Numerical methods for electromagnetic modelling of low frequency antenna arrays (SKA) and optimization of their performance

PhD student: Georgios Kyriakou (georgios.kyriakou@unifi.it)
Supervisors: Marco Romoli, Pietro Bolli

Radioastronomy is one of the most vibrant fields of astronomy in this century and has recently gained public interest with images of protoplanetary disks by ALMA, the image of a black hole by the Event Horizon elescope and other significant advances in the understanding of celestial objects providing scientists with new insights on the evolution of the universe. The next big step towards revolutionizing radioastronomy research, which is a result of improving the sensitivity of the instruments, is the SKA project (Square Kilometer Array). SKA will consist of two sites which will focus on radiation from different frequency bands. The SKA1-Low project, which will be built first in Western Australia, will enable science in the frequency range of 50MHz-350MHz and is the one which will study the 21cm Hydrogen line in redshifts of $z < 27$, going back to the Cosmic Dawn and Epoch of Reionization ages. Its capability to perform deep and wide field continuum surveys, will contribute to a unique 3D imaging of early hydrogen gas structures, as well as to Pulsar physics [4].

For this kind of array, which will consist of 131.072 elements, separated in 512 stations, a suitable active log-periodic antenna has been selected and optimally designed [1]. SKALA4.1 (SKA Log-periodic Antenna) is a dual polarized antenna, with an embedded Low Noise Amplifier (LNA), and it has been tested for technical requirements set for gain, bandwidth, crosspolarisation (IXR), smooth spectral transitions as well as manufacturing robustness. The EM performance of such antennas is well described in a series of technical documents, but the research is also ongoing to cover all of its aspects.

After completion of this prototype antenna, a range of issues has come into consideration. First a base station as those envisaged by SKA, encompassing 256 antennas in random positions within a circle must be modelled and measurements should be made in-situ to be compared to the full-wave simulations [2], emphasizing on the mutual coupling effects depicted by the EEPs (Embedded Element Patterns). A summary of these concepts referring to multiport antenna networks I have already included in my Masters thesis. Different computational techniques to best calculate these patterns will be one of the objects of my research, as traditional methods cannot readily be expanded to large arrays and therefore advanced methods, for example the use of Macro Basis Functions or the Domain Green's Function Method [5] have been used to further make this transition, improve the accuracy of the full-wave solution and still allow for acceptable computation time. Variants of these methods would be explored as part of this project. Another question that could be of high interest is whether there are any geometrical layouts of the array that could improve the EEPs and mitigate their variability across different frequency points. The pseudo-random circular layout which is currently being employed is necessary to produce low level sidelobes, but putting some constraints on the antenna positions for example could potentially improve the EEP without compromising this performance. Finally, statistical analysis of these patterns to assess their overall behavior would be implemented. These activities will be undertaken under the guidance of Dr. Marco Romoli from University of Florence and Dr. Pietro Bolli of Istituto Nazionale di Astrofisica (INAF).

This modelling shall also improve calibration of the array beam [6], since calculated EEPs constitute a crucial part of the reconstruction of the actual beam. As far as calibration measurements are concerned, a UAV based system measuring small array arrangements in-situ has already been developed, assessing some of the inaccuracies of the model and especially in the RF chain, which is more challenging to predict under real conditions. Currently the AAVS2.0 (Aperture Array Verification System 2.0) with the full arrangement is being commissioned to measure the sensitivity and polarization purity of the array and contribution to the debugging of the station can also be part of the project. It is indeed of interest to improve this method compared to the use of natural sources of known flux density, as it is a more stable reference [3] and effort must be made to meet the SKA calibration requirements.

References

[1] P. Bolli, L. Mezzadrelli, J. Monari, F. Perini, A. Tibaldi, G. Virone, M. Bercigli, L. Ciorba, P. Di Ninni, M. G. Labate, V. G. Loi, A. Mattana, F. Paonessa, S. Rusticelli, and M. Schiaffino. Test-driven design of an active dual-polarized log-periodic antenna for the square kilometre array. *IEEE Open Journal of Antennas and Propagation*, 1:253–263, 2020.

[2] D. B. Davidson, P. Bolli, M. Bercigli, P. di Ninni, R. Steiner, S. Tingay, D. Ung, A. van Es, G. Virone, and R. Wayth. Electromagnetic modelling of the ska-low aavs1.5 prototype. In *2019 International Conference on Electromagnetics in Advanced Applications (ICEAA)*, pages 1032–1037, 2019.

[3] E. de Lera Acedo, P. Bolli, F. Paonessa, G. Virone, E. Colin-Beltran, N. Razavi-Ghods, I. Aicardi, A. Lingua, P. Maschio, J. Monari, G. Naldi, M. Piras, and G. Pupillo. SKA aperture array verification system: electromagnetic modeling and beam pattern measurements using a micro UAV. *Experimental Astronomy*, 45(1):1–20, December 2017.

[4] M. G. Labate, R. Braun, P. Dewdney, M. Waterson, and J. Wagg. Ska1-low: Design and scientific objectives. In *2017 XXXIInd General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS)*, pages 1–4, 2017.

[5] D. J. Ludick, R. Maaskant, D. B. Davidson, U. Jakobus, R. Mittra, and D. de Villiers. Efficient analysis of large aperiodic antenna arrays using the domain green's function method. *IEEE Transactions on Antennas and Propagation*, 62(4):1579–1588, 2014.

[6] S. J. Wijnholds, M. Arts, P. Bolli, P. di Ninni, and G. Virone. Using embedded element patterns to improve aperture array calibration. In *2019 International Conference on Electromagnetics in Advanced Applications (ICEAA)*, pages 0437–0442, 2019.