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A-to-Z Solver : Modeling the antenna aperture illumination function

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We present a new algorithm, the A-to-Z solver, which models the antenna aperture illumination pattern (AIP) in terms of Zernike polynomials. In order to achieve thermal noise limited imaging with modern radio interferometers such as MeerKAT, JVLA, ALMA and uGMRT, it is necessary to correct for the instrumental effects of the antenna primary beam (PB) as a function of time, frequency, and polarization. The wideband AW projection algorithm [1] enables those corrections provided an accurate model of the AIP is available. We present the A-to-Z solver as a more versatile replacement for modelling the AIP as compared with the current A-solver algorithm [2].

The ideal antenna PB is axis symmetric and circular, however there are several issues that may impact this assumption - any blockages to the aperture, off-axis feeds, or an offset illumination will cause rotational asymmetries for the Stokes-I PB. The Stokes-Q, -U, and -V PBs are inherently asymmetric due to projection effects. Further, an offset between the two orthogonal feeds of the telescope will cause a "squint" - a difference in the intrinsic pointing centres of the two polarizations [3]. Given an accurate AIP model the AW projection algorithm can correct for all the aforementioned errors.

The A-solver methodology uses ray tracing to model the AIP as demonstrated for the VLA antennas. However it is a non-trivial process involving a significant development effort on the part of individual observatories to include their own AIP into the framework, requiring a precise description of the antenna geometry. The algorithm was also shown to be lacking in it's modeling of off-axis polarization effects at lower frequencies and is additionally computationally expensive [4]. The A-to-Z solver approach is a solution to the limitations of the A-solver method. This new algorithm utilizes the circular, orthonormal Zernike basis to model the AIP obtained from the measured antenna holography. This allows the method to incorporate any interferometer for which holographic measurements are available. Zernike polynomials were designed to model optical aberrations of apertures and lenses, and directly correspond to physical aberrations such as tip, tilt and defocus, amongst others.

Using this new algorithm we have successfully modeled the AIP of EVLA, MeerKAT, and ALMA with uGMRT in progress. We show that the imaging performance is comparable to beams derived from ray traced beams for Stokes-I and -V imaging, and significantly better for Stokes-Q and -U. Furthermore the A-to-Z solver directly models the electric field distribution of the AIP and works independently of antenna shape, feed basis etc. This new algorithm is significantly faster and accurately models off-axis polarization effects. The latter is a requirement for hybrid and full-Mueller AW projection algorithms. We also show that the efficacy of this approach is limited by the quality of the holographic data - although the requisite quality should be achievable by most observatories.

References

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