**Absolute Polarisation Calibration for LBA from ATCA data**
**eLBA memo 11**

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# I : Abstract

It has been argued that the ATCA data, which is collected in parallel with a VLBI observation, could be used to allow absolute polarisation calibration of LBA data. If this was the case all stokes products should be formed and placed in the LBA data archive for all suitable experiments, to maximize the future usefulness of that archive. Here we demonstrate the necessary steps to generate the final absolute-polarisation correction, following the normal miriad data reduction, and apply it to a case in which LBA polarisation calibration has already been demonstrated (V182 – see the OAN IT and eLBA memo 9 [1, 2]).

# II : Phasing up of ATCA

The phasing up of the Australia Telescope Compact Array (ATCA) is essential to use all of the collecting area. If it is done correctly we have one VLBI station for which we know the delay between the Right and Left Hand Polarisations is zero (avoiding the need to solve for this). Furthermore the D-terms for ATCA should also be zero (assuming that the polarisation of the primary calibrator is zero, for 1934-682 this is (very very nearly) true). However there is an additional complication for the case of ATCA, which is that there are 6 (or more usually 5) antennas summed into a single effective instrument. There can be significant phase fluctuation between the individual elements with time, and these will degrade the solution by introducing a time variable D-term which *can not be solved for* in AIPS. To assess the best strategy for handling this, some tests were run in February 2009 with (the now retired) ATCA systems. The new CABB system will change some details, but the basic issues remain the same and our conclusions will set the requirements for the new system. One change which will certainly come about is in the way CACAL is used.

• CACAL only calibrates on a source if the schedule marks it as ‘C’ class. We find that this is useful.

• We tested whether any noticeable difference could be found between continuous CACAL and CACAL on a 1 minute average looking at a (single) strong source. No difference was detectable. We concluded that the averaged CACAL acts as expected, and is a required feature.

• We tested running CACAL continuously with a 1 minute average looking at multiple strong sources. Solutions are averaged over 1 minutes worth of valid data, whether there was a source change or not. This can be bad if there are large slews between C-coded (i.e. calibrator) sources (as in this case). The solutions for the start of a new scan will include the old, invalid, data. On the plus side this behaviour is good for phase referencing as it allows corrections which span the scans on the target. In conclusion averaging should be allowed, but should reset if there is a large slew or a long time gap.

• We were not able to use CACAL with data from the long baselines only, as had been possible in the past. This would allow compact sources in confused regions to be used as calibrators, which we believe would assist in tying the array. We conclude that this is a feature that should be implemented.

The traditional mode of operation during ATCA VLBI runs has been to only use the shorter baselines (i.e. not including antenna 6) and to run without real-time corrections. If large deviations between antennas are seen (mostly easily monitored in the phases to antenna 6, which should all agree) either that antenna is dropped or the schedule is broken to re-tie the array. This approach certainly can work but will introduce issues for polarisation calibration – as dropping antennas would be expected to change the D-term. See figure 1 for an example of the phases between antennas in a run without re-tying or CACAL running. Shown are the phases for two different phase reference sources which are close to each other, as well as the target. There is good agreement between them. The phases wander randomly on timescales of about an hour and remain within $30^o$ of the initial starting point. This is sufficient to give only a small loss in the tied array signal, and small changes in the D-term. However this (typical) situation is not always the case and for high frequencies and during poor weather this will break down. Inclusion of ATCA calibrators (which may or may not also be suitable VLBI calibrators) allows automatic retying of the array. These calibrators do not need to be continuously observed, but the interval between calibration scans will be weather and frequency dependent.

**Conclusions** We suggest that one should run CACAL (or equivalent) continuously, if the sources are suitable. If they are not one can get acceptable results with a nearby source visited hourly. Distant sources will not be suitable because of the different atmospheric solutions for that different line of sight. We believe that the new system must support: schedule-based selection of suitable calibrators (the 'cal code'), averaging of phase correction values over arbitrary timescales, so weaker sources can be used; automatic breaking of the accumulation if there is no valid data for a significant timespan or if a large slew is performed, to prevent the averaging of incompatible values; the ability to request selection of the data products used for the calibration, to allow the exclusion (for example) of the shorter baselines.

# III : Calibrating VLBI data from connected array data

Absolute polarisation calibration can be extracted from any source, even the VLBI target, as long as one can be confident that the polarised emission detected on the short ATCA baselines ($\leq$6km) has the same polarisation angles as that detected on the LBA baselines ($\geq$100km). This is best confirmed by comparing the recovered integrated linear flux in the images from both instruments. If they are in agreement then one knows that there was no loss of polarised flux, and one can assume that the position angle found in the ATCA image can be used to set the position angle found in the LBA image.

## III.1 : Experiment V182

Experiment V182 was a VLBI observation of a compact double source at 4.8- and 8.4-GHz (part A and B). Only part A is used here. The two frequencies allow us to measure the spectral index of the two components, leading us to the conclusion

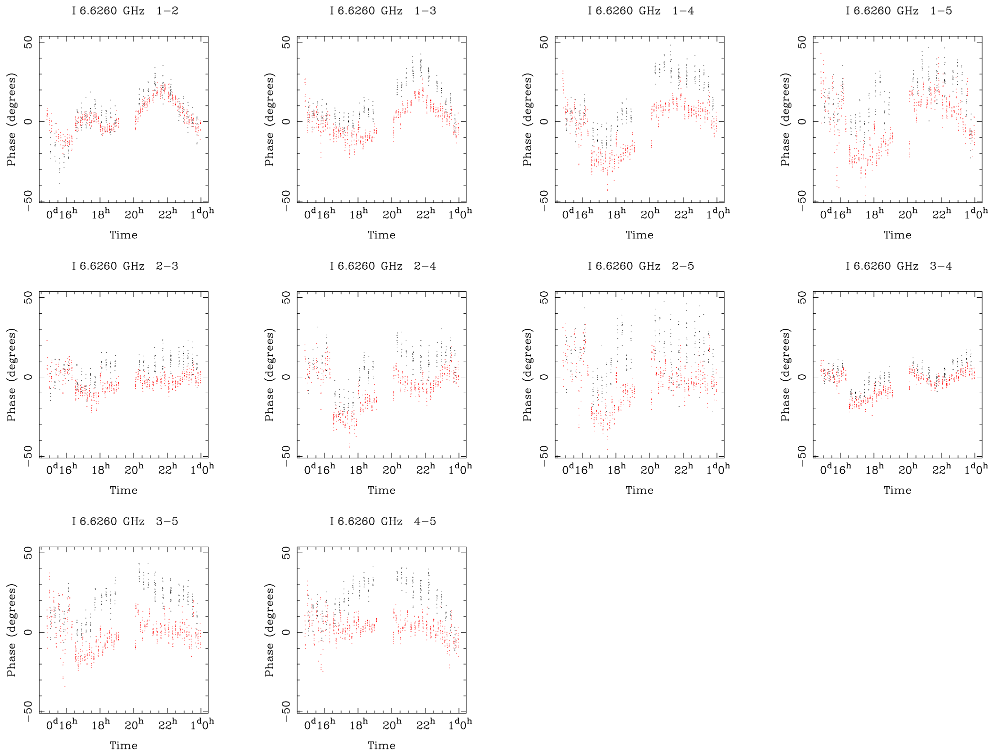


Figure 1: Phases for two close phase reference sources (1726-3608 and 1729-373, 1.8$^o$ apart) at 6.7-GHz in stokes I, from experiment V255D. No corrections were made to the antenna tie after the initial calibration. Timescales for the deviations are of the order of an hour, and the extent is typically less than 30$^o$ (i.e. less than 13% loss).

that the source is a flat spectrum core and a steep spectrum jet. The polarised flux emission is purely from the jet component. Without absolute polarisation calibration we could not comment on whether it lies along or across the jet. Fortuitously the ATCA data allows us to recover the absolute polarisation angle and we can then apply this to the VLBI data and discover the jet polarisation angle.

Despite the fact that the recording mode for VLBI is non-standard, as it includes the phase rotation for the formation of circular polarisation from the tied array, the data processing steps were standard. This is because the introduced xy-phases of $\pi/2$ are stored in the data headers, and accounted for in the data-processing. This can be confirmed by checking that **uvlist vis=v182a options=full,variables** reports the expected values. No further considerations were found to be needed.

## III.2 : Comparison to previous work

This source has been previously imaged with ATCA in full polarisation [3], although little information was published as to the polarisation angles or the observing configurations. Nevertheless there is sufficient to allow us to confirm that the ATCA data taken during the VLBI run, which has poor uv-coverage, does correctly detect the total flux. ATCA configurations during the VLBI runs tend to be compact configurations (but not always). This simplifies the phasing up of the array (see section II), but complicates imaging of sources with structure on the arcsecond scale. This was the case for the calibrator and the target in experiment V182 (sources 0637-752 & 0743-67). When we compare the ATCA V182A observations to the previous ATCA observations we find good agreement for the total intensity, but the polarised flux is significantly lower, only 47% of the previous values. This implies that the polarised flux is much more variable than the total intensity; not an unknown occurrence. The VLBI observations find less total flux, but the same amount of polarised flux as in the co-temporal compact array observations. This implies that there is resolved unpolarised emission (which would be expected for sources with arc-second scale structure) but the polarised emission is from a compact area in the jet. Therefore we can use the polarisation angle from the ATCA data for the LBA data. In this case the correction we require is a rotation of $-59^o$.

| Comp. | ATCA V182 | | | Previous | | VLBI V182 | | |
|---|---|---|---|---|---|---|---|---|
| | I/Jy | P/mJy | $\chi$ | I/Jy | P/mJy | I/Jy | P/mJy | $\chi$ |
| C | 1.16 | 44 | -20 | 1.17 | 93 | 0.39 | $< 2$ | – |
| J | – | – | – | – | – | 0.52 | 48 | 39 |
| Total | 1.16 | 44 | -20 | 1.17 | 93 | 0.91 | $<50$ | 39 |
| E2 | 0.27 | 37 | 70 | 0.31 | 68 | – | – | – |

Table 1: Total flux, linear polarised flux and polarisation angle of 0743-67 from the co-temporal ATCA observations of V182A, from the published ATCA observations, and from the V182A LBA observations. The Components **C** and **J** are not resolved in the ATCA data, and are the equivalent to **C** in the naming convention of [3]. Component **E2** is named following the conventions in [3].

# References


[1] R. Dodson, 2007, "On the solution of the polarisation gain terms for VLBI data collected with antennae having Nasmyth or E-W mounts.", IT-OAN-2006-16, Informé Technico.

[2] R. Dodson, 2009, "Polarisation gain terms for LBA data.", eLBA memo 9.

[3] Punsly, B. and Tingay, S. J., 2005, "PKS 0743-67: An Ultraluminous Accretion Disk and a High Kinetic Luminosity Jet", ApJL, L89, 633

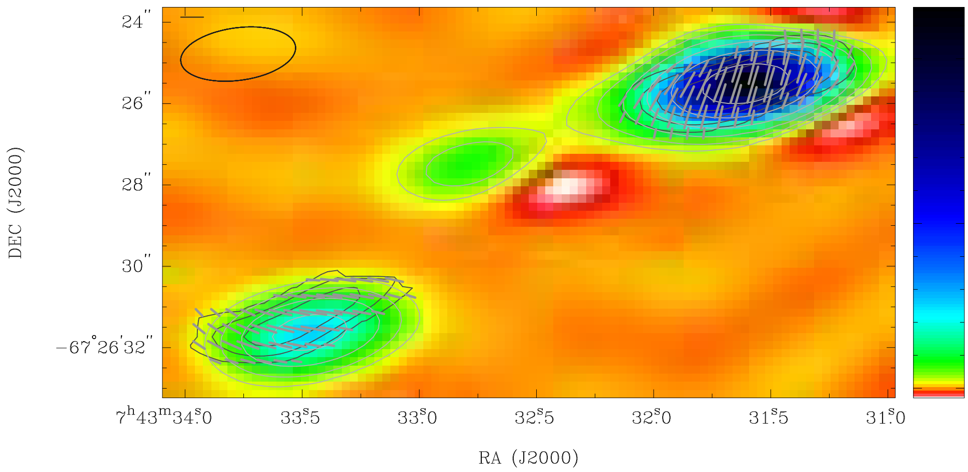


Figure 2: Image of 0743-67 from the ATCA data collected during V182A. We recover the Core component **C** (following the naming conventions in [3]) and **E2** (as before) but W could not be imaged with this ATCA configuration. The image shows the log-scaled stokes I emission with contours at 0.025,0.05,0.1,0.2,0.4,0.8 Jy/bm; the contours the linearly polarised flux are at 10,15,20,25 mJy/bm; the polarisation E-vectors are overlaid. A vector representing 50 mJy/bm of linear polarised flux and the beamsize are shown in the top left.

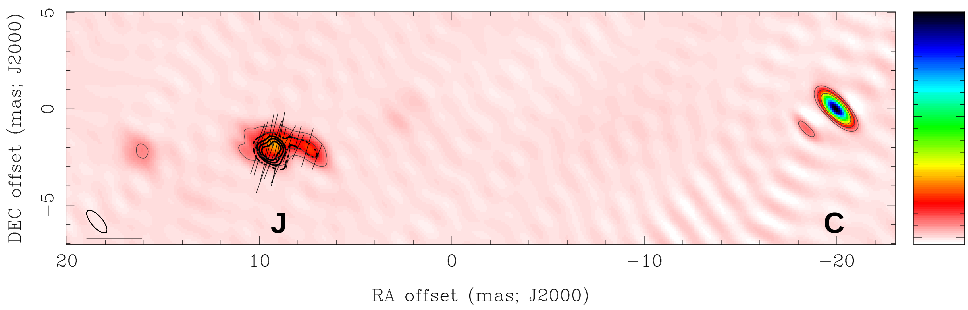


Figure 3: Image of 0743-67 from the LBA experiment V182A. We only can image the the ATCA core component (C), which is resolved into an unpolarised core (flat spectrum) and a jet to the East (with a non-thermal spectrum). The jet contains all the polarised flux from the ATCA core. The image shows the linear-scaled stokes I emission with light contours at 0.02, 0.05 and 0.1 Jy/bm; the heavy contours of linearly polarised flux are 5,8,10 and 12 mJy/bm; the corrected polarisation E-vectors are overlaid. A vector representing 10 mJy/bm of linear polarised flux and the beamsize shown at the bottom left.