TECHNICAL REPORT RDMR-WD-17-30

THREE-DIMENSIONAL (3-D) PRINTED SIERPINSKI PATCH ANTENNA

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13. ABSTRACT *(Maximum 200 Words)*

This report details the design, simulation, print, and laboratory evaluation of a Sierpinski patch antenna operating at Wi-Fi frequencies, manufactured with Three Dimensional (3-D) printing techniques.

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I. INTRODUCTION

The United States (U.S.) Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) Weapons Development and Integration (WDI) Directorate has a Fiscal Year (FY) 2016 Science and Technology (S&T) program known as PRIntable Materials With Embedded Electronics (PRIME2). PRIME2 will integrate Radio Frequency (RF) and electronics into additive manufacturing processes to reduce size, weight, and overall cost of these components and subsystems. This program will advance the state of the art in Printable Electronics and deliver a materials database, process development, modeling, and simulation of Three-Dimensional (3-D) printed objects with embedded conductive elements, passive prototypes, and RF prototypes. PRIME2 will create a new fabrication capability (applied to electronics and RF technology areas), weight reduction, higher reliability, and on-demand (local and immediate) spare components in the field.

Additive manufacturing is a rapidly maturing process by which digital 3-D design data are used to build up components in layers by depositing materials or through the melting and sintering of (powdered) materials to create solid structures. These materials can be conductive (metal) or nonconductive (polymer) and have complex material properties that are dependent on print parameters.

In the past 5 years, additive manufacturing has quickly gained adoption and acceptance as a valuable manufacturing technology. There are many different types of printers, including fused-filament deposition, stereolithography, and laser sintering. The National Aeronautics and Space Administration (NASA) has a fused filament deposition machine on the International Space Station (ISS). As this is a rapidly maturing technology, the number of printers and the expertise in this field is also rapidly expanding. The 4-year hiring trends in the field of additive manufacturing are shown in Figure 1. The number of patents issued worldwide in the field of additive manufacturing is shown in Figure 2. Note that the hiring trends correspond to the last few years when the number of patents bloomed in this area.

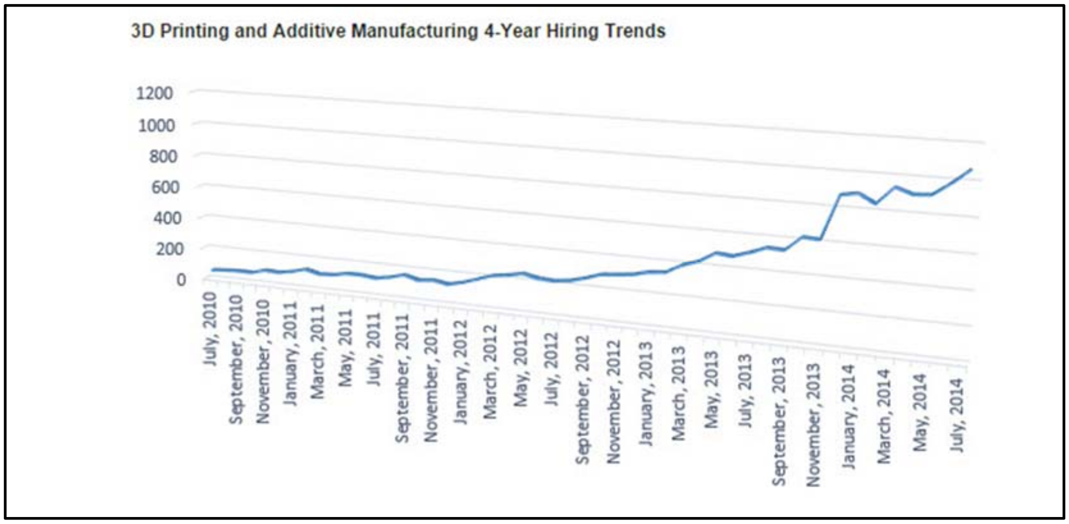


Figure 1. Additive Manufacturing 4-Year Hiring Trends From 2010 to 2014

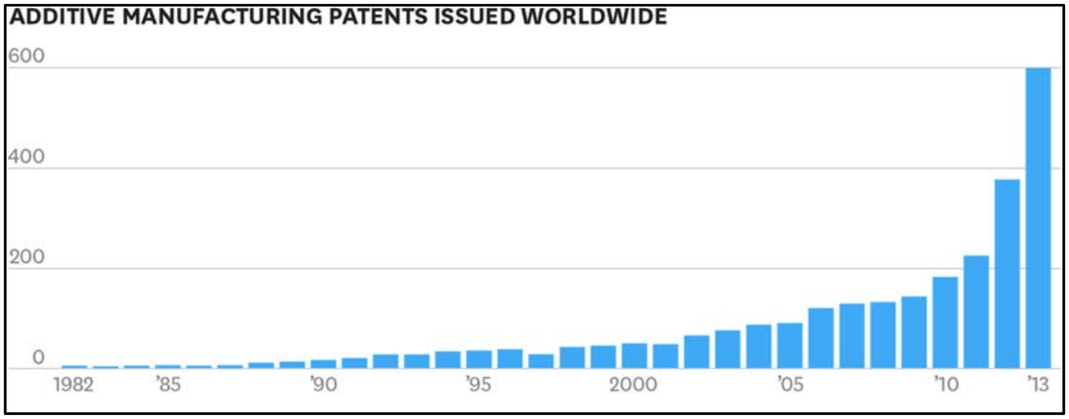


Figure 2. Additive Manufacturing Patents Issued Worldwide From 1982 to 2013

Traditionally, electronic and RF components are assembled piecemeal and are not part of the additive manufacturing process. PRIME2 seeks to exploit the opportunity to integrate electronic components during the mechanical additive manufacturing process. PRIME2 is developing enabling technologies to print in one step an entire printed wiring board with embedded passive components and integrated RF structures. Connectors could be printed to achieve commercially available connectivity in a design specific to the available working space.

Additive manufacturing brings a new capability that can be explored across all technology areas for benefits and use. The benefits can be many and varied, resulting in components that are not achievable utilizing traditional subtractive machining methods, lower weight components, low cost, local and immediate prototyping, and component creation. One of the most important aspects of the PRIME2 program is the creation of processes to achieve a means by which these modules, components, or subsystems are printed with different conductivities or embedded elements. Throughout process development, PRIME2 will explore the limitations and capabilities of additive manufacturing as it applies to military applications, specifically for AMRDEC. PRIME2 is developing pervasive technology that is useful across multiple systems in support of the Warfighter.

Through additive manufacturing, it may be possible to eventually print in one step an entire printed wiring board with embedded passive components and integrated RF structures. PRIME2 is working to achieve this and document the processes that make it possible.

PRIME2 has documented several material properties for components created using the additive manufacturing method. In addition, other prototype structures have been manufactured and evaluated. These reports are found in References 1 through 4.

II. BACKGROUND

The PRIME2 program metrics included the design and manufacture of printable electronic components and RF structures. PRIME2 participated in the AMRDEC/NASA/University of Alabama in Huntsville (UAH) Additive Manufacturing IPT (Integrated Product Team) and also with the University of Mississippi (UM) through a Cooperative Research and Development Agreement (CRADA). Through this IPT and CRADA, several areas of collaboration and opportunities were discovered. This report is focused on the design, simulation, fabrication, and testing of a Sierpinski patch antenna created using additive manufacturing techniques. The antenna was designed and simulated by UM. The antenna was printed at EngeniusMicro under the PRIME2 Science and Technology (S&T) program. The antenna was evaluated by AMRDEC and UM.

III. DESIGN OF EXPERIMENT

A. Sierpinski Patch Antenna

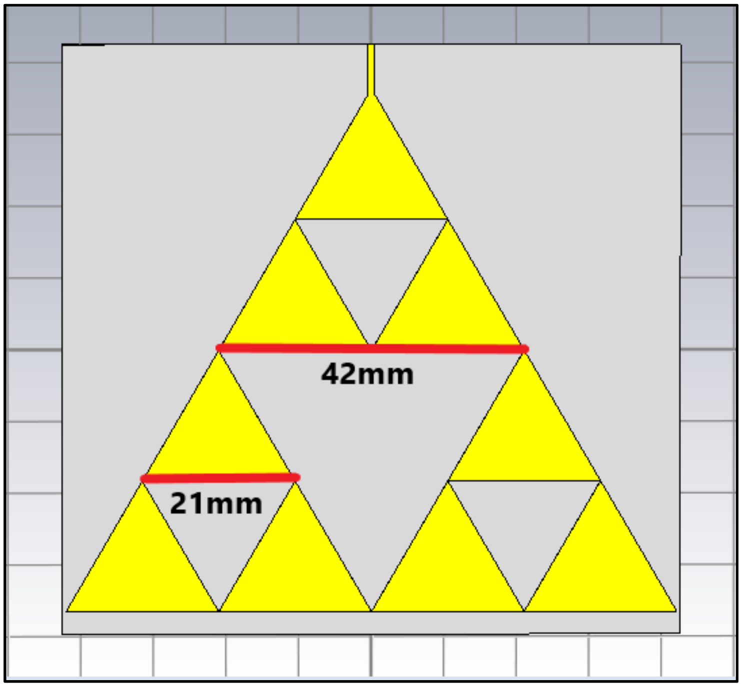
The Sierpinski antenna is based on the Sierpinski triangle, which is a fractal antenna with an overall shape of an equilateral triangle that is divided into smaller equilateral triangles. When this design is used in antenna theory, the antenna is compared to the well-known bow-tie antenna. In-depth information on the Sierpinski antenna can be found in Reference 5.

B. Computer Simulated Technology Simulation

The antenna was designed and simulated using Computer Simulated Technology (CST). The following conditions were set for the simulation:

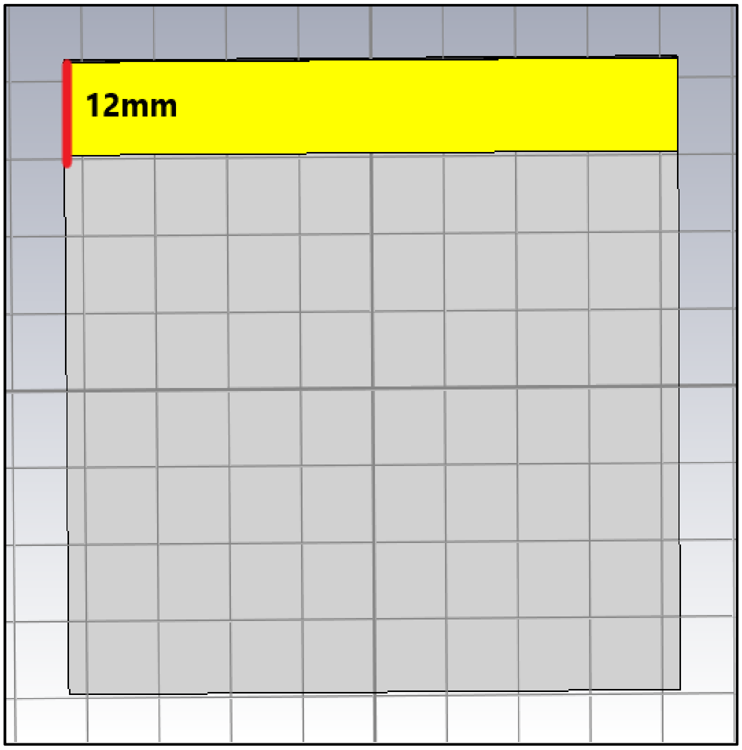
- Dielectric Constant: 3.41
- Substrate Dimensions: 82-by-85-by-1.575 millimeters (mm)
- Transmission Line Width: 1.25 mm

The model design view is shown in Figure 3.



(a) Top View

Figure 3. Antenna Design



(b) Bottom View

Figure 3. Antenna Design (Concluded)

Following the simulation efforts, the resonating frequencies for the antenna occurred at 2.413 and 5.4735 gigahertz (GHz), as shown in Figure 4.

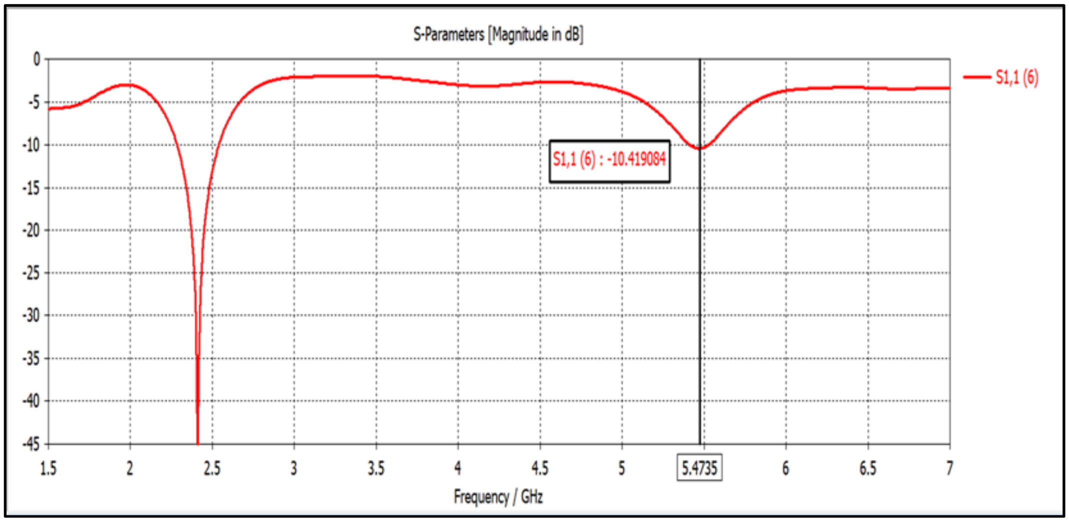


Figure 4. Simulation Results

IV. FABRICATION OF ANTENNA

The antenna was printed using a multi-material additive manufacturing tool, the Voxel8 3-D printer. Using a Polylactic Acid (PLA) thermoplastic material, the printer utilizes 80-percent (%) silver-fill conductive ink and employs a custom AMRDEC nozzle. The 6-by-6-by-5 inch print volume is shown in Figure 5.

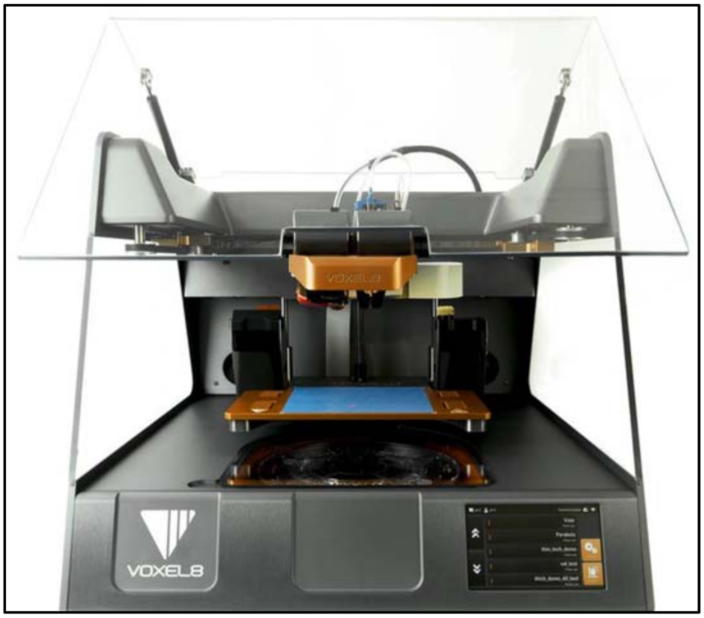


Figure 5. Voxel8 3-D Printer

A design file was provided by UM, which represented the simulated design. The printed Sierpinski patch antenna is shown in Figure 6. The copper ground plane was attached to the bottom of the antenna by hand.

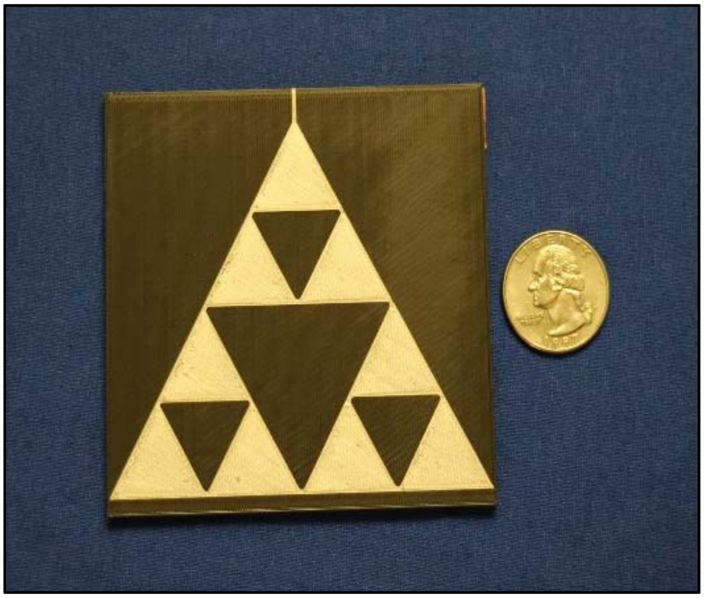


Figure 6. Sierpinski Patch Antenna Printed on Voxel8

V. LABORATORY EVALUATION

AMRDEC and UM conducted laboratory evaluations of the antenna, and the desired results were not achieved in the first print. There is a small resonance at approximately 2.5 GHz; however, this could be a coincidence. There is also resonance at approximately 5.4 and 7 GHz. The return loss was -6 and -28 dB, respectively. Though these were not the desired results, this antenna was matched for a resonance at 7 GHz with a bandwidth from approximately 6.4 to 11 GHz. Note that the SubMiniature Version A (SMA) connector for this antenna was attached by hand and soldering caused the antenna substrate (PLA) to warp. The laboratory results are shown in Figure 7.

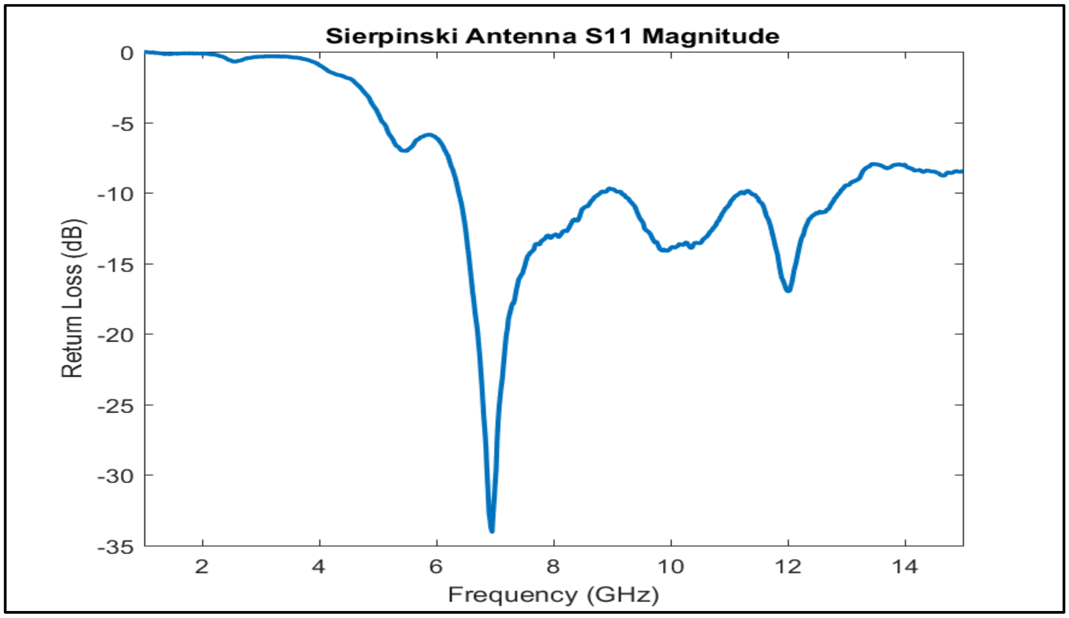


Figure 7. Laboratory Evaluation of Printed Antenna

VI. CONCLUSION

The antenna did not achieve the desired results, and a second antenna design has been supplied and printed. This antenna was delivered by hand to UM immediately upon printing and not evaluated by AMRDEC. The results were unavailable and could not be included in this report.

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

%	percent
3D, 3-D	Three-Dimensional
AMRDEC	Aviation and Missile Research, Development, and Engineering Center
CRADA	Cooperative Research and Development Agreement
CST	Computer Simulated Technology
dB	decibel
FY	Fiscal Year
GHz	gigahertz
IPT	Integrated Product Team
ISS	International Space Station
mm	millimeter
NASA	National Aeronautics and Space Administration
PLA	Polylactic Acid
PRIME2	PRIntable Materials with Embedded Electronics
RF	Radio Frequency
S&T	Science and Technology
SMA	SubMiniature Version A
UAH	University of Alabama in Huntsville
UM	University of Mississippi
U.S.	United States
WDI	Weapons Development and Integration