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The Impact of Computational Electromagnetics on the New Generation of Radio Telescopes

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Radio telescope design has long benefitted from advances in design methods in radio frequency and microwave technology in general. This paper addresses the impact of one of the more recent advances, namely the rigorous numerical solution of Maxwell's equations, Computational Electromagnetics [1]. CEM had its genesis in the 1960s; since then, several decades of development have resulted in the availability of powerful commercial codes. Almost all these started life as start-ups, but many are now owned either by multi-national companies in the multi-physics solver business, or by multinational technology conglomerates. Examples of the former are HFSS (ANSYS) and CST (Dassault Systèmes), and of the latter, Siemens (FEKO). The most widely used methods in CEM have been the Method of Moments (MoM), the Finite Difference-Time Domain (FDTD) method (and closely related Finite Integration Technique), the Finite Element Method (FEM), and high-frequency ("optical") methods such as Physical Optics and the Uniform Theory of Diffraction.

For radio astronomy, the MoM has proven especially useful for wire antenna arrays, as widely used in low-frequency telescopes; combined with the Multi-Level Fast Multipole Method acceleration technique, it has also been used for dish design. Methods such as the FDTD and FEM have been widely applied for the design of front-end components. Optical techniques are naturally suited to dish optics. These tools have impacted on the design of the current generation of radio telescopes either recently completed or currently under construction (ASKAP, LOFAR, MeerKAT, SKA), as well as upgrades to existing telescopes (APERTIF and FLAG). They have been applied to reflector design (GRASP and FEKO), PAF and/or RF front-end design (FEKO, CST and HFSS), and the analysis of dipole-like antennas (FEKO, WIPL-D and Galileo). This has allowed careful consideration of performance trade-offs at the design stage, as well as optimization studies of dish/feed design configurations. Accurate "beam models" (radiation patterns in antenna terminology) from CEM simulations permit enhanced calibration techniques to be investigated. For phased array applications, either PAFs or aperture arrays, mutual coupling is of prime concern, and CEM tools can provide rigorous predictions of the impact of mutual coupling. This is most readily done via the use of embedded element patterns, which are the radiation patterns of individual elements with all other elements appropriately terminated. Using these EEPs, the array pattern and several derived system parameters can be obtained.

Such detailed simulation models herald the era of Digital Twins for radio telescopes. An example of their use is in recent work on station configuration for SKA-Low (the low frequency component of the SKA telescope). These digital twins have enabled many studies to be undertaken on station configuration; examples may be found in [2]. Such work, combined with a bespoke array-level simulation tool (OSKAR), has recently permitted a full-array level simulation of the time-delay power spectrum method proposed to find the Epoch of Reinoisation signal, using realistic beam models.

1. D.B. Davidson, "Computational Electromagnetics for RF and Microwave Engineering", 2nd ed, Cambridge University Press, Cambridge, 2011.

2. P. Bolli, D. B. Davidson, M. Bercigli, P. Di Ninni, M. G. Labate, D. Ung, and G. Virone, "Computational electromagnetics for the SKA-Low prototype station AAVS2," *Journal of Astronomical Telescopes, Instruments, and Systems*, vol. 8, no. 1, p. 011017, 2022, doi: 10.1117/1.JATIS.8.1.011017.