A Novel Reconfigurable Origami Accordion Antenna

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Abstract — An accordion origami structure is presented, which can be expanded and collapsed. Based on this structure, one origami antenna is designed with operating frequency that can be changed based on its height. A prototype antenna model is manufactured to validate the simulation model. The return loss, far-field radiation pattern and peak gain of this antenna are reported using simulations and measurements.

Index Terms — Accordion structure, folded antennas, origami antennas, 3-D antennas.

I. Introduction

There has been a large amount of work by mathematicians and engineers over the past two decades focusing on the mathematical foundations of origami and more generally folding and unfolding systems. The property of an object being able to unfold is often referred to as deployability, which can serve different purposed for various applications. For example, deployability of a telescope lens is important as it must be packed into a tight cargo space so that it can be carried by a space shuttle into orbit [1]. Another example is a heart stent that must be compressed into a small tube so that it can travel through the blood stream to a location where it unfolds and prevents heart failure [2]. Various complex geometrical designs have also been used in electromagnetics to develop components with enhanced performance and unique capabilities, such as, fractal antennas [3]. In 2012, Olson attempted to jointly consider the performance of an antenna and its deployability [4]. In addition, 3-D folding of antennas has been performed in [5]. Also, airborne or spaceborne structures, e.g., nano-satellites or satellites, require antennas that are miniaturized as space in such structures is very limited. Also, dish antennas are widely used on satellites and even though they are deployable their base and metal dish increase significantly the weight of the antenna. Other designs, such as, patch antenna arrays, [6], have been also proposed and have attempted to find a compromise between acceptable gain and proper size.

In this paper, the design of a novel 3-D origami antenna is proposed. It is based on an accordion structure, which can be folded and unfolded to different heights thereby providing reconfigurable performance in terms of frequency of operation and gain that can support different services. This novel antenna is suitable for airborne and spaceborne structures as well as payloads as it can collapse during launch (thereby minimizing its size) and expand after it has reached orbit thereby providing optimal performance.

II. Origami Accordion Antenna Structure

Fig. 1 shows the geometry of an accordion structure. This model contains 6 levels/turns. All the odd levels (counted from the bottom) are parallel, and so are the even levels. We can precisely control the height *H* and the distance *h* between levels by folding and unfolding the accordion structure.

When this structure is totally folded, the position of every level is close to horizontal. When the structure is unfolded, all levels are inclined and the larger the ratio of *H/h* is, the larger is.

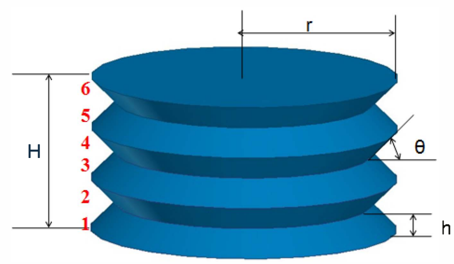
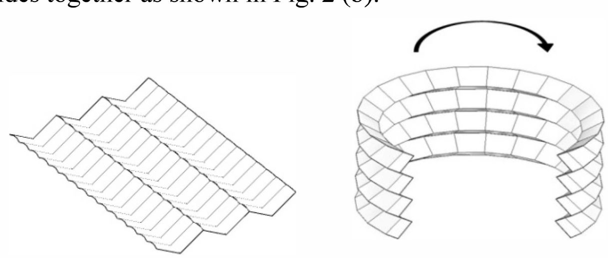


Fig. 1. Accordion lantern structure.

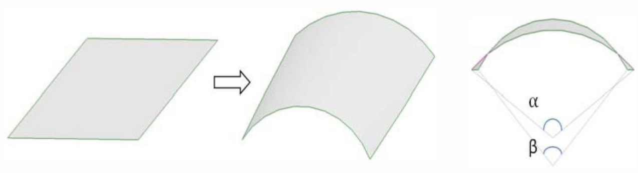
Fig. 2 shows the steps to make an accordion structure by folding a piece of flat paper or other dielectric material. First, make proper creases on the flat paper. The number of creases and the crease directions depend on the size of the accordion structure. Then fold the paper roundly, and connect the two sides together as shown in Fig. 2 (b).



(a) (b)

Fig. 2. (a) Creased base material. (b) Folding the base material roundly.

The rectangle in Fig. 3(a) is the rectangular paper unit before folding. Fig. 3(b) shows the shape of a paper unit after folding along the creases. It is obvious that the two short dimensions of the paper unit are arc-shaped folded with different central angles. Fig. 3(c) is the front view of the paper unit, and the central angle α > β. Although the two arcs have the same length, the exterior circumference of the accordion is bigger than the interior circumference.



(a) (b) (c)

Fig. 3. (a) Paper unit before folding. (b) Folded paper unit. (c) Front view of folded paper unit.

Fig. 4 shows that we can use metal layers along one level of the accordion structure and after a certain length, jump to another level. That means theoretically, we can build infinite number of metal structures on one base. Since the base material of the accordion is a dielectric, even when the antenna is fully folded, the metal on the different levels will be isolated from each other. Another important advantage of this accordion structure is that it's hollow. Therefore, it provides space where other components, such as, sensor circuits or height controllers can be placed.

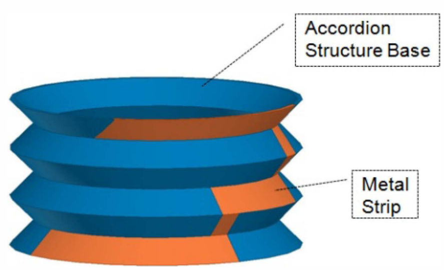


Fig. 4. Metal strip on the accordion structure base.

III. Simulation and Measurements of Accordion Origami Antenna

We designed an accordion antenna model. Fig. 5 shows the geometry of the antenna fed by 50-Ohm coaxial probe in ANSYS HFSS. The metal strip goes along the first level of the accordion paper base. After a quarter round, it goes to the next odd level. There are 9 odd levels in total. The material we used to build the antenna is copper. The thickness of the copper strip is 0.1 mm, and the width is 7mm. The radius, *r,* which is the distance between the central axis and the edge of every level, is 50mm.

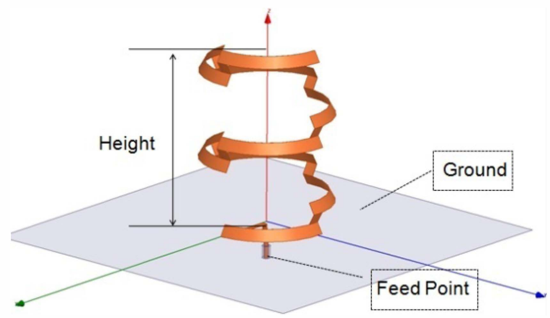
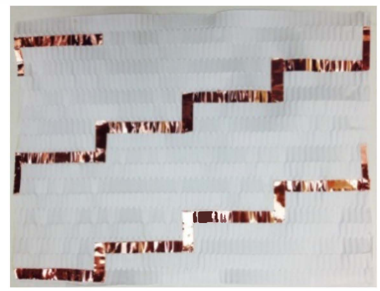
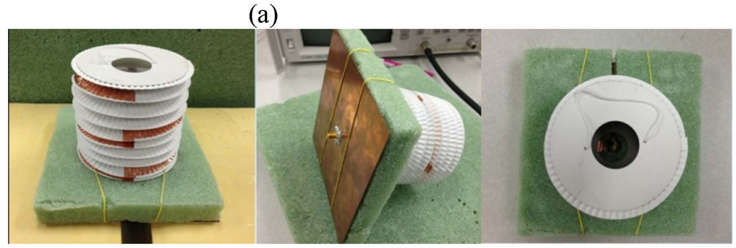


Fig. 5. Antenna model in HFSS.



(a)

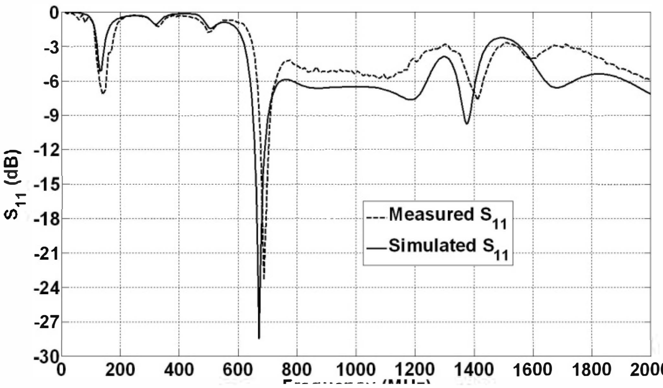


(b)

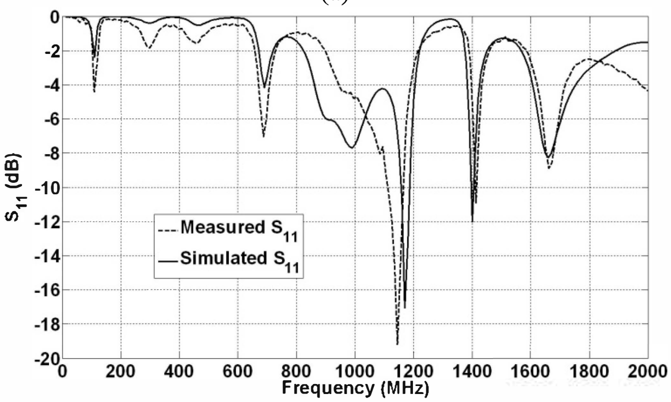
Fig. 6. (a) Flat paper with copper strip. (b) Manufactured origami accordion antenna.

We also manufactured a real model to validate our simulation results. Fig. 6(a) shows the flat creased paper with the copper strip on it before it is folded. We used a 160 mm by 160 mm copper sheet as the ground with a 20 mm thick polystyrene foam layer between the antenna and the copper sheet, as shown in Fig. 6(b).

The graphs in Fig. 7 show the simulated and measured return loss of our antenna at different heights. The simulation results are from HFSS. The measurements were obtained using a vector network analyzer. Fig. 7 (a) shows the measurements and simulation results of S11 when the height of antenna is 160 mm (unfolded state). Fig. 7 (b) shows the measurements and simulation results of S11 when the height of antenna is 40mm (folded state). Fig. 6 shows that the resonances of this accordion antenna change when it folds or unfolds thereby providing a reconfigurable performance. Therefore, this origami antenna is a spatially reconfigurable antenna.



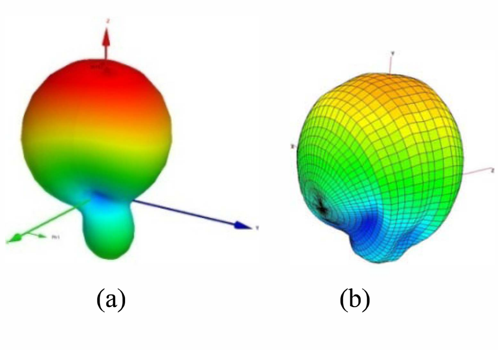
(a)



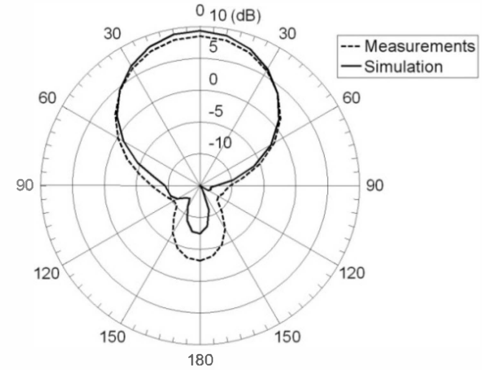
(b)

Fig. 7. S11 of accordion antenna (a) Unfolded state – 160 mm height. (b) Folded state – 40 mm height.

Fig. 8 shows the simulated and measured gain pattern of the antenna at 1300 MHz for 160 mm height. The measurements of the gain were conducted in anechoic chamber as it can be seen in Fig. 9. Fig. 8(c) compared the simulated and measured radiation pattern for the elevation plane at 1300 MHz. From the simulated and measured gain data, we see that this antenna is directional. The measured maximum gain is 7.3 dB, along the central axis (z direction), and the shape of the pattern is similar to the one of a helical antenna working at axial mode.



(a) (b)



(c)

Fig. 8. (a) Simulated gain pattern. (b) Measured gain pattern. (c) Simulated and measured radiation pattern for elevation plane.

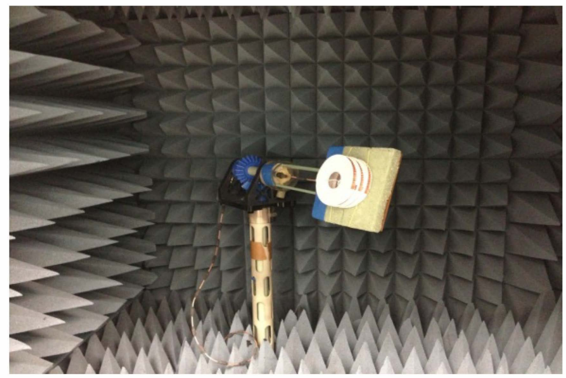
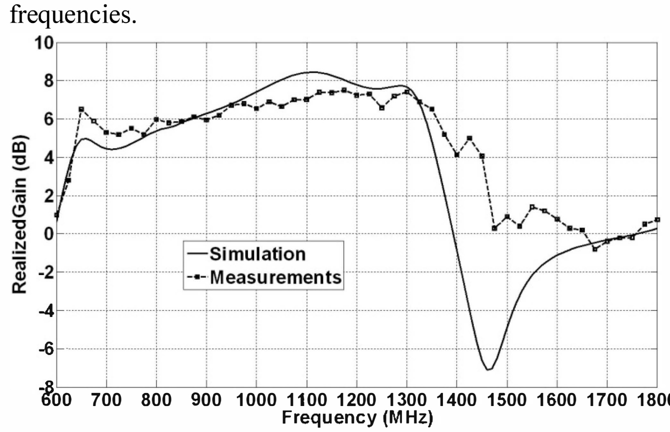


Fig. 9. Antenna is in the anechoic chamber.

Fig. 10 shows the simulated and measured realized gain along the z direction of the accordion antenna versus frequency at different heights. It can be seen from Table I, that the unfolded state has significantly larger realized gain at 650 MHz and 1300 MHz. However, at 1400 MHz, the folded state achieves a larger realized gain. Therefore, this illustrates again that this origami antenna is a spatially reconfigurable antenna that based on its height provides optimal gain at different frequencies.



(a)

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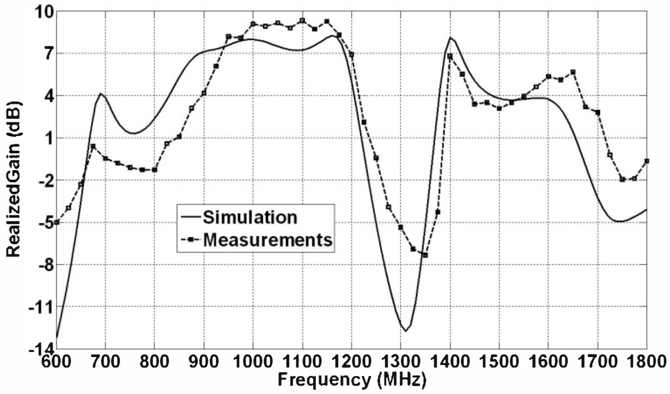

(b)

Fig. 10. Realized gain at (a) 160 mm height and (b) 40 mm height.

Table I. Measured gain in dB

Antenna Height	Realized Gain Measurements		
	650MHz	1300MHz	1400MHz
160mm	6.50	7.31	4.13
40mm	-2.29	-5.37	6.79

IV. Conclusion

A novel type of origami accordion antenna is proposed. The height of the accordion structure can be changed by expanding or collapsing the origami structure. This antenna provides reconfigurability in terms of its operating frequency and maximum gain based on its height that can be easily controlled by a simple telescoping mechanism.

Acknowledgement

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References

[1] J. P. Gardner, et, “The james Webb Space Telescope,” 2006.
[2] K. Kuribayashi, H. Onoe, S. Takeuchi, “Cell Origami: Self-Folding of Three-Dimensional Cell-Laden Microstructures Driven by Cell Traction Force,” *PLOS One*, vol. 7, issue 12, Dec. 2006.
[3] R. H. Patnam, “Broadband CPW-Fed Planar Koch Fractal Loop Antenna,” *IEEE Antennas and Wireless Propagation Letters*, vol. 7, pp. 429-431, 2008.
[4] G. M. Olson, S. Pellegrino, J. Costantine, “Structure Architectures for a Deployable Wideband UHF Antenna,” *American Institute of Aeronaustics and Astronaustics*, 2012.
[5] C. M. Kruesi, R. J. Vyas, M. M. Tentzeris, “Design and Development of a Novel 3-D Cubic Antenna for Wireless Sensor Networks and RFID Applications,” *IEEE Transctions on Antenna and Propagationl*, vol. 57, no. 10, pp. 3293-3299, October 2009.
[6] T. K. Sreeja, A. Arun, J. Jaya Kumari, “An S-band Micro-Stirp Patch Array Antenna for Nano-Satellite Applications,” *2012 ICGT International Conference*, pp. 325-328, Dec. 2012.

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