3rd URSI AT-AP-RASC, Gran Canaria, 29 May – 3 June 2022

Multifunctional and Deployable Origami Antennas

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Abstract

Multifunctional, deployable, and packable antennas are very important for many applications, including unmanned aerial vehicles, satellite communications (e.g., CubeSats) and general airborne and spaceborne communication systems. Notably, such antennas provide new capabilities for the aforementioned applications. In this work, we present emerging research on foldable and physically reconfigurable antennas, which can morph their shape to adapt and reconfigure their EM performance (e.g., frequency of operation, bandwidth, polarization, beamwidth, etc.).

1. Introduction

Reconfigurable, tunable, multifunctional, deployable, antenna systems have been extensively used to support multiple services of wireless communication systems. Electrical and mechanical reconfiguration methods have been developed and applied in various applications for airborne and spaceborne systems, such as, communications, reconnaissance, sensing and energy harvesting [1], [2].
A new family of physically reconfigurable antennas that has been recently introduced is origami antennas [3]. Origami antennas exhibit unique advantages compared to traditional antennas, such as performance reconfiguration, tunability, and efficient stowage. Their inherent electromagnetic and mechanical multifunctional behavior makes them suitable for portable military and space applications, where space requirements are stringent (e.g., the space constraints of SmallSat buses). Also, the ability of origami antennas to morph their shape enables the development of new electromagnetic (EM) systems with unprecedented and transformational capabilities, such as the following: (a) antennas can change their geometrical shape to adjust their performance as a function of time and achieve multifunctionality, (b) 2-D and 3-D antenna arrays can change their footprint, shape, and/or element separation to achieve optimal beamforming, beamsteering, and scanning range, and (c) reconfigurable frequency selective surfaces can change their performance to support the operation of tunable and multifunctional antennas and arrays (see Fig. 1). A recent review of origami antennas and deployable electromagnetic structures can be found in [4].

Origami principles for the design of deployable structures have been used to create products in various space applications, such as solar arrays, inflatable booms, sunshields, and antennas. Specifically, our group has pioneered the development of origami antennas. In this work, we present a brief overview of our most recent works in this field.

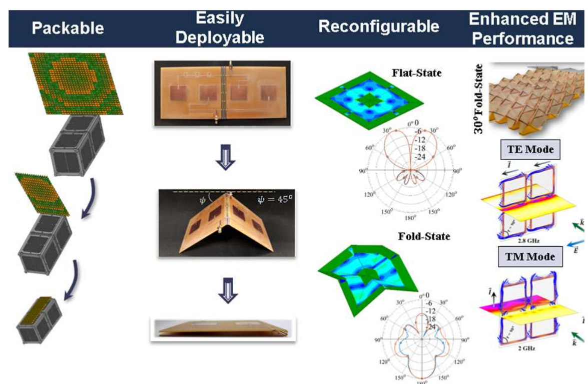
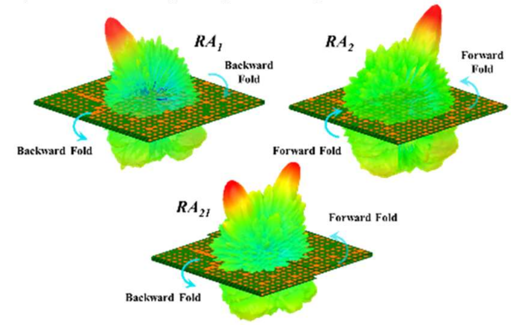


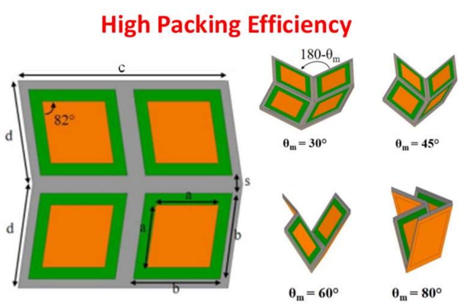
Figure 1. Advantages of origami antennas. From left to right: deployable reflectarray mounted on a CubeSat, four-element patch array printed on a deployable thick substrate, radiation pattern reconfigurability of a deployable loop antenna, dual-band origami FSS.

2. Origami Antennas for Space Applications

Several deployable structures have been developed for space applications, especially after the significant growth of CubeSat missions, [5], [6], in the last 5 years. Our group, has utilized origami principles to develop foldable and deployable high gain helical antennas and reflectarrays. In [7], Georgakopoulos et al., introduced the first origami bifilar helical antenna designed on Kapton®, which is a space qualified material. Several studies were performed to characterize the electrical and mechanical performance of this antenna, illustrating reliable operation for 50-150 cycles of folding/unfolding, depending on the thickness of the material. Kaddour et al., in [8] introduced a novel reconfigurable and monolithic reflectarray antenna (RA) with foldable panels. This RA design can change its illuminated aperture by using Lamina Emergent Torsional (LET) joints to fold/unfold its panels, as shown in Fig. 2(a). Depending on the folding direction of these panels (forward or backward), a new RA aperture is formed offering three states of operation: two states provide single beams and the third provides a dual beam. The proposed RA has extremely low fabrication cost, reconfigurable EM performance, beamsteering capabilities, efficient stowage, and excellent compatibility with CubeSat geometries. Additionally, Kaddour et al., in [9], presented a novel reflectarray unit-cell based on the Miura-Ori origami pattern, as shown in Fig. 2(b). In this design, significant area reduction was achieved by a factor of 6, when the proposed reflectarray is stowed, compared to its unfolded state. This origami inspired unit-cell allows efficient folding/unfolding, high packing efficiency, easy deployment and frequency reconfigurable behavior.



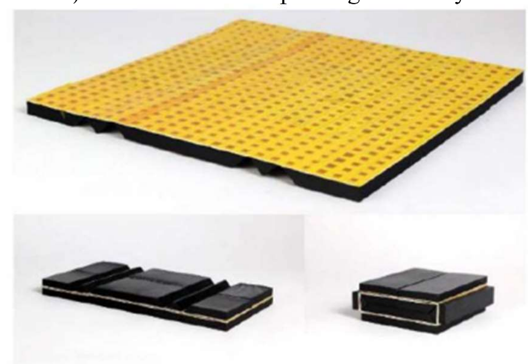
(a)



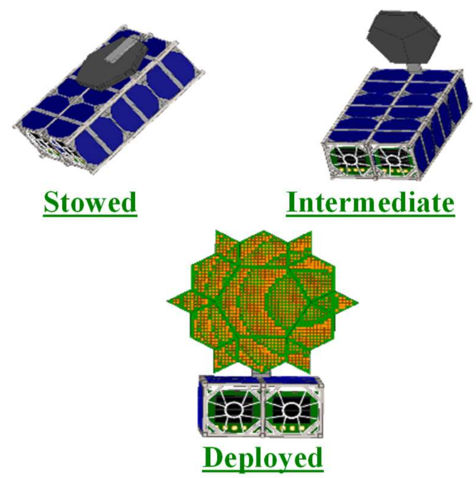
(b)

Figure 2. CubeSats deployable and reconfigure reflectarray antennas. (a) Foldable and reconfigurable monolithic RA at three different folding states. (b) Deployable and reconfigurable Miura-Ori RA.

Furthermore, Rubio et al., in [10] introduced a novel RA that is composed of 15 PCB panels, which are mounted on a straight-major square-twist (SMST) origami structure, as shown in Fig. 3(a). This structure was designed to add stiffness to the RA and accommodate the thickness of the foldable panels. Also, this design provides built-in stops that limit the motion of the panels and keep the panels parallel to each other. A Kapton membrane hinge was used to support the folding/unfolding ability of this design. For a 1 cm panel thickness, this pattern allows for a footprint increase from stowed to deployed configuration of more than 400%. This pattern also exhibits a volume packing efficiency of 92%, which increases as panel thickness decreases. Finally, Rubio et al., [11], introduced a novel deployable flat panel reflectarray antenna (RA). This array is designed based on a modified origami hexagonal twist folding structure targeting small satellite applications. Fig. 3(b) shows the proposed RA aperture as it deploys into a hexagonal geometry when it is mounted on a 6U CubeSat. Notably, this RA achieves an aperture efficiency of at least 60% (which is 10-20% higher than current rectangular apertures) and a 75% volume packing efficiency.



(a)



(b)

Figure 3. CubeSats deployable reflectarray antennas. (a) Reflectarray antenna on the straight-major square-twist origami pattern. (b) Foldable RA on a modified hexagonal twist origami pattern.

3. Conclusions

Deployable, foldable and physically reconfigurable origami antennas exhibit unique advantages, such as multifunctional electromagnetic utility, ultra-compact stowage, simple deployment, and reduced weight. Specifically, by using origami concepts superior electromagnetic and mechanical performance can be achieved thereby making these designs suitable for various terrestrial and space applications. Therefore, we anticipate that origami antennas and foldable EM systems will support the development of next-generation deployable and multifunctional communication systems.

6. Acknowledgements

This work was supported in part by the Air Force Office of Scientific Research under Grant FA9550-18-1-0191 and Grant FA9550-19-1-0290.

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