NOVEL TECHNIQUES FOR MUTUAL COUPLING CHARACTERISATION IN LOW-FREQUENCY RADIO ASTRONOMY APERTURE ARRAYS

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Several leading science goals of modern radio astronomy appear in the VHF band. Cosmology is concerned about the Universe's evolution, and currently, the dominating effort is to detect the faint hydrogen emission 13.8 billion years ago, known as the epoch of reionisation (EoR). This signal, originating from hydrogen in the early Universe, has redshifted from 1.42 GHz and should be observable in the frequency range of about 70 and 240 MHz. By measuring the time-evolution of the hydrogen radiation, we will be able to reconstruct the formation of intergalactic medium in the early Universe. Despite the numerous projects probing various aspects of reionization, no one has conclusively demonstrated its detection thus far. The Square Kilometre Array (SKA), particularly its low-frequency component, SKA-Low, stands out as a promising instrument with a capability to detect the EoR. The concept of the Square Kilometre Array (SKA) originated in the late 1990s, aiming to construct a radio interferometer with 100 times the sensitivity of its predecessors. The construction of SKA-Low commenced in 2022 in the radio quiet zone of the Murchison Radio-Astronomy Observatory (MRO) in Western Australia. Prior to this, the pathfinders Murchison Widefield Array (MWA), Engineering Development Array (EDA) and Aperture Array Verification Systems ((AAVS0.5, AAVS1.5, AAVS2 and AAVS3) were constructed at MRO. In 2023, MWA celebrated 10 years of operation.

SKA-Low stations consist of 256 dual-polarised broadband SKALA4.1 antennas and present a difficulty in their characterisation. Electromagnetic simulations of AAVS2, calculating scattering parameters and embedded element patterns (EEPs) in the operating band $50-350$ MHz with a step of 1 and 5 MHz were performed using FEKO and Galileo, yielding highly consistent results [1]. Validating simulated results through measurements is non-trivial for such large-scale arrays. Unmanned aerial vehicles (UAV) were employed to characterise the beam patterns of the AAVS1.5 prototype, which comprises 48 SKALA4.1 antennas. [2]. Until now, scattering parameters and radiation patterns of AAVS2 or AAVS3 were not characterised via measurements due to the large scale of these arrays. A recently proposed method of mutual impedance matrix (MIM) extraction from measured EEPs [3] presents a potentially viable solution for measuring a MIM of deployed SKA-Low prototypes. Fig. 1 shows that the simulated mutual impedance matrix $\boldsymbol{Z}_A$ of AAVS3 is a diagonally-dominant matrix, and therefore, solving the transformation equation from [3], shown below, requires separate treatment of the lower and upper bounds for the diagonal and off-diagonal matrix entries.

$$\boldsymbol{E}^{oc,th} = Y_0\left(\boldsymbol{I} + Y_0\boldsymbol{Z}_{A,d}\right)^{-1}\boldsymbol{Z}_A\left(\boldsymbol{I} + Z_0\boldsymbol{Y}_{A,d}\right)\boldsymbol{E}^{sc,th}$$

This presentation will review the progress and present latest updates in theoretical techniques for mutual coupling characterisation in aperture arrays for low-frequency radio astronomy.

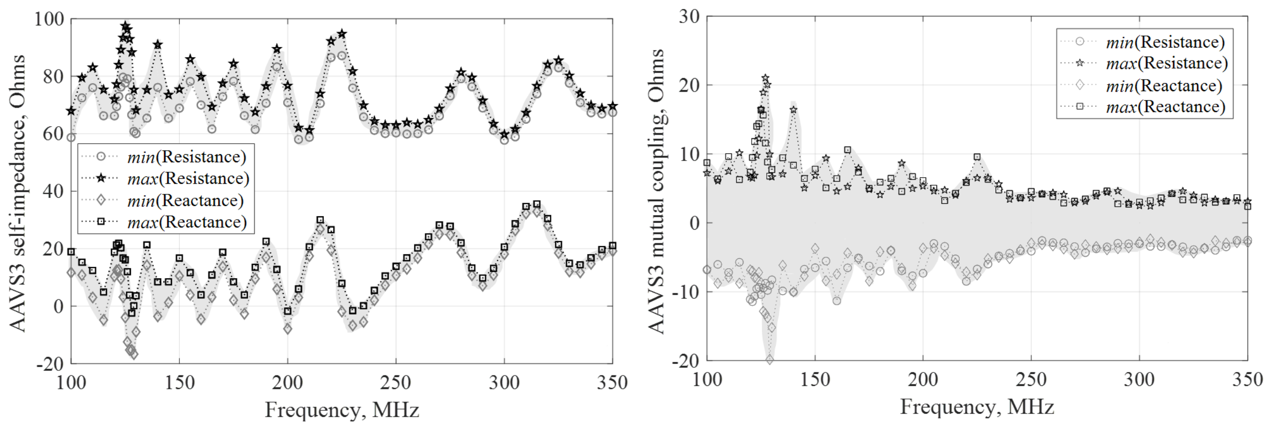

Fig. 1: FEKO-simulated mutual impedance matrix of AAVS3 (Vogel configuration) at 93 frequency points.

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[2] F. Paonessa et al., "SKA-Low Prototypes Deployed in Australia: Synoptic of the UAV-Based Experimental Results," URSI Radio Science Letters, vol. 2, 2020.

[3] D. Buck, K. F. Warnick, R. Maaskant, D. B. Davidson, and D. F. Kelley, "Measuring Array Mutual Impedances Using Embedded Element Patterns," IEEE Transactions on Antennas and Propagation, 2023.