Full Muller AW-Projection: An algorithm to correct for Antenna Direction Dependent Gains

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Next generation radio telescope arrays are being designed and commissioned to accurately measure the polarized intensity and the rotation measures (RMs) across the entire sky through deep, wide-field radio interferometric surveys. Radio interferometric antennas are affected by direction-dependent (DD) gains due to both instrumental (antenna primary beam) and atmospheric effects (ionosphere). We explore the consequences of these time and frequency dependent instrumental DD gains on polarimetric imaging and present the Full Mueller AW-Projection algorithm that corrects for the DD gains during interferometric imaging. We begin by exploring the effects of the DD gains of a parabolic dish antenna array on the measured polarized intensities of radio sources in interferometric images. We characterize the extent of polarimetric image degradation due to the DD gains through wide-band Karl. G. Jansky Very Large Array (VLA) simulations of representative point-source simulations of the radio sky at L band (1-2 GHz). We then show that at the half power beam width of the primary beam there is significant flux leakage from Stokes I to Q, U amounting to nearly 10% of the total intensity. Subsequently, we demonstrate that the effect of the DD gains due to the primary beam on the RM signals. The effect of the DD gains is primarily centered around 0 rad/m/m, while the effect is significant over a broad range of RM requiring full polarization DD correction to accurately reconstruct the RM synthesis signal. Having demonstrated the effects of the antenna primary beam on polarimetric imaging we explore the need for an accurate aperture illumination pattern (AIP) as an input to the Full Muller AW-Projection algorithm. Given an accurate model for the aperture illumination pattern (AIP) of the antenna, the Full Mueller AW-Projection algorithm corrects for the effects of its time, frequency, and polarization structure. The level to which this correction is possible depends on how accurately the A-term, represents the true AIP. We introduce the A-Solver methodology that combines physical modeling with optimization to holographic measurements, to build an accurate model for the AIP. Using a parametrized ray-tracing code as the predictor, we solve for the frequency dependence of the antenna optics and show that the resulting low-order model for the VLA antenna captures the dominant frequency-dependent terms. The A-Solver methodology is generic and can be adapted for other types of antennas and telescope arrays. The parameterization is based on the physical characteristics of the antenna structure and optics. Therefore it is a compact representation (minimized degrees of freedom) of the frequency-dependent structure of the antenna A-term. Through imaging simulations of point sources, we also show that the parameters derived from the A-Solver methodology improve sensitivity and imaging performance out to the first side-lobe of the antenna. In conclusion we introduce the Full Mueller AW-projection (FM-AWP) algorithm and utilize simulations to show that the FM-AWP algorithm can correct for the off-diagonal terms out to the first side lobe.