Complex Gain Calibration in "Hybrid" Low-Frequency Aperture Arrays: an Array Prototype and the Murchison Widefield Array

Adrian T. Sutinjo*, Randall B. Wayth, Shantanu K. Padhi,
Timothy M. Colegate, and Peter J. Hall
International Centre for Radio Astronomy Research
(ICRAR)/Curtin University, Bentley, Western Australia 6103

Complex gain calibration is a process which solves and corrects for the composite effects of the unknown electronic and antenna gains from the uncalibrated cross-correlation products ("visibilities") in radio interferometry. The resulting calibrated visibilities form the basis for astronomical post-processing such as imaging and telescope sensitivity measurements. Clearly, complex gain calibration is an essential prerequisite step.

Radio interferometers typically involve identical antennas and/or antenna arrays. This is the case for low-frequency aperture arrays (LFAAs) such as the Murchison Widefield Array (MWA; S. Tingay et al., PASA, 30, 7), the Long Wavelength Array (LWA; S. Ellingson et, al., IEEE Trans. Antennas Propagat., 61, 5, 2540-2549) and low-band LOFAR (M. P. van Haarlem et al., A&A, 556, A2), to name a few. In those cases, usual textbook analyses (A. R. Thompson et al., 2nd Ed., 2001), which assume identical antennas, are valid.

In the pre-construction stage of the Square Kilometre Array, however, we have found that very useful characterization results (P. Hall et al., ICEAA '13, 340-343) are quickly obtained by correlating the voltages from our prototype station (the Aperture Array Verification System 0.5, AAVS 0.5, which consists of 16 pseudo-random log-periodic "SKALA" antennas; E. de Lera Acedo, ICEAA '12, 353-356) with that of 127 MWA "tiles" (where each tile consists of 4×4 bow-tie antennas). It is evident that we have a situation involving one station which is not identical to the rest of the MWA tiles. Our initial work (T. Colegate et al., IEEE CAMA 2014) assumed that textbook equations apply. The scope of this work is to re-examine that assumption. Although hybrid antennas have historically been encountered in Very Long Baseline Interferometry, different considerations such as very wide field-of-view imaging and electronic beam pointing apply to LFAAs which warrant this re-examination.

Starting with a more general equation which accounts for the vector nature of radio interferometry, we will present a derivation of the one prototype array and $N-1$ identical arrays case. The resulting expression turns out to be rather simple and insightful albeit slightly different from the textbook form. It suggests conditions for which the identical array assumption is well approximated in the hybrid array case. We will offer numerical examples and discuss the impact of this finding to future work in low-frequency array prototyping with the MWA.