much less than -10dB, so if this mechanism is to be viable, the reflection from the dipoles must be correspondingly greater than -25dB.

How serious is this variable polarization to polarimetric imaging? Roughly speaking, a 1% error in the knowledge of the 'D'-term creates a 1% error in the fractional polarization – an equivalence that comes directly from Eqn. 1. If the amplitudes and phases of the variable 'D' terms are roughly randomized, the net effect upon polarization from the entire array at one time should be reduced by roughly a factor of N – the number of antennas. But even if all reflections are identical, it is hard to imagine how the polarization error in an image will be larger than any one single contributing baseline. Hence, the basic conclusion is that the presence of the dipoles will create an additional error in fractional polarization of order $\leq$1%. This is of little consequence to observations of a highly polarized source, but may be of significant importance to sources with low fractional polarization.

The argument presented above applies directly to point-sources, where all visibilities can be considered equal. However, to observations of highly extended objects, the manifestation of a variable cross-polarization error can be considerably magnified for short-spacings, where the visibility magnitudes are much higher, and the Q and U visibilities are typically very low. One can imagine a situation with a highly polarized point source embedded in a low-polarization extended region. The short spacings provide high correlation in the RR and LL correlators, and since the 'false' polarization due to the variable 'D' term is proportional to I, a large absolute false Q and U visibility will be generated, resulting in a polarization image with high 'rumble' on larger angular scales. The highly polarized point source will be relatively unaffected, but the intermediate scale structures in the extended regions could be severely affected by the variable cross polarization.