A Novel Tunable Origami Accordion Antenna

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***Abstract*—A novel origami accordion antenna 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. The return loss, far-field radiation pattern and peak gain of this antenna are examined.**

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. Various complex geometrical designs have also been used in electromagnetics to develop components with enhanced performance and unique capabilities. In [1], two concepts were proposed in theory by jointly considering the performance of antenna and its deployability: thin shell structure and pantograph structure, based on which origami antennas can be built such as conical log spiral antenna. A reconfigurable axial-mode helix antenna was built in [2], which used a shape memory alloy spring actuator to adjust its height. Although there was a plastic column to support the antenna, the folded and unfolded antenna didn't have a stable geometry. In addition, 3-D folding of antennas has been performed in [3], and the prototype was fabricated by printing metal on six planar sides, and then folded into the cubic structure. In [4], a 3-D dipole was designed for wireless sensor node applications. But both these two 3-D antennas can only work at folded state.

To generalize the three-dimensional deployable structures, we need to consider not only the initial and final folded state, but also the process of transitioning between them. For that purpose, we need to specify a sequence of folding/unfolding steps, each of which is reachable by a simple fold from the previous, so that the whole sequence can actually be realized by the folding process. Rigidity imposes relatively tight constraints on the design, however, if we are using thin layers of metal on a flexible surface, it may not be necessary to require strict rigidity. In this paper, the design of a novel 3-D origami antenna is proposed. It is based on an accordion paper 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.

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.

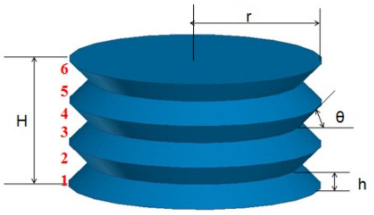

Fig. 1. Accordion structure.

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 ration of *H/h* is, the larger θ is.

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.

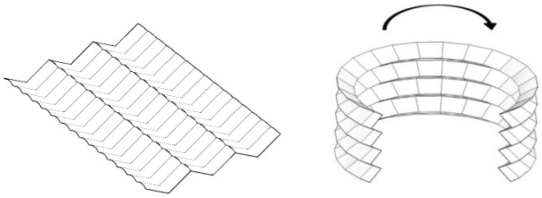

Fig. 2. Folding accordion structure

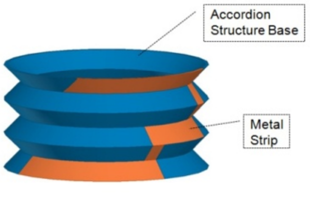

Fig. 3. Metal strip on the accordion structure base.

Fig. 3 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 is hollow. Therefore, it provides space where other components, such as, sensor circuits or height controllers can be placed.

III. TUNING THE FREQUENCY OF ACCORDION ANTENNA

We designed an accordion antenna model. Fig. 4 shows the geometry of the antenna. The metal strip goes along the first level of the accordion paper base. After a whole round, it goes to the next odd level. There are 3 odd levels in total. The material we used for the metal strip is copper. The thickness of the copper strip is 0.1 mm and the width is 5mm. The radius, r, which is the distance between the central axis and the edge of every level is 20mm. Fig. 5 shows the antenna model fed by 50-Ohm coaxial probe in ANSYS HFSS.

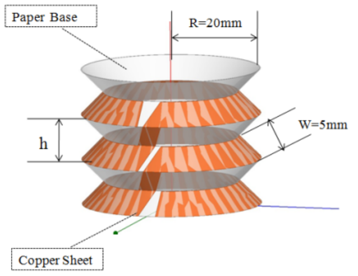

Fig. 4. Designed antenna.

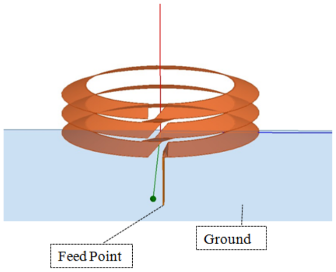

Fig. 5. Antenna model in HFSS.

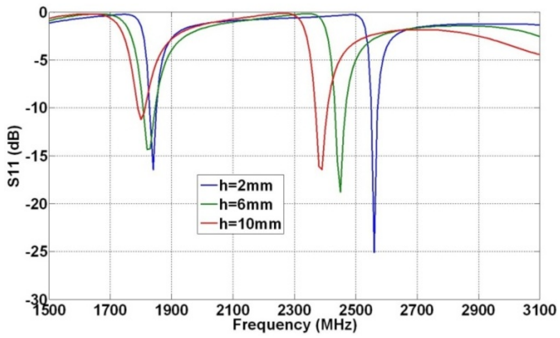

Fig. 6. Return loss for different heights.

The graphs in Fig. 6 show the simulated return loss of this antenna at different heights. From the simulation results, we can find that the S_{11} resonance shifts from 2560 MHz to 2380 MHz when we change the antenna's height from 2 mm to 10 mm, and the same shifting occurs with the peak of the realized gain, as shown in Fig. 7. Fig. 8 shows the far-field radiation pattern of this antenna at the resonant frequency for three different heights. We can see that this antenna is directional, and the peak gain is along the central axis. These results clearly illustrate that the operating frequency of the origami antenna shifts for different antenna heights. Therefore, this origami antenna is a spatially reconfigurable tunable antenna. Our results are verified by measurements.

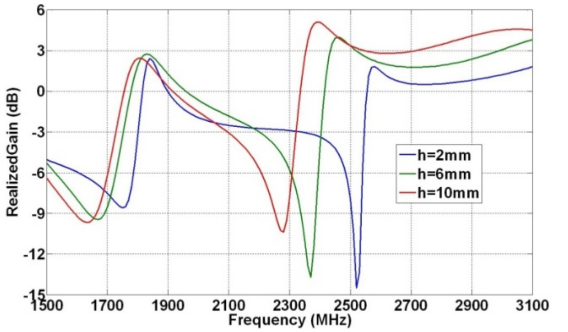

Fig. 7. Realized Gain for different heights.

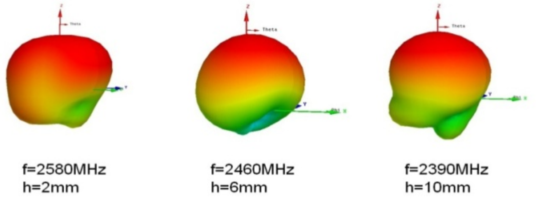

Fig. 8. Radiation pattern for different heights.

IV. CONCLUSION

A novel origami accordion antenna is proposed here. The height of the accordion antenna can be changed by expanding or collapsing the origami structure. The simulation results show that this antenna provides reconfigurability in terms of its operating frequency and maximum gain based on its height, which could be easily controlled by a simple telescoping mechanism.

REFERENCES

[1] G. M. Olson, S. Pellegrino, J. Costantine, "Structure Architectures for a Deployable Wideband UHF Antenna," American Institute of Aeronaustics and Astronaustics, 2012

[2] Jalali Mazlouman, S., Mahanfar, A., Menon, C., Vaughan, R.G. "Reconfigurable Axial-Mode Helix Antennas Using Shape Memory Alloys," 2011 Antennas and Propagation, IEEE Transactions on, vol. 59, pp. 1070-1077, April 2011.

[3] 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 Transactions on Antenna and Propagation, vol. 57, no. 10, pp. 3293-3299, October 2009.

[4] I. T. Nassar, T. M. Weller, "Development of Novel 3-D Cube Antennas for Compact Wireless Sensor Nodes," IEEE Transactions on Antenna and Propagation, vol.60, no. 2, February 2012