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Calibrating Phased Array Feeds for the ASKAP Telescope

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This paper reviews CSIRO's efforts to stabilise and calibrate phased array feed (PAF) beams for the Australian Square Kilometre Array (ASKAP) telescope. ASKAP is a synthesis array of 36 paraboloidal reflector antennas, each with a PAF at its focus operating over 700 MHz to 1,800 MHz [1]. Each PAF is a connected-element array with 188 ports (94 dual-polarisation elements). All 188 ports for each PAF are digitised and fed through a real-time digital signal processing system that generates 72 independent beams at 1 MHz resolution. Each beam is a complex-weighted linear sum of a selection of 60 PAF ports. The beamformer is typically configured to calculate a pair of orthogonal, linearly-polarised beams for each of 36 directions within the 31 deg^2 accessible field of view.

Digital PAF beamforming can adjust ASKAP's performance between or even during observations. Beamforming adjustments can improve instrument response for specific science goals and correct beam properties that need calibration. Antenna beam gain, pattern, sensitivity, and polarisation all change with intentional changes to beam weights, but also with unwanted fluctuations in electronic gains before the beamformer. Key PAF calibration goals for ASKAP are to (1) form beams with desirable properties given science goals, (2) maintain stable beams between and during observations, and (3) accurately characterise beams for correct treatment in synthesis imaging.

ASKAP uses beamformer weights that optimise signal-to-noise ratio and thereby telescope sensitivity [1]. The layout or "footprint" of beams over the accessible field of view is configured to either spread the beams out for improved survey speed or to pack them closely for improved spatial sampling and field flatness. Beam weights are calculated from covariance matrices measured by correlating all pairs of ports on a given PAF. Covariance matrices are recorded for an empty field to characterise system noise then with 36 offset pointings about the strongest available unresolved source (the Sun). Each angular offset corresponds to one desired beam pointing.

One further covariance matrix is recorded with each PAF illuminated by an external noise source mounted at the vertex of each reflector. A copy of the on-dish calibration (ODC) noise is fed into a spare port of the digital back-end and correlated with each PAF signal to estimate the complex gain of each PAF port. This information is used during weight calculation to calibrate the XY phase of each PAF beam and to set it near zero by design [2,1]. This allows polarisation results to be obtained from all ASKAP continuum observations without extended calibration observations for each beam on astronomical sources of known polarisation.

The PAF response to the ODC noise is stored with the beam weights. A quick 8 min ODC measurement at the beginning of each observation can then refresh archived beamformer weights for changes in electronic gains, phases and delays since the original beam weight calibration [1]. This avoids having to make a 1 h observation of the Sun each time the beam weights are changed. Investigations are underway to correct gain fluctuations during observations via more regular ODC calibration. This would improve synthesis imaging results without expending additional supercomputing resources to solve for antenna gain variations during long observations.

Finally, holographic measurements are made to evaluate the pattern and polarisation leakage of each beam [3]. Empirical beam models are derived from these measurements and used to calibrate primary beam pattern and polarisation effects in synthesis imaging and mosaicking. A future goal is to simplify calibration at the synthesis imaging stage by manipulating the PAF beamformer weights to make more symmetric beams that vary less between beam pointings, polarisations, and different PAFs.

References

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