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Stability of EVN D-terms

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1. Introduction

Previously, we have shown that the dynamic range of an image obtained with the EVN improves by a factor ~ 7 when corrections in the total intensity data for the effects of instrumental polarization and for fractional bit shift in the correlator are applied (Massi & Aaron 1997). The first error dominates the second, with an even greater effect in data on a polarized source. However, while the correction of the FBS amplitude loss is straightforward (and is currently implemented in more recent versions of the AIPS task MK3IN), the removal of the instrumental polarization requires special observing and additional data processing. Polarization observing also increases the load at the correlator, as all four correlations must be performed. With current limitations at the Mark III correlator in Bonn, this effectively reduces the number of antennas an observer may use. In this note we begin an investigation of the stability of the instrumental polarization (D-terms) for antennas of the EVN. If the D-terms remain constant during a VLBI session, they could be determined during each session, *e.g.*, the network CAL experiment, stored in the astbo1 area with the usual calibration material, and directly applied by the observers to their data. In this way, the performance of the network could be improved without additional effort by the observers.

Direct measurement of the stability of the D-terms will be possible soon, with two data sets from each of the February and May 1997 sessions, all at λ6 cm with a large number of EVN telescopes. In this memo, we wish to describe the procedure to analyze and quantify the maximum extent of variability of the D-terms acceptable in terms of degradation in dynamic range for the final image. The question is, what is the advantage of using D-terms derived at some t_0 time on data acquired at some later time t_1 if the D-terms are variable.

2. Right-left phase difference stability

The most important criterion for D-term stability is that the right-left phase difference of the gains at each antenna be stable; the phase of each D-term is effected by changes in this phase difference. If this term is not constant, the D-terms will not be constant. So the question to be answered is whether the relative phase of the right and left gains at the telescope remain stable over the 15-20 days period which lasts a VLBI session.

In order to set up the procedure to work with the proper data, let us examine data available in literature. In Figure 1 (Massi *et al.* 1996), we show the right-left gain difference at the Medicina, Jodrell Bank, and Westerbork telescopes using Effelsberg as the reference telescope. Variations over the 8 hours shown are evident. Let assume for the moment that the reference antenna behaves as the other one. By the analysis of the variability at the other station we can therefore deduce some information. For all telescopes we have the same standard deviation of 4° and semidispersion of 7.5°.

Because we have already shown that the instrumental polarization strongly effects the parallel hand data, could the variation be due to these effects? In Table 1, we list the expected variation of the right-left phase at Medicina arising from the instrumental polarization. We see that this effect does not explain the variations shown in Figure 1. Hence, the variation is in some way intrinsic. Is it intrinsic to each antenna or to the reference station?

In order to see how this variation is shared between each telescope and the reference telescope, we have made a cross correlation of the three curves. A cross correlation of zero would implies a null contribution for the common reference station, whereas a cross correlation of 0.5 would imply equal contribution from the reference and the other antennas. The result is shown in Table 2: we find correlation coefficients of about unity, implying that the variations are due entirely to variability at Effelsberg.

3. Impact on Closure Phase

The conclusion of the previous section is that in a run of 8 hours, there could be some variability of the right-left phase. The consequence of this variation on the D-terms is not straightforward. However Roberts, Wardle, & Brown (1994) list D-terms determined for several global 5 GHz experiments over more than one decade. The Effelsberg D-term phases show a variance of $\sim 20^\circ$ between 1984 and 1990. The amplitude of the Effelsberg right D-terms have an average of 4 with variance of 0.9 and semidispersion of 1; the left D-terms have an average value 5.8 with variance of 1.3 and semidispersion of 2. The remaining stations for which D-terms are provided are insufficiently sampled to allow meaningful determination of the stability. But, we assume for illustration that other stations show similar properties. In summary we have that the variations could range from the 4.5 degree found in 8 hours, to the maximum 20 degrees determined in a period of 6 years. For the amplitude we will assume a maximum variation of 2%.

In Figure 2, we show the closure phase on the Medicina-Onsala-Westerbork triangle determined from different instrumental polarization terms. In each panel, one curve uses the polarization terms derived from the DA 193 data described by Massi & Aaron (1997). The second curve uses D-terms corrupted by errors. The last curve shows the residual baseline error after removal of the instrumental polarization contribution. The box at $\pm 0.28^\circ$ shows the error in closure phase expected from thermal noise. Three different levels of corruption are considered. It is important

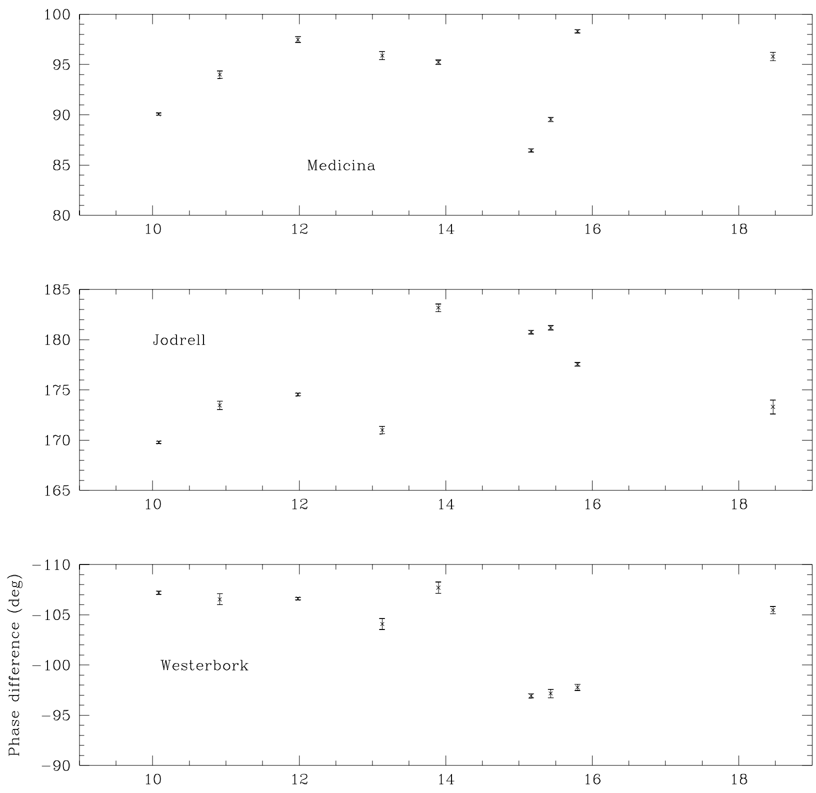

Fig. 1.— Difference in the phases of the right and left hand gains for 3 EVN telescopes.

Table 1. Contribution of the instrumental polarization to the observed right-left gain difference.

Time	Measured difference	D-term contribution
10.18	90.07	0.58
10.91	95.04	0.56
11.98	97.33	0.53
13.13	95.89	0.47
15.17	86.39	0.79
15.43	89.54	0.66
15.80	98.44	0.62
18.46	95.78	0.80

Table 2. Correlation coefficients between the gain differences shown in Figure 1.

	L	J	W
L	1.0000	0.9984	0.9987
J	0.9984	1.0000	0.9999
W	0.9987	0.9999	1.0000

to note that we consider the worst-case combination of the errors, *i.e.*, we assume that among the three antennas contributing to the the closure phase one antenna is affect by the error, the second by the error with *opposite* sign and the third remains unaffected. For the first case (top panel), we consider the amplitude corrupted by 1% and a phase error of 4.5° (which therefore can give rise to a baseline phase error up to 9° in the worst-case combination). The residual is slightly above the error box and the consequent degradation of the dynamic range is well below a factor 2. The degradation is still confined within about a factor 2 for an error of 8° (middle panel). The effect of having errors large as 25° (lower panel) is dramatic. This case should be however taken into account as a very extreme case since it reflects the maximum variation over 6 years while, we remind the reader, we are interested on variations on much shorter time scale (15-20 days).

The conclusion of this memo is therefore that if the variations are within $\sim 8°$ in phase and 1% in amplitude, our idea of determining D-terms at the beginning of each session and providing the observers with these data is feasible and will produce improvements in EVN imaging. As mentioned above, these results will be more rigorously tested using recent EVN observations, the first results of which are described below.

4. First results

The first run on DA 193 of February 1997 has been analyzed and we have derived the D-terms whose amplitudes are shown in Figures 3 and 4. One very important thing to note is the new value of the D-terms for Effelsberg. The old values were about 9% whereas the new values are $\sim 1\%$. Both Cambridge and Westerbork show strong variation with frequency. We tentatively determine an amplitude of $\sim 35\%$ for the Shanghai station. But, we have, as yet, been unable to satisfactorily correct the cross hand data. The reason for this is not yet clear. Finally, we note that the Effelsberg, Jodrell Bank, and Torun stations all show very low D-term amplitudes, *sufficiently low that their effect on closure phase in the parallel hand data can be ignored.* So, the work described here is concerned with improving the data obtained with the Onsala, Medicina, and Westerbork stations, and any other stations with comparably high D-terms.

For the Medicina station, we note that the sum of the phases of the two D-terms is about 180° in each of the 14 IF's. Roberts, Wardle, & Brown (1994) noted this property of Medicina consistently arising in observations since 1984, pointing out that, when a phase error arises in the quarter-wave section (*i.e.*, the observing wavelength is not exactly equal to the design wavelength of the feed), the phase of both the right and left D-term will equal 90° and, hence, the sum will be 180°. We are unable to measure the absolute phase of the D-term for Medicina from these data, but we note that the sum is 180° and a rotation of $\pm 44°$ (negative for the right term and positive for the left) would give phases near 90° for all values. Based on this, we suggest that the quarter-wave plate at Medicina be checked against the standard observing band and adjusted appropriately, which may greatly improve the instrumental polarization characteristics of this telescope.

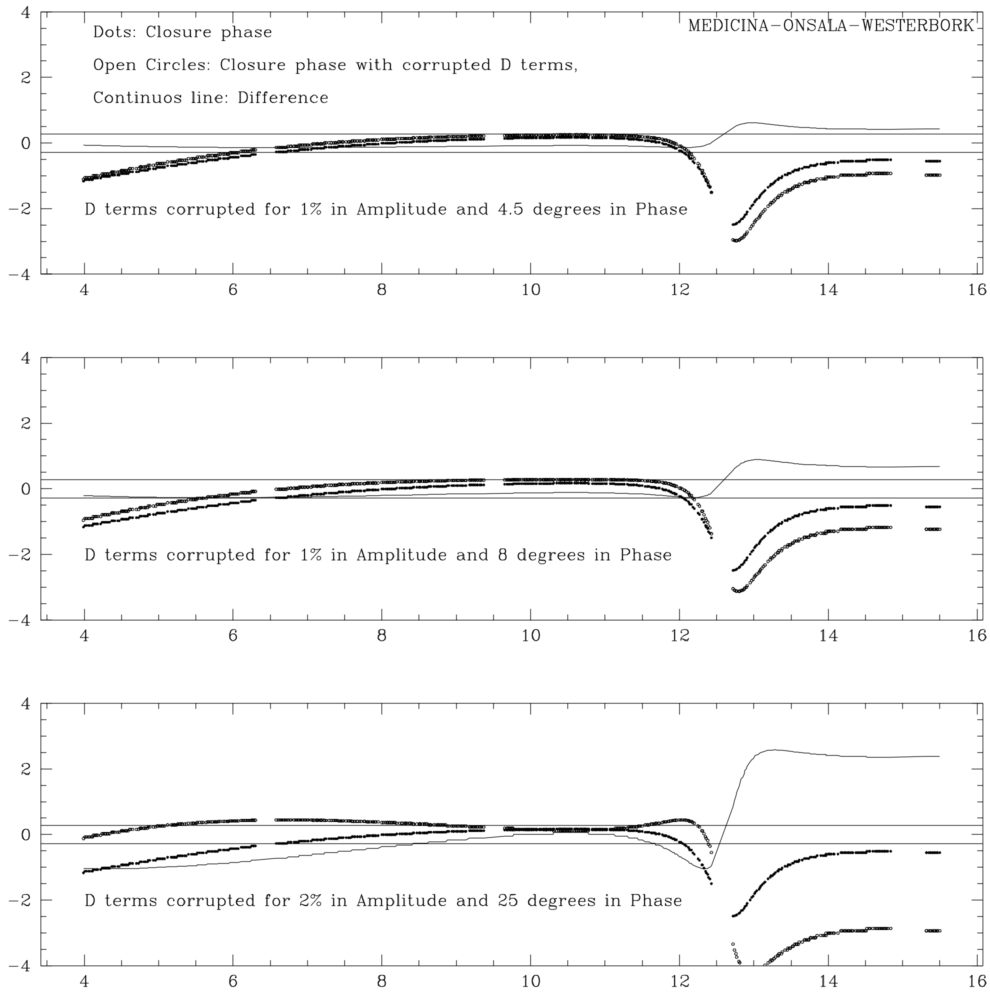

Fig. 2.— Closure phase due to instrumental polarization for different erroneous values of the D-terms.

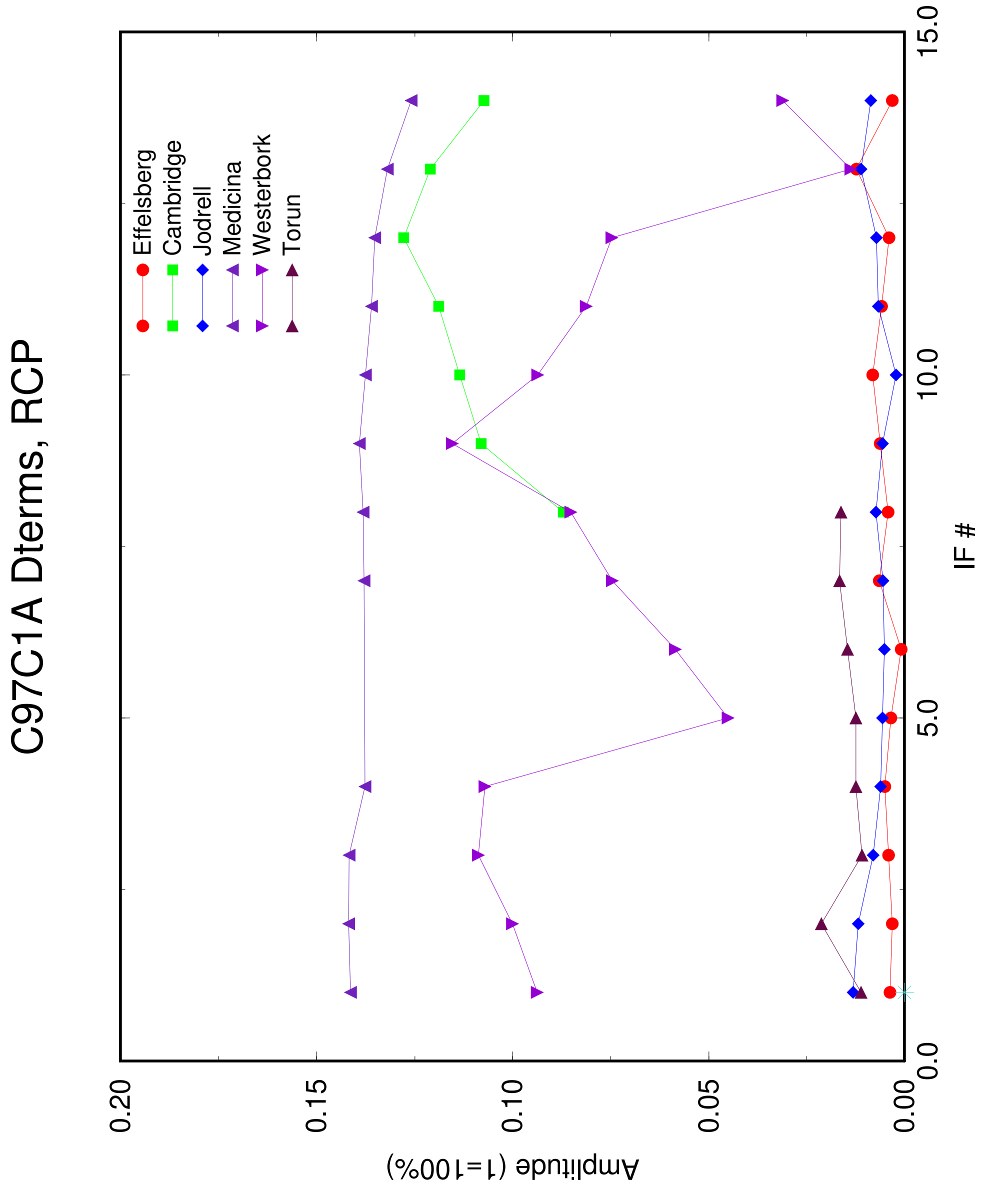

Fig. 3.— Plots of the right D-term amplitude for various EVN telescopes from one of the February 1997 network $\lambda 6$ cm CAL experiments (C97C1A) as a function of frequency, represented by the IF number. The symbols are described in the plot legend.

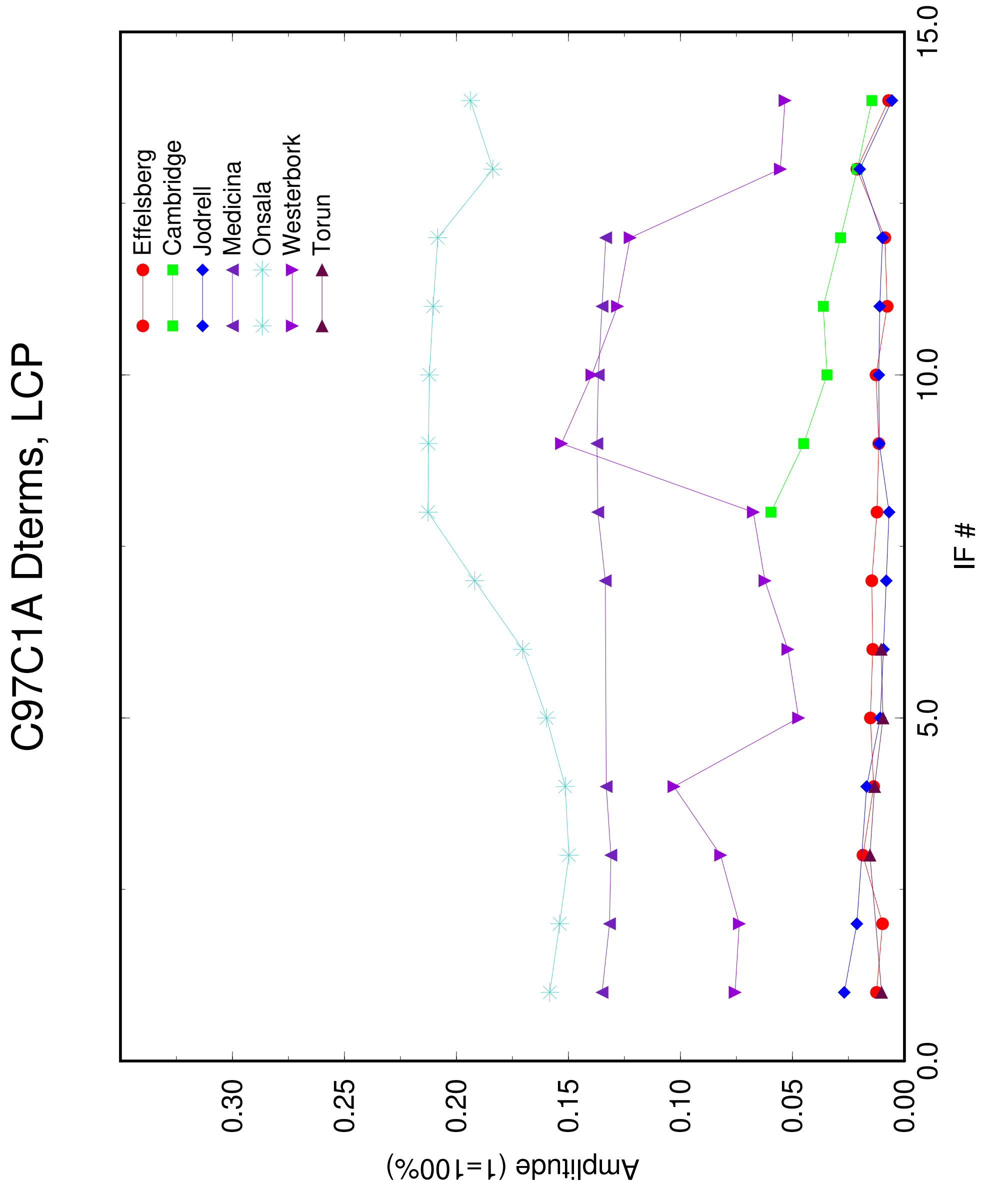

Fig. 4.— Plots of the left D-term amplitude for various EVN telescopes from one of the February 1997 network $\lambda6$ cm CAL experiments (C97C1A) as a function of frequency, represented by the IF number. The symbols are described in the plot legend.

Finally, we emphasize that the process of cataloging D-term values during each session which we have proposed should only be considered a temporary and partial solution to the problem. These efforts should not detract from or devalue efforts at the individual stations to improve their polarization purity. The best improvements in network image quality will come from higher quality data from each telescope.

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