The Journal of Open Source Software

LyceanEM: A python package for virtual prototyping of antenna arrays, time and frequency domain channel modelling

Timothy G. Pelham [1]

1 UK Intelligence Community Postdoctoral Research Fellow, University of Bristol, UK

DOI: 10.xxxxxx/draft

Software

- Review
- Repository
- Archive

Editor: Arfon Smith

Reviewers:

- @sasha-seneca
- @craig-warren

Submitted: 02 November 2022
Published: unpublished

Summary

The design of antenna arrays to meet complex requirements in sensors and communications depends upon access to robust tools to access and prototype potential antenna arrays on their intended structures without the need for in depth antenna design. Together with the simulation of wider communications and imaging problems, there is a pressing need for efficient electromagnetics tools capable of scaling from individual antennas to ultra large scale antenna arrays with 1000s of individual elements.

Statement of need

`LyceanEM` is a Python library for modelling electromagnetic propagation for sensors and communications. `Frequency Domain` and `Time Domain` models are included that allow the user to model a wide array of complex problems from antenna array architecture and assess beamforming algorithm performance to channel modelling. The model is built upon a ray tracing approach, allowing for efficient modelling of large, low density spaces.

`LyceanEM` relies upon the `Numba` package to provide `CUDA` acceleration of electromagnetics, calculating antenna and antenna array patterns, scattering and aperture projections. This has been used in a number of scientific publications (Pelham, 2022; Pelham, Freire, et al., 2021; Pelham, Hilton, et al., 2021) and has been used in a tutorial on Antenna Array Design for Complex Platforms at Radar 2022. This capability in an open source package enables exciting research by academics and professional engineers alike.

`LyceanEM` is also being used for ongoing multidisciplinary research combining channel modelling and spatial mapping using computer vision. The flexible and efficient nature of the scattering model allows for exciting exploration of the signal sources in the local environment on low power computing devices.

The benefit of this emphasis on rapid virtual prototyping is to allow the user to quickly establish the potential performance for a desired aperture and frequency, on a desired platform with relatively little design effort. Comparatively, the otherwise excellent commercial solvers like CST, HFSS, FEKO etc can provide excellent simulation fidelity, but require a significant design investment before the simulation can be run. This lack of coverage leads to an uncertain design process for antenna arrays in which the requirements for an antenna array can be specified without reference to the physical limitations imposed by the desired aperture size, location, polarisation, beamforming envelope etc. `LyceanEM` allows these factors to all be predicted rapidly, and the beamforming architecture to be simulated in a realistic way, providing crucial design insight at a low cost.

Usage Examples

While some usage examples are presented here, many more are included in the documentation for `LyceanEM`, which can be found at https://documentation.lyceanem.com/en/latest/.

Virtual Prototyping and Antenna Array Beamforming Research

The initial intended use case for `LyceanEM` was virtual prototyping for antenna arrays and apertures for sensors and communications. As show in Figure 1 & Figure 2. This allows for antenna array patterns to be predicted extremely quickly compared to the time required for antenna design, and simulation on the platform of interest. This enables research into novel conformal antenna array configurations, and modelling of the performance of radar antenna arrays for autonomous vehicles research. This is the only package offering this capability from such a limited information set. This process allows the researcher or engineer to assess the maximum achievable beamforming envelope for the aperture (Figure 3), then predict the antenna array pattern with functions supporting beamsteering to points of interest to generate an accurate prediction of the beamformed coverage (Figure 4). This has been demonstrated in published research for both antenna arrays (Pelham, Freire, et al., 2021), and for reflector antennas (Pelham, 2022). The antenna array simulation allows the researcher to define the array with any combination of polarisation and excitation functions, providing a powerful tool for antenna array research.

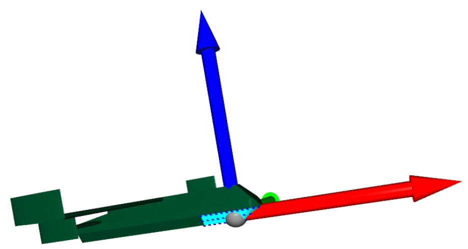

Figure 1: Flexible Modelling and Visualisation of Conformal Antenna Array Geometry.

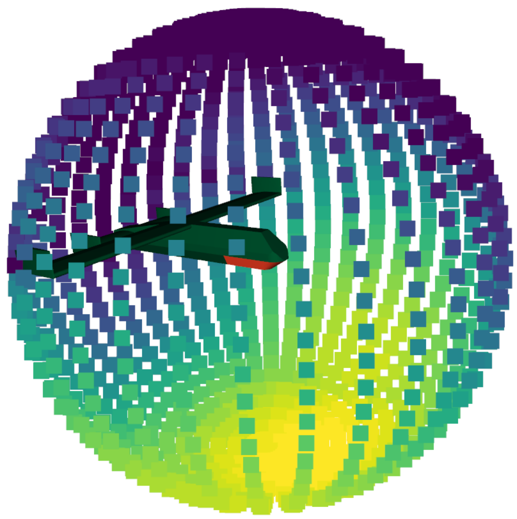

Figure 2: Flexible Modelling and Visualisation of Conformal Antenna Array Performance.

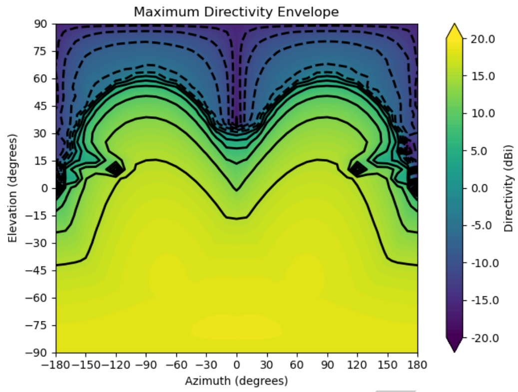

Figure 3: Maximum Achievable Beamforming Envelope via Aperture Projection.

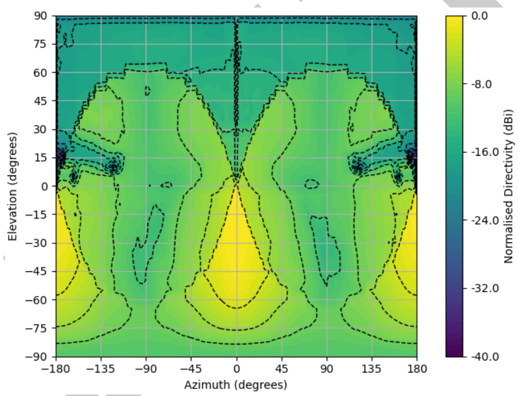

Figure 4: Beamformed Antenna Array Achieved Directivity Map vs Array Simulation.

In addition to modelling of antenna arrays with conventional polarisation and propagation modes, `LyceanEM` supports the modelling and analysis of novel propagation models such as Orbital Angular Momentum states (Allen et al., 2019) for communications links, and allowed the prediction of the supportable OAM modes of an aperture, and the fourier analysis of the modal spectrum produced both by `LyceanEM` and the measured antenna patterns.

Frequency & Time Domain Channel Modelling

`LyceanEM` can also be used as a more general electromagnetic model, allowing the definition and simulation of complex channel models. In a published example, the Frequency domain model predicted the scattering parameters produced when illuminating a rotating metal plate with a horn antenna with a root mean square (RMS) error of -69dB between the predicted scattering parameters and the measured data. (Pelham, Hilton, et al., 2021). This setup is shown in Figure 5 with the scattering plate at an angle of 45 degrees, and the transmitting and receiving horn antennas shown.

The Journal of Open Source Software

Figure 5: Scattering Scenario for 26GHz channel modelling with scattering plate orientated at 45 degrees from the transmitting antenna.

The resultant scattering with variation of normalised scattering angle (0 degrees when plate is 45 degrees offset from both transmitter and receiver) shows the comparison between the measured scattering at 26GHz, and that predicted by `LyceanEM` in Figure 6.

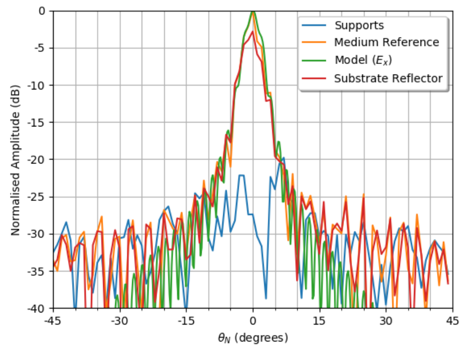

Figure 6: Comparison of scattering parameters against normalised scattering angle.

The Time domain model also produces comparable results, as shown in Figure 7, comparing the fast fourier transform of the time domain response (labelled 24GHz), and the frequency domain response (labelled FD) with the measurement.

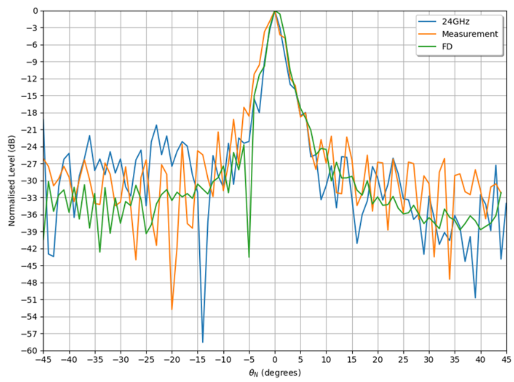

Figure 7: Comparison of scattering parameters against normalised scattering angle from both the time and frequency domain models.

Generation of Training Datasets for Machine Learning

In addition to the initial uses, `LyceanEM` allows the user to generate datasets for use in Machine Learning. This is of specific interest for channel models from spatial mapping by computer vision, allowing `LyceanEM` to predict the scattering characteristics of the local environment from computer vision or LIDAR based spatial mapping. This allows the creation of Generative Adversarial Networks for spatial multiplexing.

References

Allen, B., Pelham, T., Wu, Y., Drysdale, T., Isakov, D., Gamlath, C., Stevens, C. J., Hilton, G., Beach, M. A., & Grant, P. S. (2019). Experimental evaluation of 3D printed spiral phase plates for enabling an orbital angular momentum multiplexed radio system. *Royal Society Open Science*, *6*(12), 191419. https://doi.org/10.1098/rsos.191419

Pelham, T. G. (2022). Rapid antenna and array analysis for virtual prototyping. *IET Conference Proceedings*, 278–282(4). https://doi.org/10.1049/icp.2022.2330

Pelham, T. G., Freire, A. L., Hilton, G., & Beach, M. (2021). Polarimetric Scattering with Discrete Raytracing for OTA Analysis. *15th European Conference on Antennas and Propagation, EuCAP 2021*, 1–4. https://doi.org/10.23919/EuCAP51087.2021.9410981

Pelham, T. G., Hilton, G., Mellios, E., & Lewis, R. (2021). Conformal Antenna Array Design Using Aperture Synthesis and On-Platform Modeling. *IEEE Access*, *9*, 60880–60890. https://doi.org/10.1109/ACCESS.2021.3074317