

3D Printed Modular Origami Inspired Dielectrics for Frequency Tunable Antennas

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Abstract—We explore the impact of origami structure meta-materials on electromagnetic devices. Here two modular origami-inspired dielectric structures were fabricated by 3D printing with the ability to shift the resonant frequency of patch antennas operating at approximately 1 GHz. Tunability was achieved by deploying different dielectric origami configurations that were actuated to control the degree of folding or compression when placed on top of a standard patch antenna. The measured effects of the dielectric origami structure is to provide a 2% range of tunability of the antenna resonance frequency, with simulations showing a similar trend as experiments. The demonstration of active tuning by actuation of dielectric origami may find application in future antenna and telecommunication systems.

I. INTRODUCTION

The challenge to control and manipulate electromagnetic (EM) waves propagation is associated with having spatially varying permittivity and/or permeability materials within the device. Multi-material 3D printing may be utilized to address this requirement and also provides a flexible manufacturing capability for complex geometries at a length-scale compatible with mm-wavelength EM waves used in microwave applications.

Fused deposition modelling (FDM) is a type of 3D printing with relatively fast print speed (~ 33 mm/s) and low capital cost. FDM uses a polymeric filament including high permittivity ceramic-polymer composite filament [1] and highly conductive metal-polymer composite filament [2] so that multi-material devices with unusual functionality may be produced. For example, novel 3D printed S-shaped antennas have been successfully tested [3]. However, the fixed, usually narrow frequency band of such antennas limits their application because generally a broadband or tunable frequency capability is preferred. The latter is pursued by integrating active or tunable structures in the antenna, for example, using thermally tuned dielectrics based on temperature sensitive BaTiO_3 (BTO) [4] or varactors [5].

In this paper, a mechanical method to tune a microstrip patch antenna was investigated by placing printed dielectric origami (PDO) directly on top of the patch. By changing the configuration of the PDO, the resonant frequency of the antenna was modified. Two PDOs with movable elements comprising different permittivities were studied. The geometric configuration of the PDO could be varied from a fully

compressed or fully dense configuration (all the faces of the elements touching each other) to fully open or half dense configuration (elements touching only at their edges) thus determining the extent of the frequency shift. Further to this early demonstration, avenues for achieving broader range of tunability by using dielectric origami structures are envisaged.

II. METHODS

A FDM printer was used for the fabrication of the PDO. Commercial acrylonitrile butadiene styrene (ABS, Spoolworks, UK) and an in-house bespoke composite filament that is a mixture of micro-scale BTO powders in ABS (BTO/ABS) were used for printing. Two origami structures were investigated. The first was printed with ABS filament only ($\epsilon_r \sim 2.6$), with each individual element a simple cube with a side length of 10 mm. The second origami structure was printed with a higher permittivity composite BTO/ABS filament ($\epsilon_r \sim 11$). In this case, each unit cell was a right-angled triangle with a long side length of 8.5 mm and thickness of 7 mm.

The sample patch antenna had side length of 72.6 mm and was placed on a 150 mm by 150 mm grounded FR4 substrate with a thickness of 1.6 mm. The PDO was placed directly on top of the patch in the fully compressed or half-dense configurations shown in Figure 1. A vector network analyzer was used to energize the antenna and measure the reflection coefficient at its input port. These arrangements were also simulated using CST Microwave Studio.

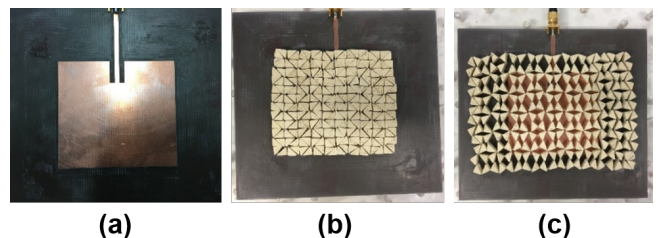


Fig. 1. (a) Reference bare inset feed patch (b) BTO PDO placed on top of the patch antenna in its fully dense configuration (c) BTO PDO placed on top of the patch antenna in its half dense configuration.

III. RESULTS AND DISCUSSIONS

A. ABS dielectric origami on a patch antenna

Figure 2 shows that by placing the fully compressed (fully dense) ABS PDO on top of the patch, the resonant frequency of the antenna was shifted downwards of 0.015 GHz from 1.005 GHz to 0.990 GHz. The change in the resonant frequency occurred because the PDO had a higher effective permittivity than air. A larger shift of 0.035 GHz was predicted by the simulations shown in dotted lines. The smaller frequency shift observed in the experiments are probably due to air gaps remaining between adjacent elements of the PDO in its fully dense state and between the PDO and the copper patch from having a rough printed surface, also due to the PDO being reconfigured by hand, and possibly a greater expansion of the partially dense configuration because of the stretch of hinges connecting the elements, both resulting in some reduction of the effective permittivity of the PDO with respect to theoretical limiting values. These effects could be reduced by printing flexible hinges that could deform during transformation and polishing the samples after printing.

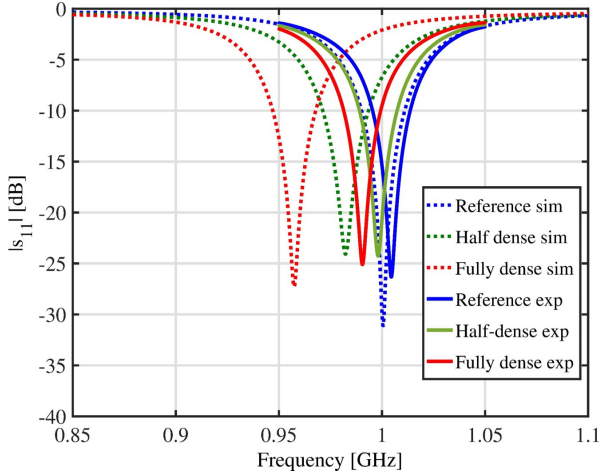


Fig. 2. Reflection coefficient of sample patch antenna resonating at 1 GHz (reference) when an ABS PDO was deployed on top of it both in fully dense and half dense configurations. Solid lines represent experimental data and dotted lines represent simulation results.

B. BTO/ABS dielectric origami on a patch antenna

A PDO with triangular elements of higher permittivity ($\epsilon_r \sim 11$), printed using the BTO/ABS composite filament, was then investigated in the same arrangement discussed above. Figure 3 shows that in the same patch antenna with the PDO fully dense, the resonant frequency shift was increased to 0.025 GHz, from 1.005 GHz to 0.98 GHz. The shift in resonant frequency was larger than for the ABS PDO shown in Figure 2 because of the higher effective permittivity of the BTO/ABS elements, producing a stronger interaction with the electric field from the antenna, concentrated at the fringe fields at the patch periphery. Once again, a half dense PDO configuration produced a shift intermediate between uncovered and fully dense.

From simulations of the same arrangement, an even larger 0.09 GHz shift was predicted for the fully dense configuration in Figure 3. As mentioned above, the lower shift achieved in experiment was due to imperfections in the printed elements and the hinges that led to small air gaps.

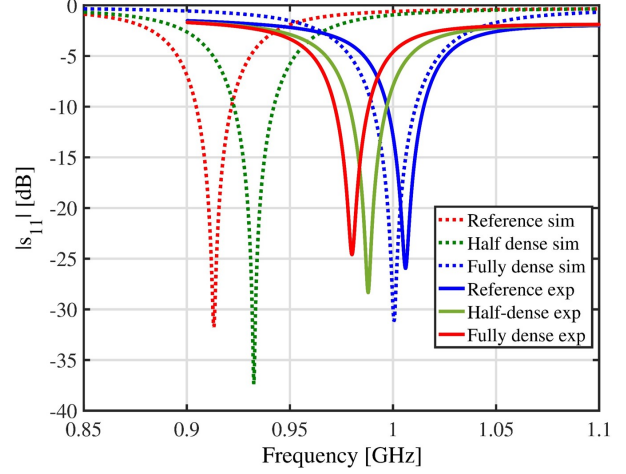


Fig. 3. Reflection coefficient from a patch antenna resonating at 1 GHz (reference) then covered with fully dense and half dense configurations of printed BTO/ABS origami. Solid lines represent experimental data and dotted lines represent simulation results.

IV. CONCLUSIONS

3D printing of ABS and BTO/ABS filament with a permittivity of 2.6 and 11 respectively has been used to fabricate multi-mm scale dielectric elements that were assembled into a flexible 2D dielectric origami structure. When placed on top of a patch antenna, a shift in resonant frequency of 2 % was achieved. This preliminary, proof-of-concept study suggests promise for tuning resonant antennas. In the future, the dielectric arrays could be readily actuated by standard mechanical actuators, and the approach extended to 3D dielectric origami arrangements.

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