# A Kirigami-Inspired Pattern-Reconfigurable Antenna with Switchable Omnidirectional and Unidirectional Beams

Qianyi Li and Ting-Yen Shih
Department of Electrical and Computer Engineering
University of Idaho
Moscow, ID, 83844, USA
li0285@vandals.uidaho.edu and tshih@uidaho.edu

***Abstract*—Pattern reconfigurable antennas can provide dynamic radiation coverage, a key for managing the heavy data traffic associated with 5G communication. Kirigami, a paper cutting and folding technique, can be applied to the design of reconfigurable antennas to introduce more flexibility and simple fabrication. In this paper, a kirigami-inspired reconfigurable antenna with one omnidirectional and two unidirectional beams is presented. The proposed antenna is composed of one monopole antenna, placed at the center of a ground plane, and two foldable kirigami parabolic reflectors. The parabolic structure enhanced the peak gain of the proposed antenna by 2.08 dB compared with its origami-based counterpart with a plane reflector. The simulated -10 dB reflection coefficient bandwidth is 13.37% for the omnidirectional mode and 10.23% for the directional mode.**

***Index Terms*—Kirigami antennas, reconfigurable antennas, radiation pattern reconfigurability.**

## I. Introduction

To handle the heavy data traffic associated with 5G communication, it is necessary to develop antennas or antenna arrays with dynamic radiation coverage. Pattern reconfigurable antennas provide advantages of adjustable radiation angles and directional gains, which make them good candidates for this purpose [1].

The mechanisms for achieving reconfigurable patterns can be roughly categorized into three groups: electrical changes, material changes, and mechanical changes [2]. Examples of the electrical approach are the use of p-i-n diodes [3] or RF switches [4] to control the location or phases of slots on the ground plane and steer the beam angles. The variable permittivity of ferroelectric materials has also been used to generate reconfigurable radiation patterns [5]. The mechanical method (e.g., origami) has drawn much attention within the reconfigurable antenna design field. In [6], an origami conical spiral antenna can be transformed into a planar dipole antenna. In [7], a microstrip patch antenna and monopole antenna became interconvertible using the origami technique. Kirigami, which is a variation of origami that includes both cutting and folding of the paper, can provide more design flexibility compared to conventional origami. However, only a few works have applied this kind of technique to antenna design to date.

In this paper, we present a kirigami-inspired reconfigurable antenna with one omnidirectional and two unidirectional beams. When compared with an origami-based antenna (reference design), the proposed kirigami structure provides an improved gain in the $x-y$ plane, exceeding that of the reference design by 2.08 dB. This is achieved while maintaining a similar -10 dB reflection coefficient bandwidth as the reference antenna (13.37% for the omnidirectional mode and 10.23% for the unidirectional mode). The center frequency of the proposed antenna is around 3.5 GHz.

## II. Antenna Design

The proposed kirigami-inspired antenna has three switchable patterns (one omni- and two uni-directional patterns) at 3.5 GHz. A monopole antenna (height = 20.4 mm) is placed at the center of a rectangular ground (256.8 mm $\times$ 85.6 mm), as shown in Fig. 1(a). This setup provides the omnidirectional beam. To achieve unidirectionality, the ground plane can be folded up to act as a plane reflector, as shown in the origami-based reference design (Fig. 1(b)). To enhance the directionality of the radiation pattern, two kirigami structures are employed in this work (Fig. 1(c)). Fig. 1(b) and (c) illustrate only one of the available unidirectional modes, and the second unidirectional mode can be created by folding the opposite side of the ground plane instead. To maximize the directionality of the proposed antenna, the two foldable kirigami structures are designed to act as parabolic reflectors (see Fig. 1(c)). The monopole antenna is placed at the focal point of the two parabolic reflectors. The focal length ($F$) is 21.4 mm and the diameter ($D$) is 71.4 mm, as shown in Fig. 1(c). The kirigami strip lines have the same width (2 mm) and various lengths.

Self-folding of the kirigami structures can be achieved using pre-stressed polymer sheets (also known as Shrinky-Dinks) which shrink in-plane if heated uniformly [8]. To attain the desired geometry, black ink can be applied to the valley folds of the kirigami structures. Fabrication of the proposed antenna is in progress.

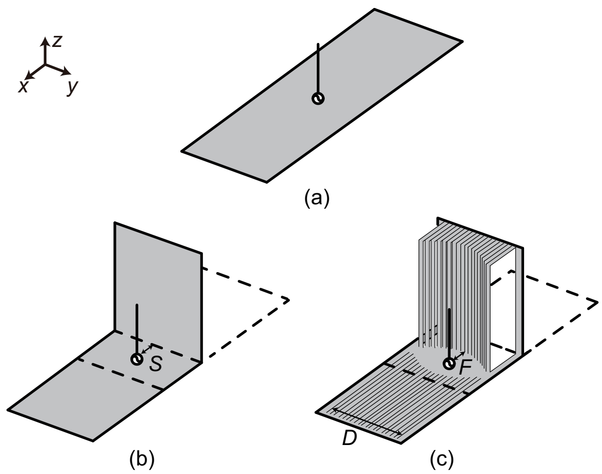


Fig. 1. The monopole antenna (a) without reflectors, (b) with one origami plane reflector, and (c) with one kirigami parabolic reflector ($S = F = 21.4$ mm and $D = 71.4$ mm).

## III. Results

In Fig. 2, the -10 dB reflection coefficient fractional bandwidth of the monopole antenna without reflectors (also the omnidirectional mode of the antennas in Fig. 1(b) and (c)) is 13.37%. The fractional bandwidths of the antennas with an origami plane reflector and a kirigami parabolic reflector are 12.7% and 10.23%, respectively. The kirigami-based antenna has a narrower bandwidth and a slight shift in the operating frequency because the cutting of the ground plane changes the resonant impedance. These issues could be improved by optimizing the size and shape of the kirigami reflectors.

The simulated gain patterns of the antennas without reflectors, with one origami plane reflector, and with one kirigami parabolic reflector are compared in Fig. 3. As expected, the monopole antenna without reflectors has an omnidirectional radiation pattern (peak gain = 0.26 dB), while the two antennas with reflectors are directional. Both the origami- and the kirigami-based antennas have a single major beam towards the $\phi = 0°$ direction. The peak gains in the $x-y$ plane of the origami-based antenna and the kirigami-based antenna are 4.99 dB and 7.07 dB, respectively. The proposed kirigami-based design shows an advantage in gain (2.08 dB improvement).

## IV. Conclusion

In this paper, a kirigami-inspired reconfigurable antenna with one omnidirectional and two unidirectional beams was presented. The simulated -10 dB reflection coefficient fractional bandwidths of the omnidirectional mode and the unidirectional mode are 13.37% and 10.23%, respectively. The peak gain of the unidirectional mode of the proposed kirigami-based antenna is 7.07 dB, which is 2.08 dB higher than the origami-based reference design. The design details and the measurement results will be presented at the symposium.

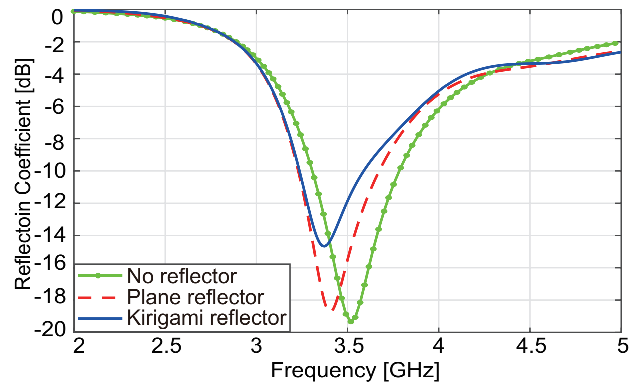


Fig. 2. Reflection coefficients of the antennas shown in Fig. 1 (a)-(c).

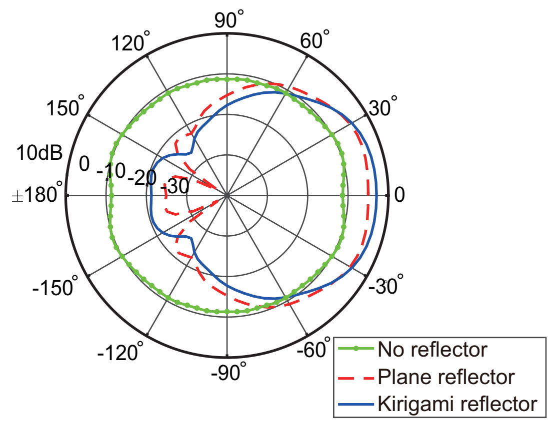


Fig. 3. Gain patterns in the $x-y$ plane of the antennas shown in Fig. 1 (a)-(c).

## References

[1] S. I. H. Shah and S. Lim, "Thermally Beam-Direction- and Beamwidth-Switchable Monopole Antenna Using Origami Reflectors With Smart Shape Memory Polymer Hinges," *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 8, pp. 1696–1700, Aug. 2019.

[2] J. T. Bernhard, "Reconfigurable Antennas," *Synthesis Lectures on Antennas*, vol. 2, no. 1, pp. 1–66, Jan. 2007.

[3] J. Ouyang, Y. M. Pan, and S. Y. Zheng, "Center-Fed Unilateral and Pattern Reconfigurable Planar Antennas With Slotted Ground Plane," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 10, pp. 5139–5149, Oct. 2018.

[4] H. A. Majid, M. K. A. Rahim, M. R. Hamid, and M. F. Ismail, "Frequency and Pattern Reconfigurable Slot Antenna," *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 10, pp. 5339–5343, Oct. 2014.

[5] G. Lovat, P. Burghignoli, and S. Celozzi, "A Tunable Ferroelectric Antenna for Fixed-Frequency Scanning Applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 5, pp. 353–356, 2006.

[6] S. Yao, X. Liu, and S. V. Georgakopoulos, "Morphing Origami Conical Spiral Antenna Based on the Nojima Wrap," *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 5, pp. 2222–2232, May 2017.

[7] G. J. Hayes, Y. Liu, J. Genzer, G. Lazzi, and M. D. Dickey, "Self-Folding Origami Microstrip Antennas," *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 10, pp. 5416–5419, Oct. 2014.

[8] Y. Liu, J. K. Boyles, J. Genzer, and M. D. Dickey, "Self-folding of polymer sheets using local light absorption," *Soft Matter*, vol. 8, no. 6, pp. 1764–1769, 2012.