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Antenna Design for the REACH Global 21cm Experiment

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The Radio Experiment for the Analysis of Cosmic Hydrogen (REACH) is a collaboration between a number of institutions, led by Cambridge and Stellenbosch Universities, to build and operate an instrument to probe the 21 cm Hydrogen signal from the early epochs of the universe. The experiment hopes to achieve a detection of the expected absorption feature in the 21cm line from primordial Hydrogen, due to the formation of the first galaxies, red-shifted to between about 60 and 130 MHz. A first possible detection of this signal, centered at ~ 78 MHz, was made by the EDGES experiment [1], but the resulting form of the absorption feature does not fit current theoretical models. There has been speculation that part of the reason might be to undetected system systematics [2], and therefore the REACH system will be designed and developed with the goal of being relatively simple to characterize.

REACH plans to observe with two different antennas, in overlapping frequency bands, to detect and isolate antenna hardware systematics. A multi-level design approach is followed in the development of the antennas. At the top level the general topology is down-selected, and more detailed designs are performed at lower levels of the most promising set of antenna types. The first level of down-selection is informed by a set of figures-of-merit (FoMs) describing the chromaticity of the antenna beam, as well as the impedance frequency response. A smooth beam is enforced by minimizing the variance of the normalized convolution of the antenna beam, as a function of angle and frequency, with a background sky temperature model as a function of time and angle. Normalization is done by selecting a reference frequency for the beam, so that the resulting function will go to unity for beams that have no frequency variation. For the impedance response, we sought to maximize the frequency bandwidth where reflections into a 50 Ω load is below -10 dB in magnitude, while enforcing the lowest reflection levels occur in the $60-130$ MHz band. Additionally, we prefer antennas with smoother impedance variation over frequency, as these are generally easier to model in computational electromagnetics (CEM) solvers. The point of simple modelling is also considered in the down-selection process. Smaller antennas, with mechanically simpler structures, are generally easier to manufacture and model accurately. Once a few promising candidate antennas have been identified, more complete pipeline analysis are performed on the nominal structures to estimate the likelihood of a detection. Since these analyses are extremely time consuming, they are not used in the direct optimization loop. Results from the pipeline simulations identified the conical log-spiral and horizontal hexagonal dipole antennas as the most promising structures. While the spiral antenna has a broader operating bandwidth than the dipole, it is mechanically and electromagnetically more complex. The substantial difference in radiating mechanisms between these antennas, however, make them an attractive pair for REACH where we will use both antennas to identify and isolate hardware systematics in the analysis pipeline.

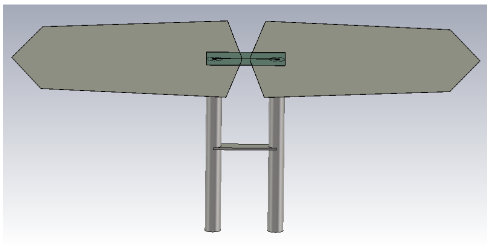

Figure 1. Dipole antenna simulation model.

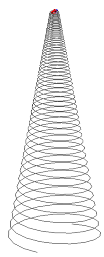

Figure 2. Conical log-spiral antenna simulation model.

References

[1] J. Bowman, A. Rogers, R. Monsalve, *et al.*, "An absorption profile centred at 78 megahertz in the sky-averaged spectrum," *Nature*, **555**, March 2018, pp. 67–70, doi:10.1038/nature25792.

[2] R. Hills, G. Kulkarni, P.D. Meerburg, *et al.*, "Concerns about modelling of the EDGES data," *Nature*, **564**, December 2018, pp. E32–E34, doi:10.1038/s41586-018-0796-5.