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A 3D-Printed mm-Wave Deployable Origami Dielectric Reflectarray Antenna

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Abstract—**This paper presents a state-of-the-art fully 3D-printed mm-wave origami-inspired reflectarray with one-shot deployability. The prototype is fabricated with flexible photosensitive resin using stereolithography 3D printing technology. The proposed design demonstrates a tremendous size reduction in its retracted state which can be very useful for various outer-space and terrestrial applications such as CubeSats, 5G stations and long-range mm-wave backscattering applications.**

Keywords—3D printing, additive manufacturing, antenna arrays, origami, reflectarrays.

I. INTRODUCTION

High-gain antennas are very desirable for long range mm-wave communication applications. Reflectarrays combine the advantage of both parabolic reflectors and phased arrays with flat-surface designs, relatively low-cost, easy to fabricate, and can exhibit a high gain while solely relying on a single feeding source [1]. However, reflectarrays are generally designed with microstrip structures which can limit the bandwidth and produce high conductor losses at mm-wave and THz frequencies. In recent years, dielectric reflectarrays have received increasing attention due to their low-cost, ease of fabrication, high gain and no conductor losses [2-3].

Most dielectric reflectarrays are designed using a solid block representing the unit cell and the arrays are fabricated with rigid materials. Phase-shifting elements are generally tuned by changing the height of the unit cell. As a result, they occupy a larger space compared to the microstrip reflectarrays, form an uneven surface and demonstrate lacks in the ability of being transformed to a retractable or portable design. Therefore, the realization of deployable and compressible designs have become a major challenge for dielectric reflectarrays.

This paper presents a retractable and one-shot deployable mm-wave dielectric reflectarray achieving both high gain and wide bandwidth. The prototype was fabricated using a stereolithography (SLA) technique with a flexible photosensitive resin. The flexible material enables a unique rhombus-shaped design that can be folded for volume reduction and can be deployed on demand. The phase distribution was achieved by changing the unit cell's wall thickness instead of varying its height, resulting in a planar design. These features make it an ideal candidate for various applications such as CubeSats, 5G stations and portable long-range communication devices.

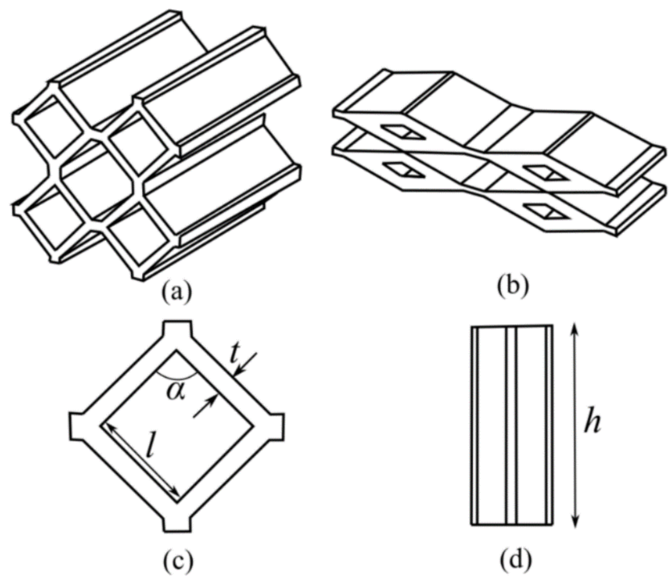

Fig. 1. Unit cell design: (a) deployed unit cells, (b) retracted unit cells, (c) unit cell, top view, (d) unit cell, side view. (l = 8mm, h = 20mm, $\alpha = 90^o$)

II. REFLECTARRAY UNIT CELL

The structure of the unit cell was inspired by the origami design involving cut sections called Kirigami. The unit cell design is shown in Fig. 1. The dimensions of the structure are defined by the element length l, folding angle α, element height h and wall thickness t. The utilized material for printing is "rubber-like" Formlabs FLGR02 Flexible photosensitive resin. The material was characterized utilizing a WR28 waveguide sample with the Nicolson-Ross-Weir NRW methodology and the measured dielectric constantat 30GHz was found to be 2.82 with a loss tangent of 0.029 [4].

The unit cell was designed and simulated in CST Studio Suite 2019 with the frequency domain solver and unit cell Floquet boundary conditions. The phase of the reflected wave was controlled by varying the element thickness t. As shown in Fig. 2, the thickness had to be varied from 0.4mm to 1.3mm to obtain a full 360^o phase shift at 30GHz while maintaining a good foldability and printability. The data extracted from the simulation was post-processed with an interpolative curve fitting algorithm to ensure a continuous data curve.

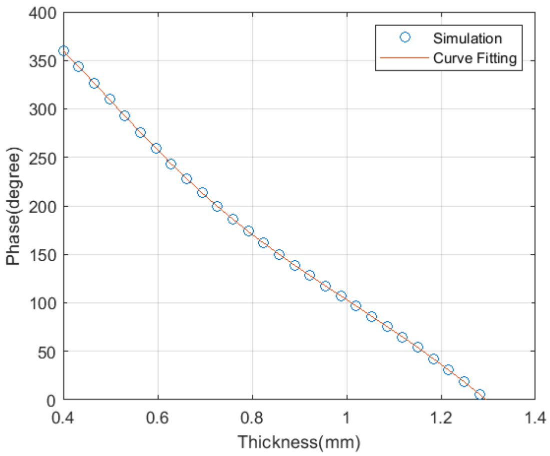

Fig. 2. Simulated phase response of the unit cell for different unit cell wall thicknisses.

III. Reflectarray Design

The phase shifting value *Φ(x_i, y_i)* at a given position *(x_i, y_i)* can be calculated by (1) and (2) [1].

$$\Phi(x_i, y_i) = k_0(d_i - (x_i \cos(\varphi_b) + y_i \sin(\varphi_b)) \sin(\theta_b)) \qquad (1)$$

$$d_i = \sqrt{(x_i - h_a \sin(\theta_b))^2 + {y_i}^2 + (h_a \cos(\theta_b))^2} \qquad (2)$$

where k_0 is the propagation constant in vacuum, *di* is the distance between the feed horn phase center and element *i*, φ_b is the main beam steering angle with respect to the azimuth angle ($\varphi_b = 0^o$ in proposed design).

The reflectarray was designed and simulated in CST Studio Suite 2019 with Visual Basic script. The simulation configuration is shown in Fig. 3. The feeding antenna was tilted with an angle $\theta_a = 20^o$, to reduce the beam squint effect. The main beam direction was also tilted with $\theta_b = 20^o$ accordingly. The generated array has 16x16 elements with a total dimension of 128mm x 128mm.

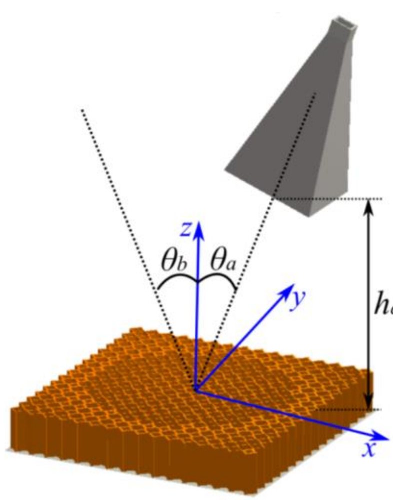

Fig. 3. Simulation configuration of the full reflectarray design in CST Studio.

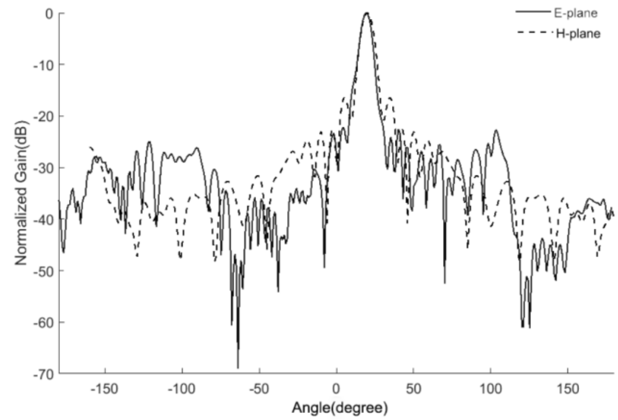

Fig. 4. Simulated E-plane and H-plane radiation patterns.

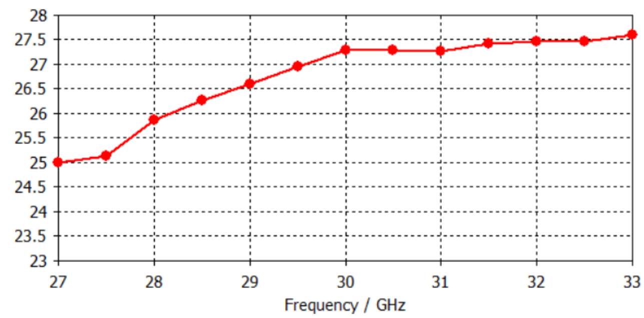

Fig. 5. Simulated realized gain (dBi) vs frequency (GHz).

The simulated radiation pattern is shown in Fig. 4, demonstrating side lobe levels (SLL) below -16dB in both E and H planes. The gain vs frequency curve is shown in Fig. 5 achieving a realized gain at 30GHz of 27.3dBi with 13.3% 1dB bandwidth.

IV. Conclusion

This work proposes a novel 3D-printed deployable origami dielectric reflectarray antenna that simultaneously demonstrates a high gain, wide bandwidth and deployability. The flexible and foldable design enables more applicable scenarios for dielectric reflectarrays.

Acknowledgment

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