A 3D Printed Microstrip Patch Antenna using *Electrifi* Filament for In-Space Manufacturing

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***Abstract* — Additive manufacturing technology has emerged as a very effective solution in recent times for prototyping complex and conformal radio frequency (RF) circuits due to its inherent features of fast turn-around, custom modeling, easier fabrication, and cost-effective implementation. A commercially available conductive filament, *Electrifi* has been lately reported by multiple researchers as a potential candidate for replacing traditional copper traces on printed circuit boards using additive manufacturing technologies. Using the fused filament fabrication method of additive manufacturing, this paper presents a 3D-printed microstrip patch antenna based on an improved version of conductive *Electrifi* filament on a planar TMM4 substrate for space-born applications, such as, 3D-printed satellites, space-suits, and zero gravity experiments etc. which are also very recent interest of NASA. Furthermore, a detailed comparative analysis between a full-wave model and a 3D-printed prototype of the antenna is also presented here. The antenna dimensions have been optimized for an operating frequency of 2.56 GHz in S-band (2 – 4 GHz) for suitable in-space applications.**

Keywords—additive manufacturing, Electrifi, flexible, 3D-printed antenna, in-space manufacturing.

I. INTRODUCTION

Additive manufacturing (AM) has revolutionized both the commercial and research industries by presenting different kinds of rapid prototyping for realizing complex geometries and structures. Researchers are also investigating to see AM technique as a promising method for realizing radio frequency (RF) systems. Lately, by adopting the economic fused filament fabrication (FFF) method, researchers have developed and demonstrated 3D-printed microstrip transmission lines (TLs) [1] and simple microstrip antennas [2] based on the commercial conductive *Electrifi* filament [3] for applications such as terrestrial Wi-Fi systems, DoD applications, and WLAN. Recently, NASA [4] suggested on developing a fused filament fabrication method for printing RF circuits for their in-space manufacturing program using regular benchtop 3D printers. A significant challenge in such an approach is in realizing the conductive trace using FFF technique of 3D printing method. This paper presents the development of a radio frequency circuit in the form of a 3D-printed antenna based on an improved version of commercial conductive *Electrifi* filament using traditional benchtop 3D printers by FFF technology which will thus be compatible to NASA's existing in-space manufacturing program.

II. METHODOLOGY AND FABRICATION OF PROTOTYPE

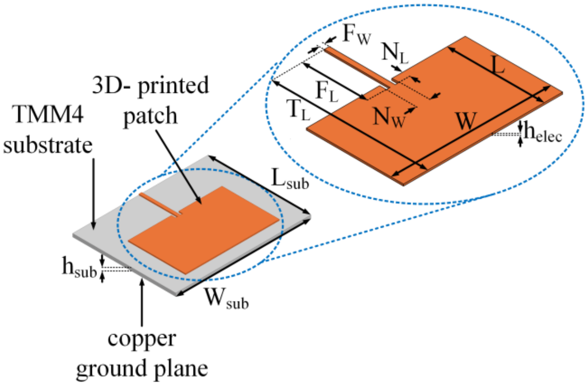


Fig.1. An isometric layout of the 3D-printed antenna prototype. The final dimensions (in mm) for the patch antenna were W_{sub} = L_{sub} = 51, h_{sub} = 1.52, L = 27.85, Wc = 45.55, T_L = 45.87, F_L = 18.88, F_W = 1.40, N_L = 2.00, N_W = 3.48, and h_{elec} = 0.5.

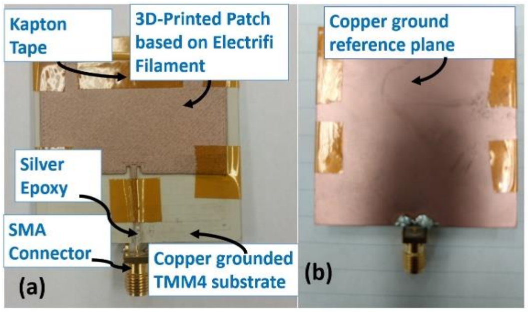


Fig. 2. Photograph of the fabricated Prototype (a) top view (b) bottom view.

For a graphical representation, the isometric layout of the proposed *Electrifi* patch antenna prototype is shown in Fig. 1. The dimensions were optimized for an operating frequency at the S-band of 2.56 GHz, which is very suitable for space-born applications. The fabricated prototype is shown in Fig. 2. The substrate used for the antenna prototype was a square shaped Rogers TMM4. It has a relative permittivity of ε_r =4.5, a loss tangent of $tan\delta = 0.002$ and a thickness of 1.52 mm with a 35μm thick copper cladding on the bottom (i.e., grounded substrate). While placing the 3D printed top conductive layer on the TMM4 substrate, the possibility of any trapped air between the conductive and substrate layers was minimalized by manually applying Kapton tape, as shown in Fig. 2. Kapton tape is a polyimide film, widely used for flexible printed circuit boards due to its large temperature stability and its electrical isolation ability. An improved version of commercially available *Electrifi* filament [1] was used to fabricate the top conducting layer of the patch antenna prototype using a Creality CR-10 printer by the FFF method. The 3-D printing settings mentioned in [1] were strictly followed. The 3D-printed patch was electrically connected to

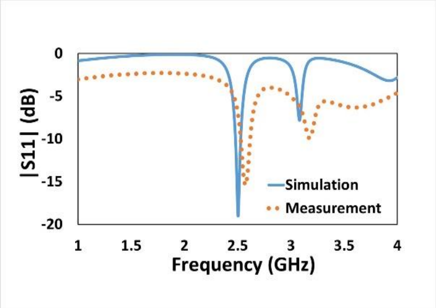


Fig. 3. Simulated and measured input return loss of the 3D-printed *Electrifi* microstrip patch antenna.

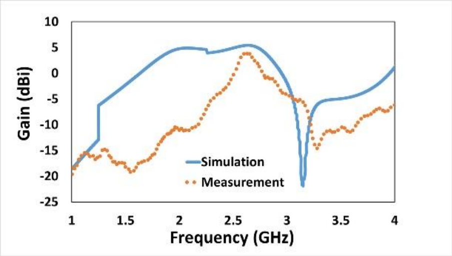
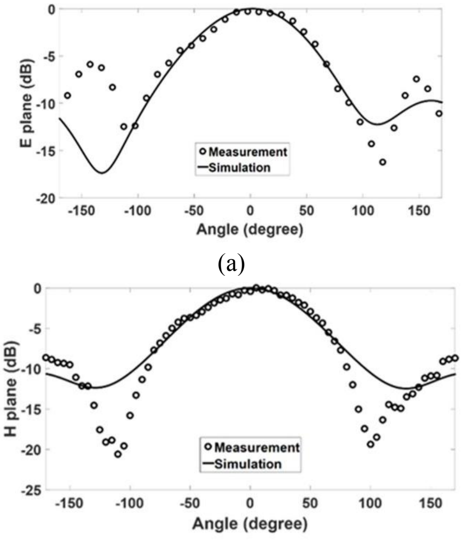


Fig. 4. Simulated and measured gain of the 3D-printed *Electrifi* microstrip patch antenna prototype at 2.54 GHz.

a 50Ω SMA connector (jack assembly, self-fixture end launch type). The ground pins of the SMA connector were initially soldered to the ground plane of the TMM4 substrate, excluding the microstrip feeding line of the patch due to the very low melting point of the conductive *Electrifi* material of 60ºC. The microstrip feeding line was then connected to the center male pin of the SMA connector using an industrial silver epoxy (MG Chemicals 8330-19G) and kept for 24 hours at room temperature for proper curing. During the full-wave modeling in Ansys HFSS, the effects of SMA connector, silver epoxy, and Kapton tape were modeled and considered.

III. RESULTS AND DISCUSSION

The performances of the 3D-printed *Electrifi* microstrip patch antenna was evaluated through the measurement of the return loss, far-field radiation patterns, and gain. All measurements were performed using a Keysight E5071C ENA series network analyzer. The radiation patterns and gain were measured in a 10 × 10 × 10 ft^3 fully calibrated anechoic chamber. The magnitude of the reflection coefficient is shown in Fig. 3. The overall agreement is very good between the prototype and full-wave simulation over a frequency span from 1 to 4 GHz. Comparison between the simulated and measured gain of the 3D-printed *Electrifi* microstrip patch antenna prototype is shown in Fig. 4. During the gain measurements, high degree of dimensional stability and polarization purity were retained for improved results. The simulated maximum gain of the antenna was found to be 5.3 dB, whereas the measurement yielded as 4.23 dB at 2.54 GHz. Moreover, Fig. 5 shows the comparison between the measured and the simulated normalized radiation pattern of the antenna at 2.54 GHz, in both the E-plane (Fig. 5(a)) and H-plane (Fig. 5(b)). Small discrepancies can be attributed to the imperfections of the measurement feeding cables and minor misalignments of the receiver and transmitter antennas in the anechoic chamber. Overall, a fair agreement between both measurement and full-wave simulation can be observed.



(a)

(b)

Fig. 5. Simulated and measured normalized radiation pattern of the prototype at the resonant frequency, 2.54 GHz in the principal (a) E-plane and (b) H-plane.

IV. CONCLUSION

This paper presents an additive manufacturing technique for prototyping low-profile microstrip radio frequency circuits such as antennas. Using the FFF method of additive manufacturing, a 3D-printed patch antenna prototype was developed on a rigid substrate with top conductive layer of *Electrifi* filament and the bottom conducting ground layer was a conventional copper. The fabricated prototype measures 51 × 51 × 1.52 mm^3 in size and resonates at a frequency of 2.54 GHz with a gain of 4.23 dB. For validation, the developed prototype was modeled in Ansys HFSS. Overall, very good agreement between simulations and measurements were observed, showing a radio frequency circuits can be manufactured using a traditional benchtop 3D-printer and thus be compatible to NASA's in-space manufacturing program.

ACKNOWLEDGEMENT

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