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Article

Broadband RF Phased Array Design with MEEP: A 3D-Printed Open-Source RF Horn in the multi-GHz Bandwidth

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Abstract

Radio-frequency (RF) antenna design traditionally proceeds in four phases. First, the RF antenna design performance is modeled with expensive and proprietary computational electromagnetism (CEM) software. Second, the design is fabricated using expensive metal machine tools. Third, the design performance is characterized using benchtop RF measurement tools. Fourth, if the fabricated design does not match specifications from CEM, the design is modified and the process is repeated. The fourth phase includes machine learning algorithms to optimize the design. We have developed an open-source alternative process that utilizes the MIT Electromagnetic Equation Propagator (MEEP) CEM package for design and simulation, and 3D printing with conductive filament for fabrication. Using our open process, we created a broadband RF horn antenna. To characterize our RF horn antenna, we measured the E-plane and H-plane radiation patterns, the VSWR, and the cross-polarization ratios. The results match our CEM calculations, indicating the RF horn performs just like a linearly polarized, broadband RF horn antenna. We observe optimal performance in the [5.5-6] GHz bandwidth, exceeding the limits of our 6 GHz instrumentation. The CEM-simulated bandwidth is predicted to be larger.

Keywords: Computational Electromagnetism (CEM), Additive Manufacturing, MEEP, RF Engineering, Open-Source Design

1. Introduction

The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance. The current state of the research field should be reviewed carefully and key publications cited. Please highlight controversial and diverging hypotheses when necessary. Finally, briefly mention the main aim of the work and highlight the principal conclusions. As far as possible, please keep the introduction comprehensible to scientists outside your particular field of research. Citing a journal paper [1]. Now citing a book reference or other reference types . Please use the command for the following MDPI journals, which use author–date citation: Administrative Sciences, Arts, Behavioral Sciences, Businesses, Econometrics, Economies, Education Sciences, European Journal of Investigation in Health, Psychology and Education, Games, Genealogy, Histories, Humanities, Humans, IJFS, Journal of Intelligence, Journalism and Media, JRFM, Languages, Laws, Literature, Psychology International, Publications, Religions, Risks, Social Sciences, Tourism and Hospitality, Youth.

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This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

3.1. Subsection

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Bulleted lists look like this:

- First bullet;
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Table 1. This is a table caption. Tables should be placed in the main text near to the first time they are cited.

Title 1	Title 2	Title 3
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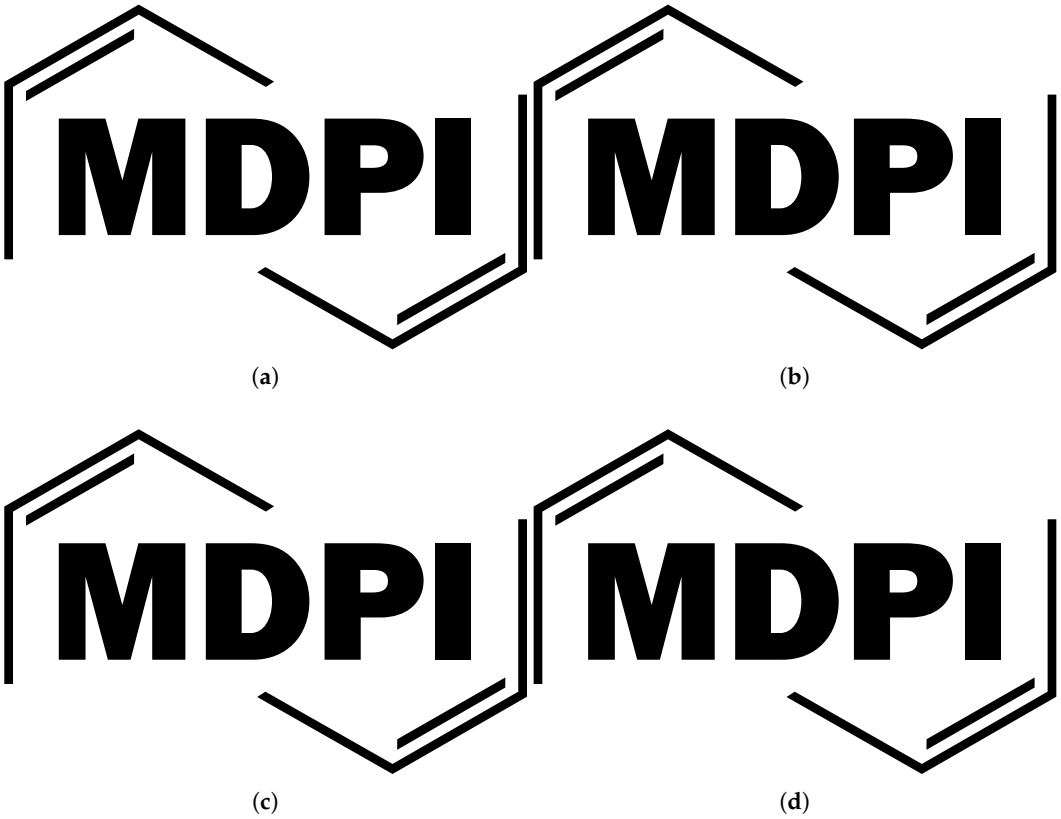

(**a**) (**b**)

(**c**) (**d**)

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Title 1	Title 2	Title 3	Title 4
Entry 1 *	Data	Data	Data
	Data	Data	Data
	Data	Data	Data
Entry 2	Data	Data	Data
	Data	Data	Data
	Data	Data	Data

* Tables may have a footer.

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This is the example 1 of equation:

$$a = 1, \tag{1}$$

the text following an equation need not be a new paragraph. Please punctuate equations as regular text.

This is the example 2 of equation:

$$a = b + c + d + e + f + g + h + i + j + k + l + m + n + o + p + q + r + s + t + u + v + w + x + y + z \tag{2}$$

Please punctuate equations as regular text. Theorem-type environments (including propositions, lemmas, corollaries etc.) can be formatted as follows:

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The text continues here. Proofs must be formatted as follows:

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Abbreviations

The following abbreviations are used in this manuscript:

MDPI	Multidisciplinary Digital Publishing Institute
DOAJ	Directory of open access journals

Appendix A

Appendix A.1

The appendix is an optional section that can contain details and data supplemental to the main text—for example, explanations of experimental details that would disrupt the flow of the main text but nonetheless remain crucial to understanding and reproducing the research shown; figures of replicates for experiments of which representative data are shown in the main text can be added here if brief, or as Supplementary Data. Mathematical proofs of results not central to the paper can be added as an appendix.

Table A1. This is a table caption.

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Entry 1	Data	Data
Entry 2	Data	Data

Appendix B

All appendix sections must be cited in the main text. In the appendices, Figures, Tables, etc. should be labeled, starting with "A"—e.g., Figure A1, Figure A2, etc.

References

1. Vieregg, A.; Bechtol, K.; Romero-Wolf, A. A technique for detection of PeV neutrinos using a phased radio array. *Journal of Cosmology and Astroparticle Physics* **2016**, *2016*, 005. https://doi.org/10.1088/1475-7516/2016/02/005.