A 3D Printed Fragmented Aperture Antenna

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***Abstract*— This document describes a method of generating, optimizing, and fabricating a three-dimensional (3D) fragmented aperture antenna. The 3D design was able to achieve right-hand circular polarization with a single unbalanced feed. Measured results are shown to confirm the designed performance.**

***Keywords*—Antenna, 3D Printing, 3D Printed Antenna**

I. Introduction

Many current design approaches for designing and fabricating highly customized broadband antennas rely on 2D metal patterning on a substrate using traditional Printed Circuit Board (PCB) fabrication techniques. One such example is the Fragmented Aperture [1]. Improvements to 3D printers allow some of these 2D design approaches to be expanded into 3D. This paper demonstrates a 3D fragmentation technique and shows an example design that uses an unbalanced feed to radiate circularly polarized energy over a 3:1 bandwidth in a compact space.

II. Technical Approach

A. Designing for Printability

This effort expanded GTRI's current fragmentation techniques to three dimensions. Creating a 3D fragmented antenna requires a template of voxels, rectangular prisms of predetermined size, covering the region to be optimized. The basic building blocks were structured to avoid a design with voxels connected only by a single edge or corner to prevent non-manufacturable structures and model accuracy issues. The technique used for preventing corner touches in the 2D template code was a brick-laying approach that was extended to 3D templates. To prevent the corner-touch problem in three-dimensions, a similar brick-laying approach was used. To make this approach easily to visualize, Figure 1 shows an example structure using this approach with every-other brick turned on.

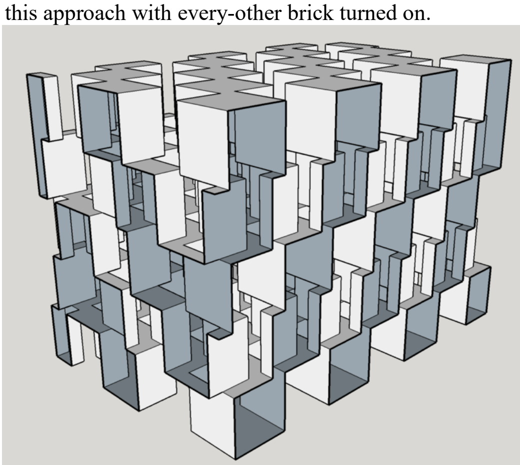

Figure 1. Staggered Layers to Ensure Voxel Overlap.

B Gridding for the Desired Space

A MATLAB function was developed to create the basic brick layout for a number of basic shapes using the bricklaying approach shown previously. For the design presented here, a cylindrical volume was used. Figure 2 shows this initial layout. Partial bricks, highlighted in cyan, were removed from the optimization to prevent hanging partial bricks that could result in non-manufacturable structures. In this figure, the bricks color is alternated between gray and orange to make them visually differentiable.

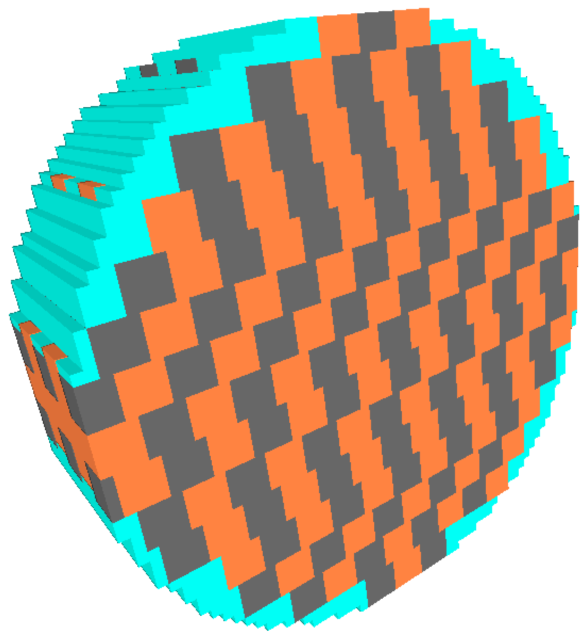

Figure 2. Cylindrical Brick Layout.

C. Optimizing the Antenna

The size of the structure was constrained to a diameter of 43 mm and a height of 15 mm. The size of each individual brick was 2.5 mm on a side. Each parameter in our solution space represented the presence or absence of metal within a specific brick. The optimization scheme used a multi-objective Genetic Algorithm (GA) to search through the solution space with 2^{801} possible antenna configurations. The design efficiency of this approach has been demonstrated previously [2]. The fitness function used by the GA in this case weighted both the VSWR and the broadside RHCP gain from 6GHz – 18GHz. Additionally, since this antenna was designed for 3D printing from a single material, only pixels connected to the feed or to the ground may be metal. Any floating pieces of metal were removed during the optimization process. This was done by mapping each cell of the FDTD model into an adjacency matrix representing the DC connections between metal Yee cells and their immediately touching neighbors. By a property of adjacency matrices, raising the matrix to the k^{th} power produces a matrix that tabulates the number of paths of length k between nodes. Raising the adjacency matrix to the power equal to the number of bricks gives the number of paths through the structure from a given starting point. Any disconnected bricks would have resulting matrix entries far lower than in a fully connected structure, so those specific bricks were removed from simulation [3]. The final design is shown in Figure 3.

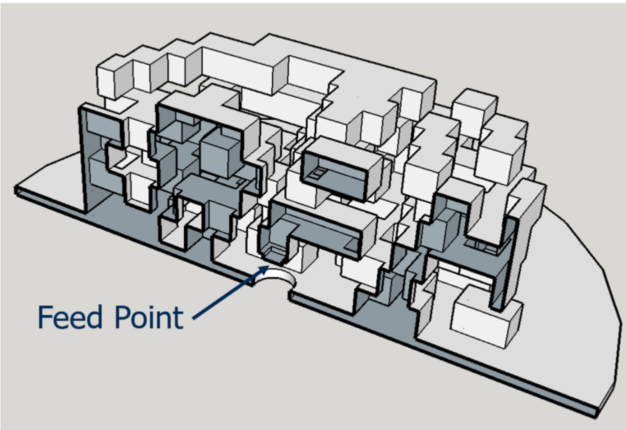

Figure 3. Cross-Section of the Final Design for the 3D Printed Antenna.

III. Fabrication

The initial plan for antenna fabrication was to have the antenna printed directly out of metal using a process known as Direct Metal Laser Sintering (DMLS). Unfortunately, none of the vendors we contacted were able to print a structure of this complexity using the DMLS technique, citing concerns that they wouldn't be able to remove all of the remaining metal powder from the voids after printing. Several vendors said they could print it out of plastic using a Laser Sintering technique, and ProtoLabs [4] was willing to print the design and have it plated by one of their partners, RepliForm Inc [5]. The metal used for the plating was nickel. One of the 3D printed and plated test articles is shown in Figure .

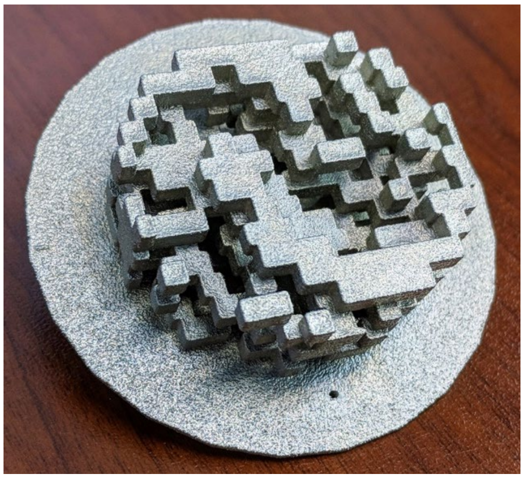

Figure 4. One of the 3D Printed and Plated Test Articles.

IV. Results

Measurements of the RHCP broadside gain were performed in an anechoic chamber at GTRI's facilities in Atlanta, GA. Three test articles were fabricated. These test articles were labeled 'A', 'B', and 'C', and then all three articles were measured. Calibration was performed according to the gain-substitution method using a pair of Satimo QH2000 quad-ridge horns. Vertical and horizontal polarizations were measured independently and circular polarization synthesized from these measurements. The measured and modeled gain performance for this antenna are shown in Figure 5.

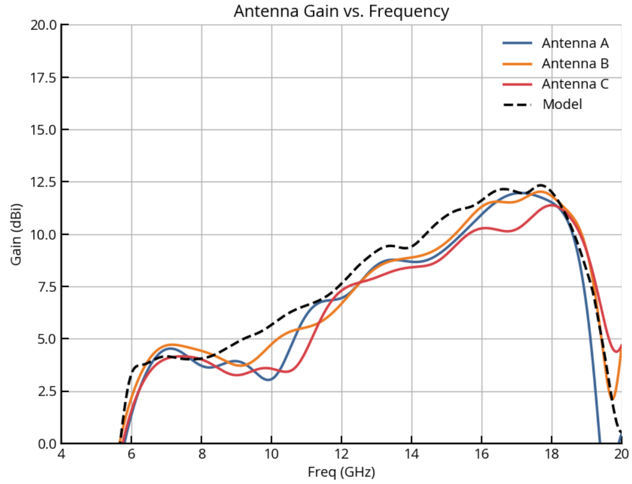

Figure 5. Measured and Modeled Antenna Gain vs Frequency for the 3D Printed Fragmented Aperture Antenna.

V. Conclusions

A method for designing a 3D printed antenna based on Fragmented Aperture technology was presented. The resulting design was fabricated and shows excellent agreement with the modeled performance. Right hand circularly polarized gain was achieved over a 3:1 bandwidth using an unbalanced feed.

Acknowledgment

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References

[1] J.G. Maloney, M.P. Kesler, P.H. Harms, T.L. Fountain, and G.S. Smith, The Fragmented Aperture Antenna: FDTD Analysis and Measurement, Millennium Conference on Antennas and Propagation (AP 2000), Davos, Switzerland, 4 pages, April 2000.

[2] Maloney, J. G., Lee, R. T., & Landgren, D. W. (2013, July). Genetic algorithms for fragmented aperture antennas: A complete evaluation of a 24-bit design. In Radio Science Meeting (Joint with AP-S Symposium), 2013 USNC-URSI (pp. 115-115). IEEE.

[3] Bondy, J. A., & Murty, U. S. R., Graph Theory With Applications, New York: Elsevier, p. 42, 1976.

[4] www.protolabs.com

[5] www.repliforminc.com