A Generic and Efficient "E-field Parallel Imaging Correlator" Software for Next-Generation Radio Telescopes

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We present the E-field Parallel Imaging Correlator (EPIC) software to provide the first detailed demonstration of the Modular Optimal Fast Fourier (MOFF) imaging, a generic FFT-based direct imaging algorithm. This software, now publicly available, is an efficient alternative to those implementing conventional correlator-imaging algorithms in radio interferometry, particularly for dense antenna array layouts. It takes raw antenna voltages as input, computes the spectrum using a temporal FFT (F-engine) and calibrates these antenna voltage spectra (in a companion talk) without ever forming cross-correlation products from antenna pairs unlike usual FX/XF correlators in radio interferometry. Using the finite extents of antenna apertures, the calibrated electric fields and the antennas' collecting areas are projected onto a grid on the ground. Images are obtained by squaring the spatial Fourier transform of the electric fields projected on this grid, thereby completely avoiding the need to estimate $\mathcal{O}(N^2)$ cross-correlations between antenna pairs. For densely packed antenna array layouts, the imaging cost scales efficiently as $\mathcal{O}(N \log N)$. Since the electric fields are stochastic, they are gridded and imaged every cycle before they can be coadded to lower the noise. However, the projection onto the grid is required only for a fraction of the grid size and the antenna-to-grid mapping is determined just once per fringe timescale. This is done efficiently via sparse matrix operations. Another significant advantage of our software is that the gridding naturally allows for direct imaging even from irregularly placed antenna array layouts and antennas whose power-patterns are not identical. It also has FX/XF correlator and imager modules built in for reference. We demonstrate that the images so obtained with our code are equivalent to those from conventional correlators and imaging techniques to well within the rms in the sidelobes of point spread function. We make a detailed comparison of its performance with regard to these important stages – temporal FFT, gridding, imaging, and accumulation – relative to its traditional counterpart. We identify specific science cases that will be more effectively enabled with this software implementation like real-time search of radio transients with future arrays such as HERA, LWA and the SKA.