Novel 3D-Printed "Chinese Fan" Bow-Tie Antennas for Origami/Shape-Changing Configurations

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***Abstract*—This paper presents a novel approach to realize 3D-printed flexible reconfigurable antennas, along with a proof-of-concept tunable bow-tie antenna inspired from Chinese origami fan. Stereolithography (SLA) printing, a low-cost high-performance additive manufacturing technique, is utilize to enable the easy fabrication of origami structure prototypes and the structure is metallized using a liquid metal alloy (LMA) to facilitate folding without breakages. The proposed bow-tie antenna features a frequency tuning range from 896 MHz to 992 MHz and bandwidth reconfigurability. This reconfigurable antenna can be applied to various dynamically changing scenarios such as wireless communications, collapsible/portable radars, wearable applications.**

I. Introduction

Recently, researchers have applied various origami structures to antenna structures, to effectively realize mechanically reconfigurable microwave/radio frequency (RF) systems. Reconfigurable antennas, can adapt to changing requirements or environmental conditions; they can eliminate these restrictions and provide additional levels of functionality for any system while adding substantial degrees of freedom and functionality to communication, radar and sensing systems while expanding the applications range. Origami structures can easily define the change of the shape of the antenna so that several reliable configurations can be achieved with a simple actuator. However, prototyping of traditional origami structures usually requires labor-intensive folding, which can be simplified and approximated by 3D printing the 3D origami structures using flexible material [1].

3D printing has attracted a growing amount of attention, due to its inherent time-, effort- and cost-effectiveness of fabricating complex 3D objects directly from computer-aided design (CAD) files [2]. Various printing technologies have been developed, such as fused deposition modeling (FDM), stereolithography (SLA), and Selective Laser Sintering (SLS), all with their own advantages and disadvantages in different applications. SLA printing, using a moving ultraviolet (UV) laser beam to selectively cure/solidify photo-polymer patterns layer by layer to prototype 3D objects, was utilized in this paper as it features a good balance of high resolution and low cost.

Most 3D printing technologies deal with material that have no or a low conductivity, which cannot be directly used to realize antenna topologies. Meanwhile, liquid metal alloy (LMA) has demonstrated a great potential in flexible/shape-changing antennas due to its virtually "unlimited" stretchability [3], while it can be easily patterned by 3D printed microfluidics channels. Eutectic Gallium-Indium (EGaIn)(Ga 75.5% and In 24.5%), a room temperature non-porous LMA, features a high-conductivity [4], which can be a great candidate for antenna applications [5]. In this paper, a novel reconfigurable bowtie antenna is designed using a 3D origami structure inspired by Chinese fan and is prototyped with 3D printing and LMA, enabling numerous potential applications that require real-time adjustment to the environment or time-varying requirements including flying and space platforms, wearable electronics, wireless communications.

II. Fabrication

The origami structure with the embedded microfluidics channel shown in Fig. 1 was 3D printed and LMA was injected into the microfluidics channel. The printing platform used is FormLabs Form 2, a stereolithography (SLA) 3D printer featuring 50 μm z-layer resolution. The flexible resin, FormLabs FLGR02, was characterized having a relative permittivity of approximately 2.78 and a loss tangent of 0.06, featuring 80% elongation and thus a great flexibility. To further improve the flexibility, a flex-supporting topology was added to the model by engraving out a mesh, as shown in Fig. 1 (b, c), so that the stress in the substrate can be largely decreased without changing the macro shape of the structure while also saving material and production time. A very good flexibility is achieved, as shown in Fig. 1(c), that would facilitate the use of this antenna in wearable applications. The LMA used is EGaIn (Sigma-Aldrich, 495425), featuring a 15.5°C melting point, a 1.9910 mPa·s bulk viscosity of EGaIn, and a $29.4 \times 10^{-6} \Omega\cdot$cm resistivity that enables easy injections and high-performance electronic designs [4].

III. Theory of Operation

The bow-tie antenna is a simple antenna configuration as well as an extended form of the dipole antennas, which have a wider bandwidth because of the triangle area. The bandwidth of the bowtie antenna depends on the apex angle of the isosceles triangle, as shown in the Fig. 1(a). By applying the Chinese fan structure to the bow-tie antenna, the apex angle of the bow-tie antenna antenna can be easily tuned. Therefore,

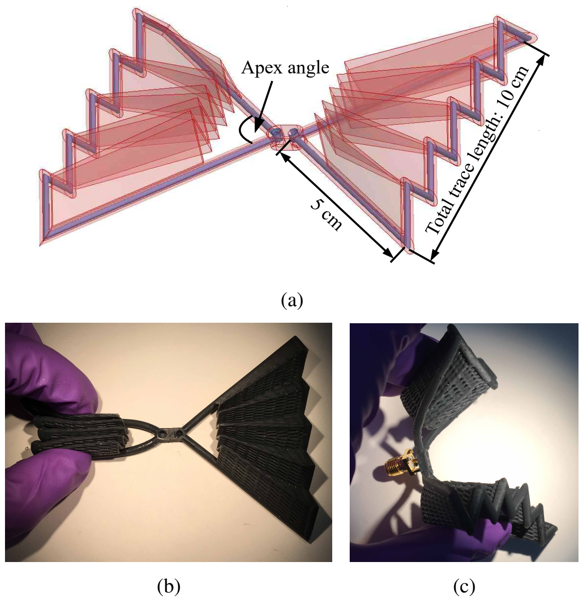

Fig. 1. Geometry (a) and photographs of a prototype (b, c) of the proposed "Chinese fan" bow-tie origami antenna. In (a), the red part is the 3D printed origami structure and the blue part stands for the microfluidic channel to contain LMA. In (b), the right fan is in its original state with a 80 degree apex angle and the left fan is compressed by two fingers to achieved a 30 degree apex angle. In (c), the antenna is folded up to show the flexibility.

the bandwidth of the bow-tie antenna can be changed by folding and/or unfolding the Chinese fan. In the same time, the distance between the two folded triangles can be easily varied by folding the fan sides in different relative angles, so that the resulting capacitance is increasing and the imaginary part of input impedance is decreasing. That effectively leads to a higher resonating frequency of the structure.

IV. Results

The proposed bow-tie antenna was designed and optimized with Ansoft HFSS simulations with the return loss shown in Fig. 2 for a 50 Ω. A resonant frequency shift from 896 MHz to 992 MHz can be observed from no compression (80° apex angle) to maximum compression (20°). The bandwidth of the antenna depends on both the real input impedance (imaginary part is 0) and the input impedance varying slope near that frequency. The -10 dB bandwidth in Fig. 2 shows the result of both factors. Fig. 3 shows the slope (the Z_{11} value variance per frequency) from "no compression" to "maximum compression", in which the slope of real part of input impedance is increased from 0.113 Ω/MHz to 0.149 Ω/MHz (32% increase) while slope of imaginary part is relatively stable (<7% variance), which generally led to narrower bandwidths for smaller apex angles.

V. Conclusion

This paper presents a reconfigurable origami bow-tie antenna, which is inspired by Chinese origami fan geometries and is fabricated by SLA 3D printed printing and LMA injection. The operating frequency of the antenna can be tuned

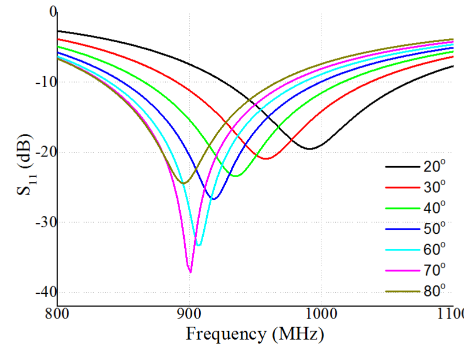

Fig. 2. S11 of the bowtie antenna for various apex angles.

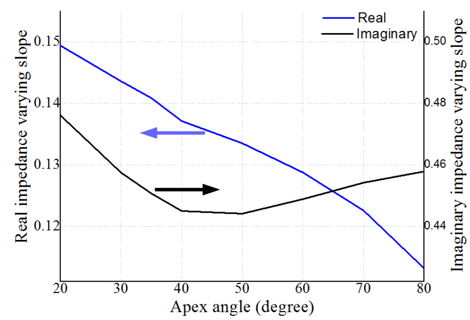

Fig. 3. The slope, variance of the real part and imaginary part of the antenna input impedance per frequency (Ω/MHz), at the frequency of zero imaginary impedance for various apex angles.

by 11% by mechanically folding the fan and the bandwidth tunability within this configuration has also been explored. This reconfigurable antenna can be applied to various dynamically changing scenaria as well as conformal/wearable applications.

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