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Final implementation of algorithms for polarimetry conversion

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1 Introduction and problem formulation

Wide-band receivers is an important trend in radio interferometry that allows telescopes to cover wide spectral bands with fewer feeds. The wider the band a feed is meant to cover, the more difficult it is to design linear-to-circular transformer (L2C) that performs well over the entire band (L2C are hardware components that convert linearly polarized waves to circularly polarized waves, such as a quarter-wave plate). And even if such L2Cs could be designed they would probably be bulky and costly to build. Thus many telescopes choose to keep their voltage output in linear polarization. Such is the case, for instance, for the ALMA telescope.

On the other hand, VLBI techniques nominally requires telescope voltages to be circularly polarized.

An alternative to hardware conversion to circular is instead to convert the linearly polarized voltage signals to circular in software after digitization of the signal.

It is this later solution that has been explored in this document. We have investigated, and come up with a final implementation for the algorithms to convert the polarimetry from a radio interferometer.

2 Solution and Algorithm

The solution to the problem of producing circularly polarized radio interferometer data developed within the framework of this RINGS project is based on the ideas initiated in the ALMA Phasing Project (APP). The strategy is as follows:

- Start with the nominally recorded linearly polarized data stream as per normal
- Solve for the full Jones response matrix of each antenna
  - Solve for X/Y phases and amplitudes
  - Solve for X,Y relative phase and amplitudes
  - Solve for cross-polarization ratios (D-terms)
- Apply inverse of full Jones matrix calibration
- Convert linear antenna baselines to pure circular basis
  - while leaving circularly polarized antennas in circular basis

Let us go through these steps in more mathematical detail, most of which can also be found in Marti-Vidal (2016). The voltage response of a dual-polarized antenna to an incident signal can be modelled as a linear, multivariate equation where the proportionality is a complex matrix called the *Jones matrix*,

$$\boldsymbol{v} = \boldsymbol{J}\,\boldsymbol{e}$$

where v is a 2x1 complex vector representing the voltages out of the dual-polarized feed, J is the 2x2 complex Jones matrix and e is the incident electric field.

In a interferometer, these voltages are correlated to produce visibilities. After correlating all polarization channels from an antenna with all polarization channels from another antenna, one obtains a complex 2x2 matrix called the *visibility matrix*,

$$\boldsymbol{v}_i \otimes \boldsymbol{v}_j^H = \boldsymbol{V}_{ij}$$

for the i-th and j-th antennas, where H represents Hermitian transpose.

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For baselines between a linear (denoted with index +) and a circularly polarized (denoted with index ⊙) feed, the visibility matrix is then called a *mixed basis visibility*. In this case a full, polarimetric calibration can be written as

$$\boldsymbol{E}_{+\odot} = \boldsymbol{J}_{++}^{-1} \boldsymbol{V}_{+\odot} \boldsymbol{J}_{\odot\odot}^{-H}$$

One can convert the linear half of the mixed visibility matrix by using the linear to circular basis conversion matrix

$$\boldsymbol{C}_{\odot +} = \begin{pmatrix} 1 & -j \\ 1 & j \end{pmatrix}$$

by multiplying from the left

$$\boldsymbol{E}_{\odot\odot} = \boldsymbol{C}_{\odot +} \boldsymbol{E}_{+\odot}$$

So now finally we can write the full pol-conversion formula as

$$\boldsymbol{E}_{\odot\odot} = \boldsymbol{C}_{\odot +} \boldsymbol{J}_{++}^{-1} \boldsymbol{V}_{+\odot} \boldsymbol{J}_{\odot\odot}^{-1}$$

Analogous formulas apply for the cases of (non-mixed) linear-to-linear and circular-to-circular baselines.

As regards to calibration of the individual Jones matrices. They can be calibrated as per normal. That is, full polarization calibration implies we find solutions for parametrized version of the Jones matrix components. As `polconvert` is based on CASA, we mention that the CASA formalism for the Jones matrices is roughly as follows. The Jones matrix is parametrized as

$$\boldsymbol{J} = \begin{pmatrix} 1 & D_x \\ D_y & 1 \end{pmatrix} \begin{pmatrix} G_x & 0 \\ 0 & G_y \end{pmatrix}$$

where Gx and Gy are the co-polarized channel gains and Dx and Dy are the cross-polarized gains, also known as the D-terms or pol-leakage terms.

3 Final Status and Conclusions

We have developed an algorithm to convert the linearly polarized halves of interferometric data of mixed visibilities. This has been found to work well and will be of great use in combining mixed visibility interferometers. The software implementation of this algorithm is called *polconvert*. It has been implemented as task in CASA. It can be downloaded from the address:

http://bele.oso.chalmers.se/nordicarc/sw/PolConvert_1.3.tar.gz

The latest publicly available version is 1.3, and has been incorporated into the DiFX software. It has also been used at Jive.

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4 References

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