Reconfigurable Helical Antenna Based on an Origami Structure for Wireless Communication System

Xueli Liu[(1)], Shun Yao[(1)], Stavros V. Georgakopoulos[(1)], Benjamin S. Cook[(2)] and Manos M. Tentzeris[(2)]

(1) Department of Electrical and Computer Engineering

Florida International University

Miami, FL, United States

(2) The School of Electrical and Computer Engineering

Georgia Institute of Technology

Atlanta, GA, United States

xliu038@fiu.edu

Abstract — This paper presents a reconfigurable axial mode helical antenna which could be folded and unfolded using rigidly foldable origami structure to work at different resonant frequencies for kinds of wireless systems. Measured results show that the folded state could operate at both 1.82 GHz and 2.14 GHz. And the measured operating frequency for the unfolded state is 860 MHz. The frequency reconfigurability up to 1.28 GHz was achieved, and the height of the folded state could be reduced to 17% of the height of the unfolded state.

Index Terms — Axial mode, helical antennas, origami structure, reconfigurability, wireless system.

I. INTRODUCTION

Antennas have played crucial roles in wireless communication systems for receiving and transmitting interested signals in various electromagnetic frequency bands [1]. In satellite communications, antennas with properties of light weight, compact volume, durability and high directionality are widely applied. And rigidly foldable origami structures are preferred due to conquering limitations of storage or transportation [2]. As for an origami antenna, frequency reconfigurability could be achieved by changing the antenna's appearance, and a more compact volume could be achieved by folding the origami antenna when the unfolded state is not in usage.

Previous work has been done on reconfigurable axial mode helical antenna with memory alloy on a rigid plastic supporter [3]. Impacts of reflectors on the gains of an helical antenna were also investigated earlier in [4].

This paper presents an origami reconfigurable helical antenna constructed with copper foil on stretchable and light-weight paper base. Total height of this antenna could be reduced by 83% from its unfolded state to folded state. Also the proposed antenna has a frequency reconfigurability of up to 1.28 GHz at folded and unfolded states for varied purposes of wireless communications.

Commercial products are now available to make paper base water-proof. And new mechanical ways to fold and unfold the antenna are to be investigated in the future.

II. ORIGAMI MODEL CONSTRUCTION

The origami pattern adopted [2] is shown in Fig. 1. Solid lines denote hills and dash lines denote valleys. The brown part is where the copper foil was located. The acute interior angle α of each rhombus is given by $\alpha = 2\pi/n$, of which, n is the number of sides of each polygon as shown in Fig. 3.

To construct the origami cylinder, the pattern in Fig. 1 was folded and its left side should be connected to its right side, as shown in Fig. 2.

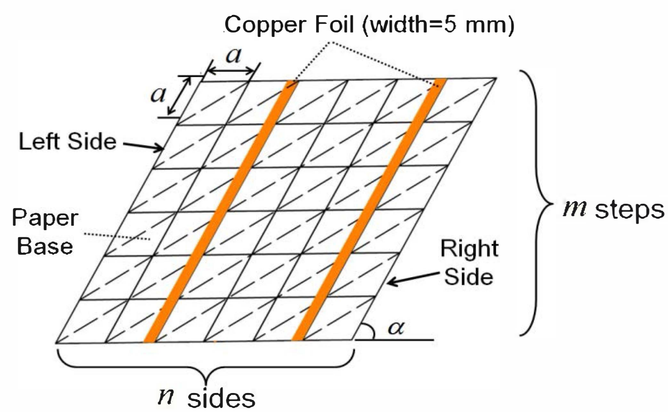

Fig. 1. Basic origami pattern adopted.

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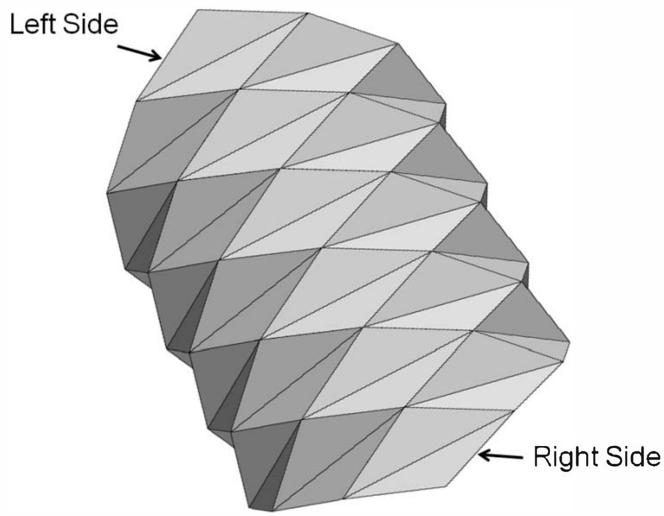
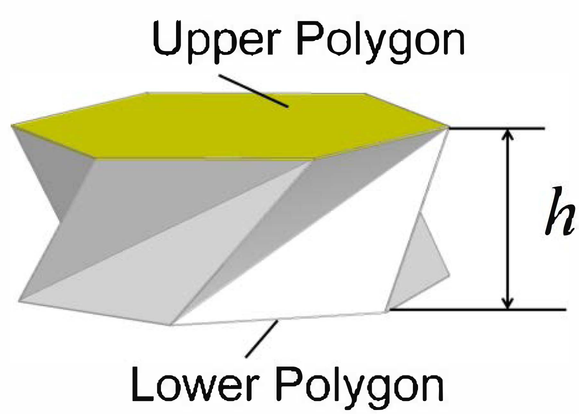


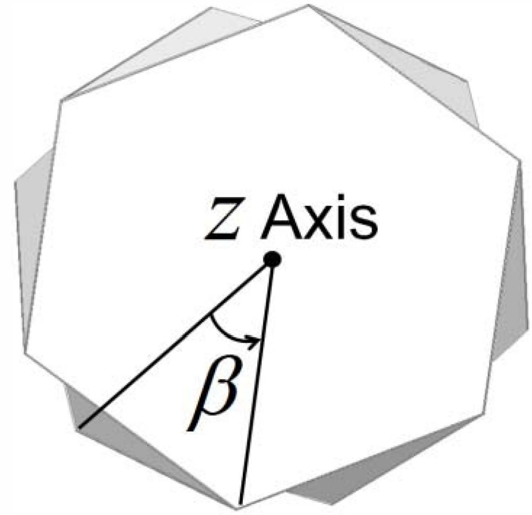
Fig. 2. Folded origami pattern.

The upper sides and lower sides of the rhombuses in a same step form two polygon planes, as shown in Fig. 3. The distance h between the upper and lower polygons of a same step decreases as β increases, as shown in (1), and β is the rotated angle from the lower polygon to the upper polygon around the helical axis.

$$h = \sqrt{a^2 - (2a\sin\frac{\beta}{2})^2} \quad (29^\circ < \beta < 60^\circ) \qquad (1)$$



(a)



(b)

Fig. 3. Model of 1-step origami structure (a) Side view. (b) Top view.

The antenna model was constructed and simulated using 3-D High Frequency Structure Simulator (HFSS) based on Finite Element Method (FEM).

III. Design and Simulation

For an axial mode helical antenna with a fixed copper length L, the number of loops N increases as angle β increases, of which β is the angle rotated from the upper polygon plane to the lower polygon plane of each step around the helical axis. Therefore, the resonant frequency f would increase as N increases, as shown in (2).

$$f = \frac{c}{\lambda} \approx \frac{cN}{L} \qquad (2)$$

Fig. 4 shows an 18-step origami antenna with the radius a =21.75 mm for total height H_{Folded} =38 mm and $H_{Unfolded}$ =255 mm. The corresponding β for H_{Folded} and $H_{Unfolded}$ are respectively 59.66° and 44.5°. The brown line is the signal line and the blue line is connected to the ground whose side length is 106 mm.

Simulated S_{11} for the folded and unfolded states are depicted in Fig. 5, whose corresponding realized gain given by $Gain_{realized} = \frac{4\pi U}{P_{inc}}$ at the axial direction is shown in Fig. 6.

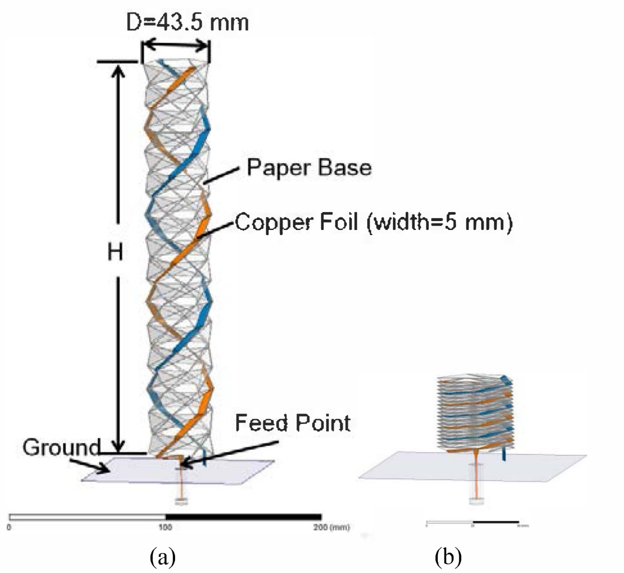


Fig. 4. Simulated model of the 18-steps origami helical antenna (a) Unfolded state, H=255mm. (b) Folded state, H=38mm.

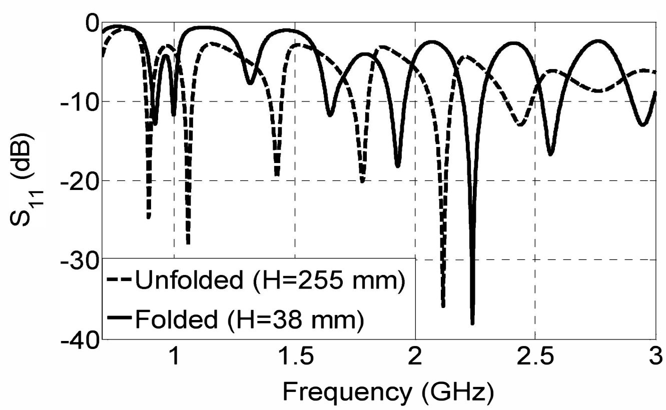


Fig. 5. simulated S_{11} of folded and unfolded states.

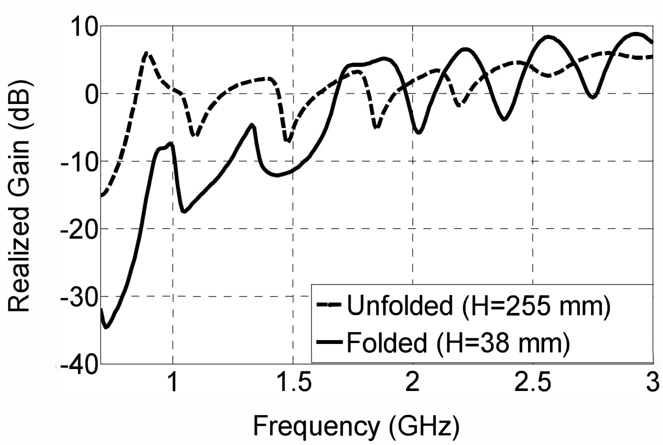


Fig. 6. Simulated Realized Gain at the axial direction of folded and unfolded states.

IV. Measurement

The designed antenna in Fig. 4 was manufactured as shown in Fig. 7. The S_{11} at folded and unfolded states were measured with Agilent Network Analyzer. And the comparison of the simulated S_{11} and measured S_{11} for the two states is shown in Fig. 8 and Fig. 9.

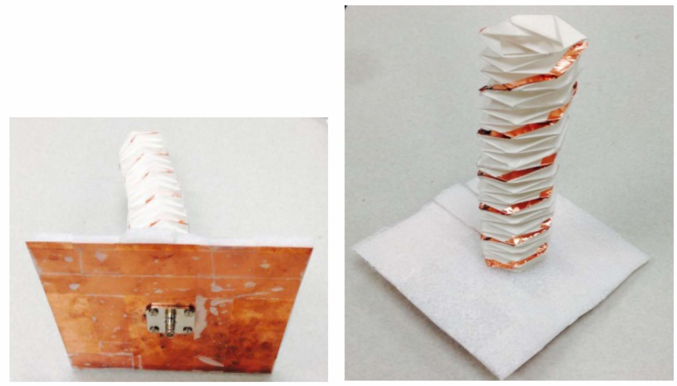


Fig. 7. Manufactured 18-steps origami helical antenna.

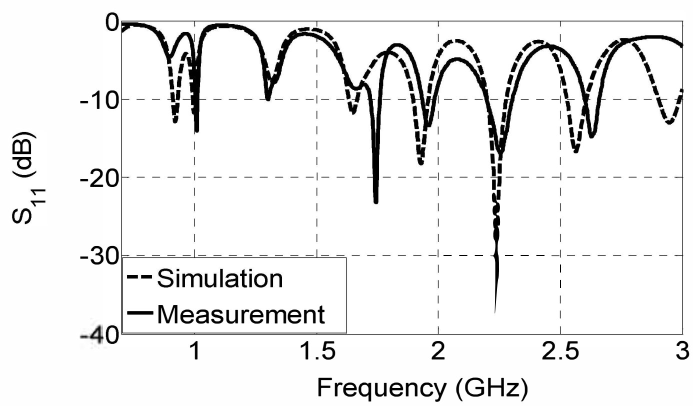


Fig. 8. Simulated and measured S_{11} of the folded state.

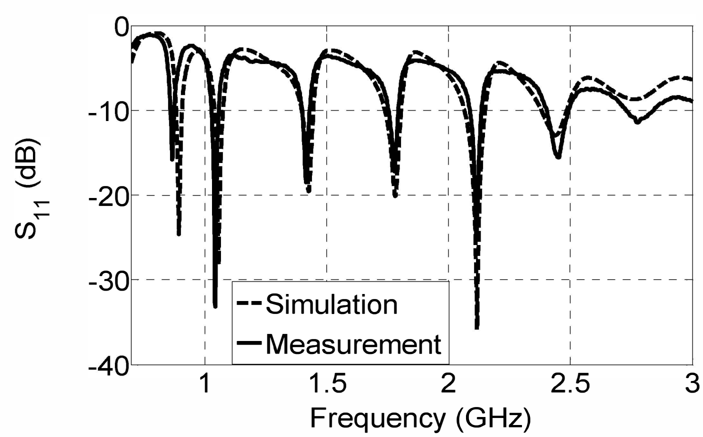


Fig. 9. Simulated and measured S_{11} of the unfolded state.

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The gain was measured in ETS-Lindgren's Anechoic Chamber. The simulated and measured gain differences along the helical axial direction between the unfolded and the folded state are shown in Fig. 10. The unfolded state would operate at the resonant frequency 860 MHz where the measured gain difference is the maximum, while the folded state could operate at resonant frequences 1.82 GHz and 2.14 GHz where the measured gain differences are valleys.

The 3-D radiation pattern at operating frequencies are shown in Fig. 11.

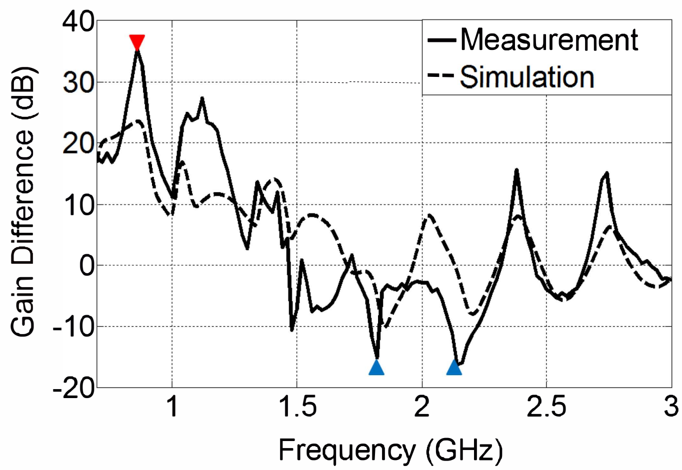
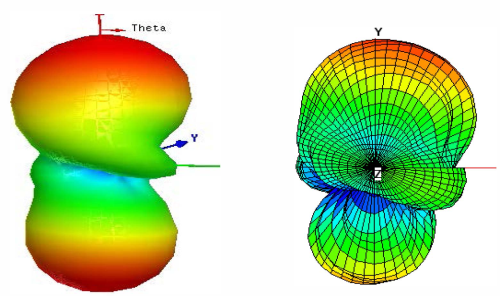
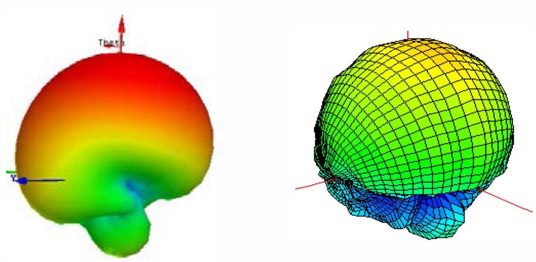


Fig. 10. Simulated and measured gain difference at the axial direction between the folded and unfolded states.



(a)



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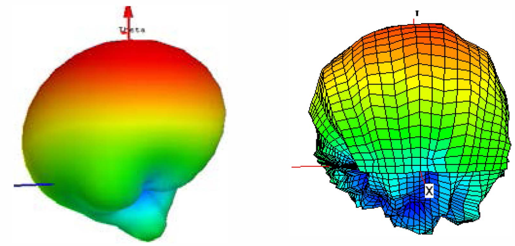

(c)

Fig. 11. Simulated and measured 3-D Radiation pattern at: (a) 860MHz of unfolded state. (b) 1.82 GHz of folded state. (c) 2.14 GHz of folded state.

V. CONCLUSION

A kind of origami helical antenna with frequency reconfigurability at folded and unfolded states was designed and measured. Simulated and measured results show that the antenna could successfully achieve a frequency reconfigurability of 1.28 GHz with considerable gain differences. This antenna could operate at 860 MHz when unfolded and at 1.82 GHz and 2.14 GHz when folded with its height reduced by 83%.

This antenna will be investigated for reflector antenna and quadrifilar antenna in the future to enhance performances of the antenna. Also self-deployable ways to fold and unfold the antenna will be developed.

ACKNOWLEDGEMENT

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REFERENCES

[1] Constantine A. Balanis, "Antenna theory analysis and design, " *Third Edition*, 2005.

[2] Gökhan Kiper, Eres Söylemez, "Deployable space structures," *2009 4th International Conference on Recent Advances in Space Technologies,* pp. 131-138, 2009.

[3] 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.

[4] A. R. Djordjevic, A. G. Zajic, M. M. Ilic, G. L. Stuber, "Optimization of Helical antennas ,"*2006 Antennas and Propagation Magazine,* Vol. 48, Issue: 6 2006 , pp. 107-115, 2006.

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