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Akila S. Udage, Hunter Heath, Nadarajah Narendran, "Impact of ink deposition and trace path variations on 3D-printed antenna performance," Proc. SPIE 12670, 3D Printing for Lighting, 126700D (29 September 2023); doi: 10.1117/12.2678352

Event: SPIE Optical Engineering + Applications, 2023, San Diego, California, United States

Impact of ink deposition and trace path variations on 3D-printed antenna performance

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ABSTRACT

The application of 3D printing in the lighting industry has the promise to transform the production of custom luminaires on demand. The connected lighting system trend in the lighting industry has created the need for custom antenna design and production to improve reliable data transfer. Antenna design accuracy is crucial to the functional efficiency of wireless data communication that could be integrated into lighting products with 3D printing. The trace paths of most paste and ink deposition technologies determine the physical dimensions of the material deposited on the substrate, which can affect the performance of the antenna. A laboratory experiment study was conducted to investigate the relationship between antenna pattern and its dimension and resonance frequency in patch antenna. The study examined the variations in trace paths resulting in antenna dimension variation and compared them with theoretical model predictions of the same antenna design. One of the primary observations in this study was the 3D-printed antennas did not resonate precisely at the modeled 2.4GHz frequency, as predicted by CST Studio Suite®. Further investigation showed that the resonance frequencies were at 2.355 Hz for hatched fill pattern antennas and 2.385 Hz for concentric fill antennas, resulting in 0.045 Hz and 0.015 Hz deviation compared to the designed value of 2.4 GHz.

Keywords: printed electronics, 3D printing, paste deposition, patch antenna, antenna modeling

1. INTRODUCTION

In recent years, the lighting industry has begun to explore 3D printing of light fixtures that promise reasonable cost custom products that can be manufactured on-demand.[1] The integration of electrical and electronic components into lighting devices stands out as one of the possibilities.[2] This not only presents new opportunities for innovation but also holds the promise of ushering in a new era of lighting solutions uniquely tailored to the demands of the modern world.

The escalating demand for connected systems has magnified the importance of efficient and reliable communication devices along with antennas within lighting products. 3D printing is a potential method for creating novel antennas for this application. To use 3D-printed antennas in this application for reliable data transfer, the accuracy of antenna printing is important. In this regard, the ink deposition accuracy for different antenna patterns and its impact on antenna performance is very important. A previous study mentioned that 3D printing antennas onto light fixtures can significantly augment communication performance.[3] This study underscored the need for additional research to uncover the subtleties of how 3D printing process parameters influence antenna performance.[3]

Prior research delved into the realm of 3D printing techniques for fabricating electrical traces.[4,5] These investigations have ventured into diverse materials[6] and patterns,[7] leveraging ink-jet printing to create intricate electrical pathways. Within this body of work, however, a conspicuous research gap exists: a comprehensive understanding of how ink deposition and variations in trace paths impact the frequency and amplitude of the 3D-printed antennas remains elusive. Therefore, the objective of this study was to unravel the relationship between 3D printing parameters, specifically ink deposition trace path variations, and their influence on the performance of 3D-printed antennas.

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3D Printing for Lighting, edited by Nadarajah Narendran, Govi Rao,
Proc. of SPIE Vol. 12670, 126700D · © 2023 SPIE
0277-786X · doi: 10.1117/12.2678352

2. METHODOLOGY

The methodology employed to investigate the impact of ink deposition and trace path variations on 3D-printed antenna performance involves patch antenna modeling, 3D printing, and data collection and analysis.

2.1 Antenna Design and Modeling

A micro-strip patch antenna was designed based on fundamental principles of patch antenna theory.[8] Next, its performance was optimized utilizing CST Studio Suite®, a commercial antenna design software.[9] The objective was to design an antenna with minimal return loss in proximity to the 2.4 GHz frequency, commonly used for wireless communication applications, namely, BLE (Bluetooth Low Energy) technology. This modeled antenna served as a reference point for our subsequent practical experiments. The antenna design and the corresponding dimensions are shown in Figure 1.

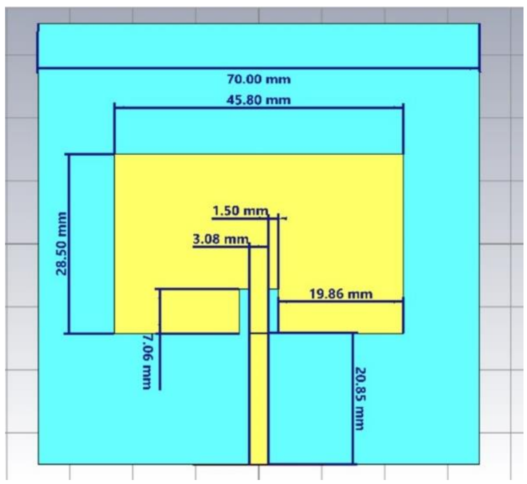
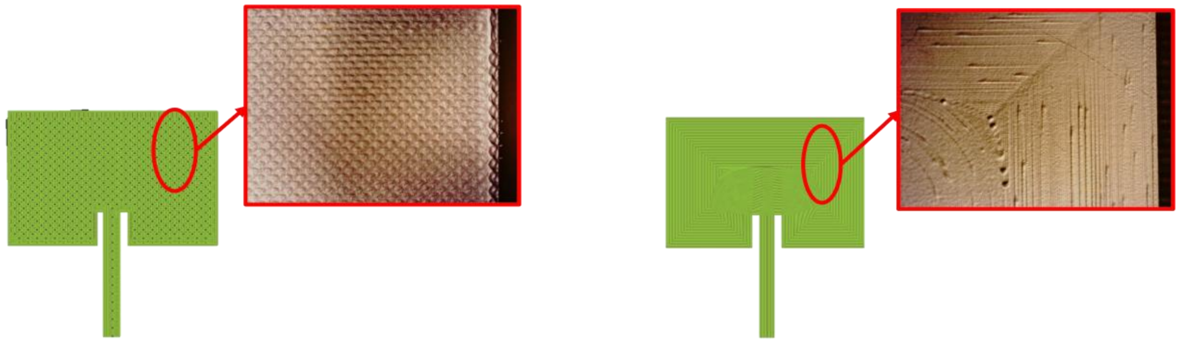


Figure 1: Antenna dimensions

2.2 3D Printing of Antennas

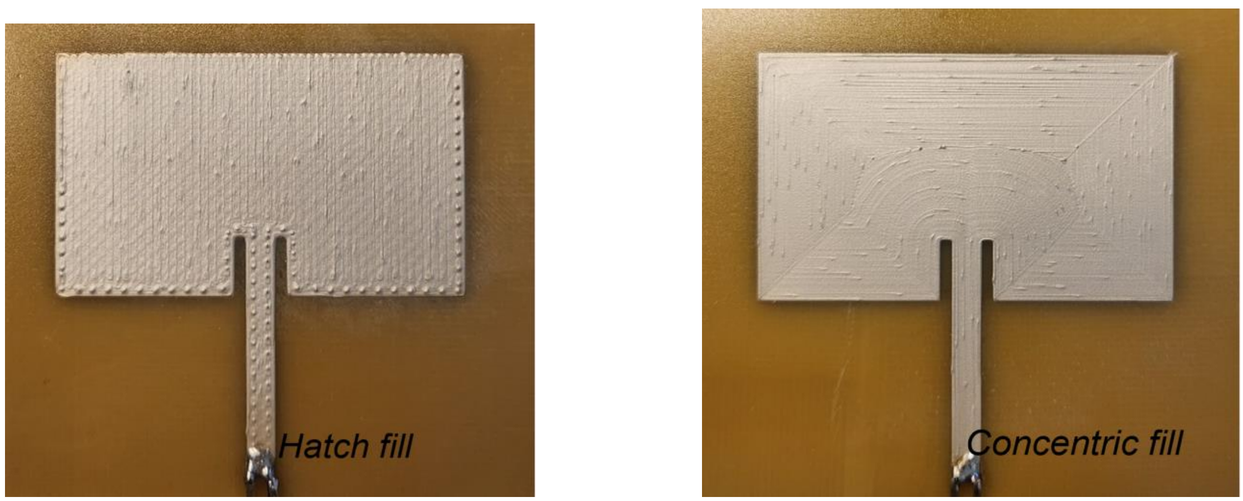
Using the dimensions derived from the CST Studio Suite® analyses, patch antennas were fabricated using two trace paths: concentric fill and hatched fill. These trace paths were chosen to explore the variances in ink deposition patterns and their potential effects on antenna performance. Conductive antenna patches were printed using Voltera Perky Pegasus and conductive ink on FR 4 laminated substrates with a copper ground plate affixed to one side. The method focused on exploring variations in trace paths, shown in Figure 2, particularly Hatched fill (HF), (Fig. 2a) and Concentric Fill (CF) (Fig. 2b). These figures show the patch antenna surface, thickness, and unevenness caused by the printing process. A comprehensive examination of how these trace path intricacies influenced the performance of 3D-printed antennas was carried out. Figure 3 reveals imperfections in our printed antennas, characterized by lumps or irregularities. These imperfections are a result of excessive extrusions at the point of nozzle path reversals and overlap in ink deposition during the printing process. In an ideal antenna, such irregularities would not be present, and achieving a uniform and smooth surface would be a goal for future improvements in the printing process.



(a) Hatched fill ink deposition pattern

(b) Concentric fill ink deposition pattern

Figure 2: Ink deposition patterns



(a) Printed antenna: Hatched fill (HF) pattern

(b) Printed antenna: Concentric fill (CF) pattern

Figure 3: 3D-printed antennas

2.3 Data Collection and Analysis

The schematic of the experiment setup used for collecting the data is shown in Figure 4. To collect empirical data and analyze the minimum return loss (resonance frequency) of the printed antennas, a measurement setup was created. The antenna patches and ground planes were connected to a coaxial cable through SMA connectors. For data acquisition and analysis, we utilized a NanoVna V2 vector network analyzer (VNA).

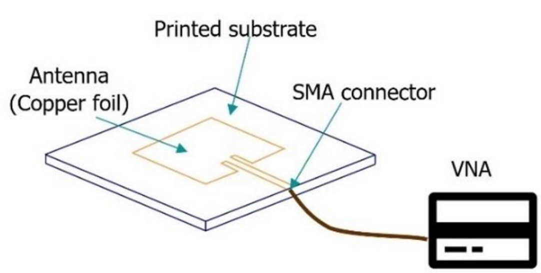
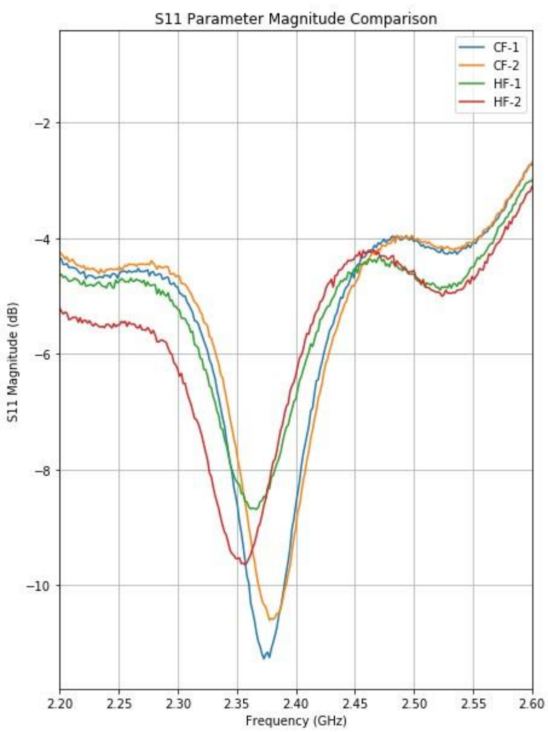


Figure 4: Experiment setup used for antenna measurements

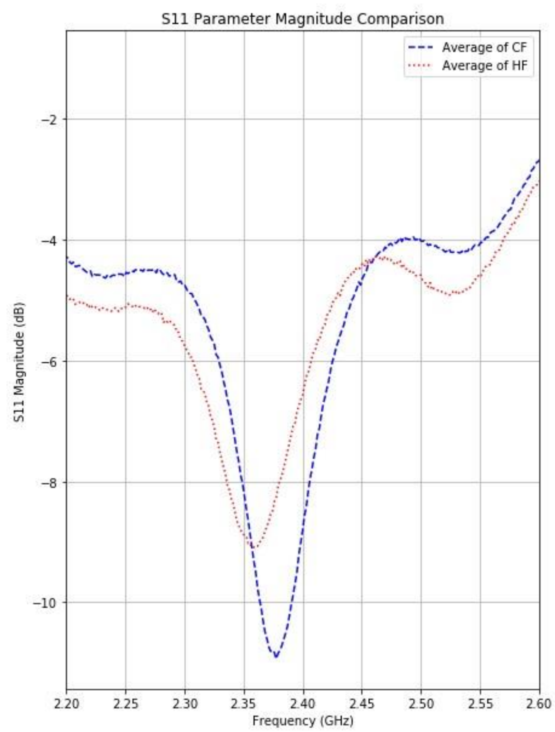
This instrument enabled the assessment of various parameters and their influence on return loss and resonance frequency. The collected data were analyzed, which enabled comparisons between the different trace paths. This methodology enabled the investigation and quantification of the intricate relationship between ink deposition trace path variations, and the performance of 3D-printed antennas. The empirical insights gained from this approach are crucial for advancing our understanding of antenna design in the context of 3D printing for lighting applications.

3. RESULTS

Figure 5 shows the analysis of both hatched fill and concentric fill antennas. There are deviations from the expected 2.4GHz frequency. Hatched-filled antennas, on average, displayed more deviation from simulation results when compared to their concentric-filled counterparts. The S_{11} parameters, as illustrated in Figure 5a, reveal notable differences among various print methods. These averages of the S_{11} parameters demonstrate differences in both magnitude and resonance frequencies, as depicted in Figure 5b. Notably, the 3D-printed antennas with both ink deposition patterns achieved minimum return loss values (S11) near 2.355 GHz for Hatched Fill and 2.385 GHz for Concentric Fill, as illustrated in Figure 5b. The hatched fill antennas have smaller return losses on average when compared to concentric fill antennas.



(a) S_{11} parameters for antennas with different ink deposition methods.



(b) Average S_{11} parameter results for each ink deposition method.

Figure 5: Antenna performance

4. DISCUSSION

In this study, the impact of ink deposition and trace path variations on 3D-printed antenna performance was investigated. It became evident that the antennas fabricated did not operate precisely at the modeled 2.4GHz frequency. One thing that is evident from this study is the choice of ink deposition and trace path affect the operating frequency of the antenna. Further research is needed to better understand the mechanisms causing this deviation.

ACKNOWLEDGMENTS

This work was made possible by the New York State Energy Research and Development Authority's (NYSERDA) grant, Agreement Number: 204289, and we gratefully appreciate Jennifer Taylor from the Lighting Research Center (LRC) for her invaluable help in preparing this manuscript. Special thanks also go to Jean Paul Freyssinier and Indika U. Perera from the LRC for their valuable feedback and guidance. Additionally, we extend our gratitude to the Lighting Research Center's Robert S. Roller Fellow in Lighting program for providing financial assistance to attend the SPIE conference.

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