Hyper Spectral FFT Imager: Beamforming on HERA antennas

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Dynamic Phased Arrays have been used in radio astronomy for over six decades to achieve higher angular resolution than single dish telescopes. One of the major challenges in using phased arrays for astronomy is calibrating the gains and phase offsets of antenna elements to ensure a good estimate of the source flux density which is orders of magnitude smaller than any terrestrial radio signal.

There are two major calibration techniques depending on how the phased array is being used. To observe point sources, like planets, pulsars or galaxies, the beams are all phased in the direction of the source. In such applications, calibration is achieved using a known calibrator in the sky whose location, intensity and frequency of emission are known to good accuracy. While drift scanning the sky for new objects or sources, the direction of observation is not known apriori. In such cases, cross-correlation products of the elements in the array are built, indirectly building all possible beams on the sky. When the array has redundant baselines (like phased arrays do), the cross-correlation products of the antennas with equal baselines are expected to be the same. This can be used to calibrate the offsets from expected behaviour.

Building radio interferometers for drift scans is becoming increasingly common. In the past decade, multiple arrays like the MWA (Murchison Widefield Array), LOFAR (Low Frequency Array), CHIME (Canadian Hydrogen Intensity Mapping Experiment), PAPER (Precision Array for Probing the Epoch of Reionization) and HERA (Hydrogen Epoch of Reionization Array) have come up with the common purpose of detecting and measuring the power spectrum of the unique signature of hydrogen from the epoch of reionization- a time in the universe when the first stars and galaxies formed. A common characteristic of all these arrays is the large number ($\sim 10^3$) of simple antenna elements.

The average number of computations required to build cross-correlation products of N antennas scales as N^2 for every frequency channel and time sample recorded. This implies that, to keep the cost of electronics in check, the bandwidth or the time resolution of the survery has to be decreased to improve the sensitivity of the signal with larger number of antennas. In this is paper I discuss a new algorithm which scales only as $N \log N$, for building and calibrating beams from phased arrays.