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Cross-validation of Antennas for 21 cm Cosmology Experiments with Electromagnetic Simulation Software

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Detection of redshifted 21-cm signal promises to unravel key information about astrophysics of the first galaxies. The 21-cm signal from neutral hydrogen atom from the cosmic dawn and epoch of reionization is expected to lie in the 40-200 MHz. The predicted strength of the cosmic signal is orders of magnitude weaker than the astrophysical foregrounds in this band. However, it is possible to separate these foregrounds owing to their spectral smoothness, unlike the cosmological signal that is spectrally rich. Therefore, the experiments designed to detect the cosmic signal need to have spectrally smooth and frequency-independent characteristics so that they do not introduce any spectral feature of their own. SARAS and PRATUSH are two such experiments, aiming to detect redshifted 21-cm signal from the cosmic dawn and epoch of reionization via stringent control of systematics.

SARAS is a ground-based radiometer, whereas PRATUSH is designed to operate in space, preferably in lunar orbit. Both experiments employ custom-designed monopole antennas as sensors of electromagnetic radiation. The entire assembly for SARAS, which consists of the antenna, reflector and analog receiver floats on water with the help of a raft. PRATUSH antenna will be mounted on a bus, which would house the analog and digital receivers when deployed in space in the simulation.

Antenna is a crucial component in such experiments which is likely to produce frequency-dependent variations in its characteristics. Electromagnetic simulation techniques prove extremely useful to model the antenna properties. However, the accuracy of solvers is of paramount importance given the faint nature of the cosmological signal. In this work, we have evaluated accuracy of different simulation platforms with FEKO and CST. We present criteria for suitability of antenna designs for cosmological studies by developing beam chromaticity factors and maximally smooth functions. We find our metrics to be of reasonable agreement across the platforms, with the appropriate choice of solvers. We further notice a strong dependence of antenna properties on the surrounding media, and differences in the way the electromagnetic solvers handle it. We conclude with highlighting differences from FEKO and CST and argue how such differences should be factored into the model uncertainties in the analysis of precision measurements.

Keywords: 21 cm cosmology, EM simulation software, chromaticity