3D Printed 2.45 GHz Yagi-Uda Loop Antenna Utilizing Microfluidic Channels and Liquid Metal

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***Abstract*— A 3D printed deployable Yagi-Uda loop antenna designed to operate at the Ultra High Frequency (UHF) Industrial, Scientific and Medical (ISM) band is presented. Utilizing high resolution Stereolithography (SLA) 3D printing, microfluidic channels are incorporated into a 3D structure that enables utilization of liquid metal conductors for deployable antenna, with multiple spiral parallel dielectric structures interconnecting the loops together in a manner that enables a flattened design under compression.**

Keywords—3D Printing, Additive Manufacturing, Deployable, Microfluidics, Stereolithography

I. INTRODUCTION

The use of additive manufacturing (AM) techniques for the fabrication and prototyping of Radio-Frequency (RF) structures and antennas has gained more traction over the years. Additive manufacturing techniques provide some very unique opportunities for the fabrication of complex RF structures while ensuring that no material is wasted in the process waste compared to subtractive methods such as milling and etching. A wide library of AM techniques exist, with common 3D printing technologies such as fused deposition modelling (FDM), stereo-lithography (SLA) and selective laser sintering (SLS) becoming commonplace among labs [1]. More advanced lithography technologies, such as 2-photon polymerization, can achieve resolutions up to 100 nm.

Typically, three-dimensional (3D) antenna structures are difficult to realize using available planar methods of fabrication. As a result, the advancements in 3D printing technology presents a unique opportunity for the rapid prototyping and realization of a complex 3D topology. However, with 3D printing there are limitations in metallization for the production of 3D structures with conductive elements. In this effort, a liquid metal alloy, Eutectic Gallium-Indium (EGaIn) is used to overcome this limitation. The metal alloy is non-porous and features very low resistivity (29.4 x 10^{-6} Ω-cm) thus making it suitable as a conductive material for antenna fabrication. It has been used in a variety of tunable antennas and microwave applications [2-4].

In section II, the theory of operation and design considerations for the presented antenna are reviewed, this is followed by an overview of the steps taken to fabricate the model as well as a discussion on the integrated design solution in section III. Finally, the results obtained are evaluated in section IV.

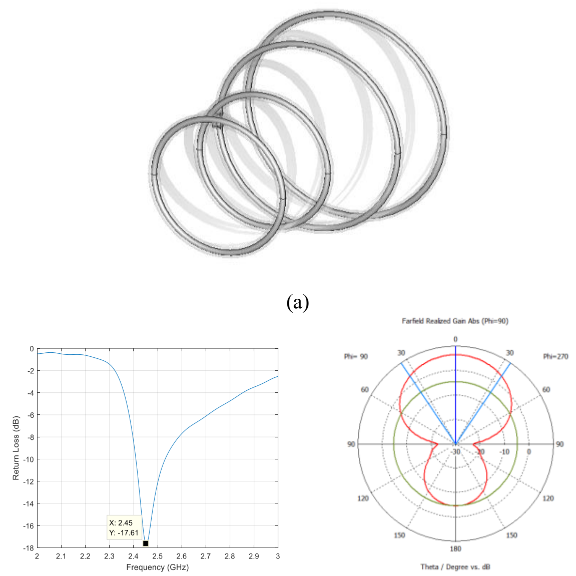
II. DESIGN AND THEORY OF OPERATION

A Yagi-Uda antenna array typically consists of a number of linear dipole antenna elements where only one of the elements is excited by a transmission line feed while the other elements in the array act as parasitic elements with their currents induced via mutual coupling. The Yagi-Uda antenna arrays are fairly common in practice due to desirable qualities such as simplicity, low cost of manufacture, lightweight, etc. This structure is resonant, hence it has a very restricted bandwidth of operation typically on the order of two percent or less thus it is reserved for applications with single frequency operation. Loops are commonly used as alternatives to linear dipoles in a Yagi-Uda antenna array for various applications as they have some more desirable properties that are application specific [5]. By carefully choosing the dimensions and spacing of the loop elements, a unidirectional beam can be formed co-axially with the antenna array. The performance of the loop Yagi-Uda antenna array is controlled by the geometrical parameters of the driven, reflector and director elements as well as the spacing between these elements [5]. For a loop-based Yagi-Uda antenna presented here, the relevant parameters for the design are the diameter of the reflector loop, diameter of the driven loop, diameter of the director elements as well as the spacing between each successive loop.

The structure is simulated in CST Microwave Studio and optimized for performance at the 2.45 GHz center frequency. The model demonstrated in Fig.1(a) includes dielectric sheaths for metal encapsulation and support structures to connect the loops together into a single structure.

III. MODEL FABRICATION

The Yagi-Uda antenna is fabricated using a FormLabs Form 2 stereolithography (SLA) 3D printer which is capable of supporting model printing with up to 25 um z-layer resolution. Four parallel spiral dielectric support structures are integrated into the Yagi-Uda antenna in order to enable dynamic configuration upon actuation, while maintaining the original printed shape when strain is not applied. The spirals are extruded from a square cross section of 1.5 mm x 1.5 mm, with a pitch of 40 mm and varying diameters. The loops of the antenna are



(a)

(b) (c)

Fig. 1. (a) Antenna model with integrated dielectric supports. (b) Return loss. (c) Radiation Pattern.

formed by metallization of hollow channels that form a loop which creates a sheath for the conductor. The thickness of the dielectric sheath for the microfluidic channels is 0.5 mm, encapsulating the liquid metal conductor of 1.0 mm diameter. The feed on the driving loop has two 1.0 mm diameter holes separated center-to-center by 2.3 mm.

The material used is FormLabs Durable, enabling transparency and rigidness compared to other materials, while still enabling flexible, deployable structures. The design is then printed with additional supports automatically generated by the PreForm software, which are manually removed after fabrication. Samples of the durable material were characterized for their electromagnetic properties, with similar values to other photopolymers, resulting in a dielectric constant of 2.78 and loss tangent of 0.06 [2]. While most known commercial photopolymers are lossy, 3D printing enables very select deposition of the material to reduce the total amount of losses, as well as enabling more complex structures at diminutive additional cost to counteract with additional gain. After printing, support structures are removed, and the antenna is washed in a circulating isopropanol bath for 10 minutes using the Form Wash. The channel is further rinsed by injecting isopropanol into the channel to remove any uncured photopolymer resin that may not have been washed away in the bath. After allowing all isopropanol to dry, the part is finished with a UV and thermal cure at 60 °C for 1 hour using the Form Cure. A NaOH solution is injected into the channel, which prevents oxidation of the EGaIn liquid metal. The EGaIn liquid metal is then injected into the channel containing the NaOH solution. An oxidation layer is formed at the injection point

(a) (b)

Fig. 2. (a) Uncompressed fabricated antenna structure. (b) Compressed antenna structure.

when the syringe is removed, enabling the metallization to stay relatively contained within the channels. For reflector and director rings, a small amount of photopolymer resin is used to coat the injection points, which is then cured to completely seal those channels.

IV. Results and Conclusion

The simulation results demonstrate a deployable antenna utilizing the modeled structure, matching performance comparable to ideal Yagi-Uda loop antennas. The fabricated model demonstrates an intricate model where additive manufacturing and 3D printing is justified, while also demonstrating performance at an exceptionally low cost. The 3D printed antenna and how the printed model compresses are shown in Fig. 2. The antenna is matched at 2.45 GHz, with -17.61 dB return loss. The results demonstrate a peak realized gain of 6.43 dB, as demonstrated in the radiation pattern plots shown in Fig. 1(c).

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