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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 three phases. First, the design performance is modeled with expensive and proprietary computational electromagnetism (CEM) software. Second, the design is fabricated using expensive metal machine tools. Third, the fabricated design is characterized using benchtop RF measurement tools. The traditional process can include machine learning algorithms for optimization. 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. Following this process, we designed and fabricated an RF horn antenna. To characterize our design, we show that the E-plane and H-plane radiation patterns, the VSWR, and the cross-polarization ratios match our CEM calculations. These results indicate that our design performs just like a linearly polarized, broadband RF horn antenna in the [5.5-6] GHz bandwidth. Because the bandwidth of our instrumenation is limited to 6 GHz, and because our CEM calculations predict good performance above 6 GHz, we conclude the bandwidth of our printed design extends above 6 GHz. Future work will include expanding to lower bandwidth by fabricating larger RF horns, and fabricating a broadband RF phased array.

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

1. Introduction

Broadband RF antennas are ubiquitous tools within scientific instrumentation and communication applications. Traditionally, RF antennas are designed using expensive, proprietary software packages, like XFDTD and HFSS [1,2]. Designs are fabricated by cutting and shaping metal with precision machine tools. This technique is sometimes called *subtractive manufacturing*, as opposed to *additive manufacturing*. Compared to *additive manufacturing* techniques, subtractive manufacturing can be costly [3,4]. Open-source additive manufacturing would boost cost efficiency in RF antenna design and fabrication.

Previously, J. C. Hanson (2021) demonstrated that the MEEP software package may be used as an RF antenna design tool [5]. MEEP operates via the FDTD algorithm for Maxwell's Equations on a Yee lattice [6]. Specifically, the author of [5] produced RF phased array designs in two and three dimensions using MEEP code. The designs included broadband RF horn elements in the [0.5-5] GHz bandwidth. Further, J. C. Hanson demonstrated that open-source CAD software may be used to create complex designs that can be 3D-printed [7].

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3.1. Subsection

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Bulleted lists look like this:

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All figures and tables should be cited in the main text as Figure 1, Table 1, etc.

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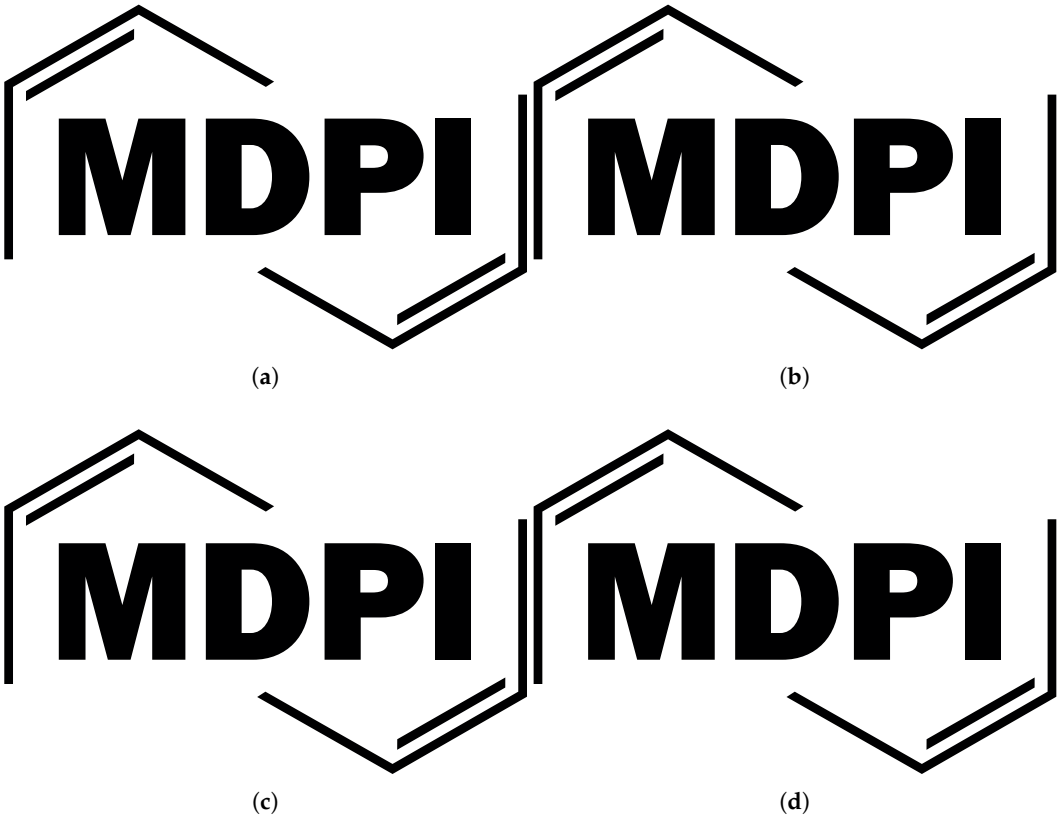

(**a**) (**b**)

(**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:

Theorem 1. *Example text of a theorem.*

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

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Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

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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.

Title 1	Title 2	Title 3
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.

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