# Origami Quadrifilar Helix Antenna in UHF Band

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***Abstract*—This paper presents an origami Quadrifilar Helix Antenna (QHA) which could work at different operating frequencies in Ultra High Frequency (UHF) band with different heights for optimum realized gain. This antenna is designed to be applied to space wireless communication with little limitations of storage or transportation due to a compact size. Principle of this design was first validated by the ideal helix antenna model. The simulated frequency reconfigurability of QHA is up to 1.92 GHz, and the height of the folded state is 26% of the height of the unfolded state.**

## I. INTRODUCTION

Rigid origami structures are playing enormous roles in the modern world ranging from space satellite to paper shopping bags for their portability and compact size [1]. As demonstrated in this paper, a rigid origami structure is applied to construct collapsible and re-configurable QHA.

A deployable helix antenna was proposed in [2]. However, its compacted height is limited by the strip width and hinges size. Also, this deployable structure would be complicated to construct bifilar helix antenna or QHA, whose compacted size would probably be further enlarged.

This paper proposed an origami QHA with a frequency reconfigurability over 1.92 GHz. Simulated gain is over 7 dB at operating frequencies. It could be constructed with copper foil on rigidly foldable paper base, which makes the antenna light-weight, more compactable, portable and economic. This design provides a new direction for satellite communication and global positioning systems. It could also be used in disposable devices.

## II. THEORETICAL MODEL

For axial mode helix antenna as in Fig. 1, the pitch angle $\alpha$ and total wire length $L$ are given.

$$\tan\alpha = S/C \tag{1}$$

$$L = N \cdot (S^2 + C^2)^{1/2} \tag{2}$$

where $S$ is the pitch between two adjacent turns as shown in Fig. 1 and $C = \pi D$ is the circumference of the helix.

In the optimum range of parameters shown in Table I, empirical formulas can be derived that describe the performance of the axial mode helix [3] as:

$$Directivity = C_\lambda^2 N S_\lambda \tag{3}$$

$$HPBW = \frac{52}{C_\lambda \sqrt{N S_\lambda}} (\deg) \tag{4}$$

$$R_{in} = 140 C_\lambda (ohms) \tag{5}$$

TABLE I. OPTIMUM PARAMETERS

| Parameter | Optimum Range |
|---|---|
| Circumference | $\frac{3}{4}\lambda < C < \frac{4}{3}\lambda$ |
| Pitch Angle | $12^\circ < \alpha < 15^\circ$ |
| Number of Turns | $3 < N < 15$ |
| Ground Plane Diameter | At least 0.5$\lambda$ |

The ideal helical antenna model of Fig. 1 was simulated using ANSYS HFSS for various pitches from 13.3 mm to 133.6 mm and the results are shown in Fig. 2. The simulated realized gain in the axial direction at resonant frequencies for different pitches is listed in Table II.

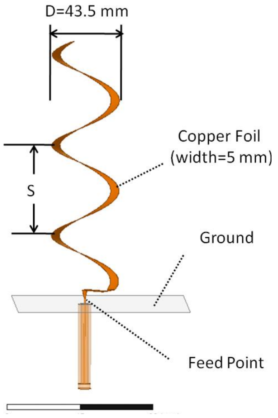

Fig. 1. 3-loop ideal helical antenna model.

It can be seen that when the pitch is 13.3 mm, this helical antenna has the most compact size at operating frequency 2.49 GHz. By increasing the helix's pitch, the operating frequency shifts gradually to 1.39 GHz with a realized gain of 7.1 dB. This represents a frequency reconfigurability (tunability) over 1

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GHz. If a proper ground or feeding approach is applied, the realized gain can be improved for the pitch of 113.6 mm at 1.0 GHz, which will provide an enlarged frequency tunability of 1.49 GHz.

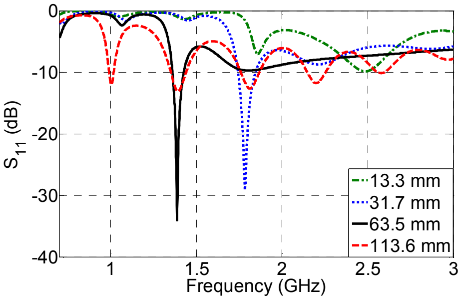


Fig. 2. S11 of 3-loop ideal helical antenna model for different pitches.

TABLE II. REALIZED GAIN OF IDEAL HELIX ANTENNA

| $S$ (mm) / $f_r$ (GHz) | 13.3 | 31.7 | 63.5 | 113.6 |
|---|---|---|---|---|
| **2.49** | **8.8 dB** | 8.3 dB | 5.9 dB | 2.3 dB |
| **1.78** | -0.1 dB | **8.0 dB** | 6.0 dB | 0.5 dB |
| **1.39** | -3.1 dB | -13.3 dB | **7.1 dB** | 2.2 dB |
| **1.00** | -15.7 dB | -12.7 dB | -16.8 dB | **3.0 dB** |

## III. MODEL AND SIMULATION OF QHA

The adopted origami pattern is shown in Fig. 3, where $a$ is the side length of each rhombus, and $\alpha = 360^\circ/n$. The yellow strips denote locations of the copper foil. The 3-D structure of 1 step folded from this pattern is shown in Fig. 4. Also, $\beta$ is the rotated angle between 2 adjacent steps around the helical axis. When $\beta$ is increased, the height of each step $h$ is decreased, as shown in (6). Therefore the pitch would be reduced to shift the operating frequency downward. The theoretical range of $\beta$ is from $29^\circ$ to $60^\circ$.

$$h = \sqrt{a^2 - (2a\sin\frac{\beta}{2})^2} \tag{6}$$

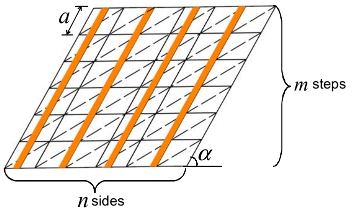
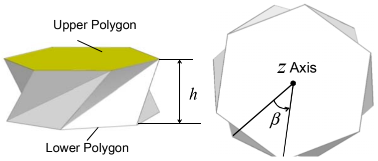


Fig. 3. Rigidly foldable origami pattern.



(a) (b)

Fig. 4. Model of 1-step origami structure (a) Side view. (b) Top view.

The antenna model was constructed and simulated using High Frequency Structure Simulator (HFSS).

The models of QHA at folded and unfolded states are shown in Fig. 5. Their simulated results are shown in Fig. 6 and Table III. A frequency reconfigurability of 1.92 GHz is acquired with realized gain over 7 dB at operating frequencies.

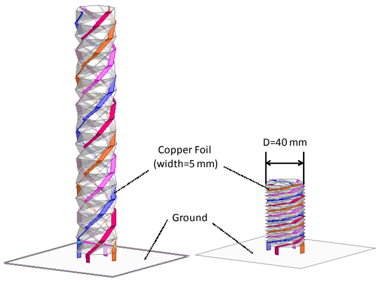


Fig. 5. Model of QHA at unfolded ($\beta$ =44 deg) and folded ($\beta$ =59 deg) states

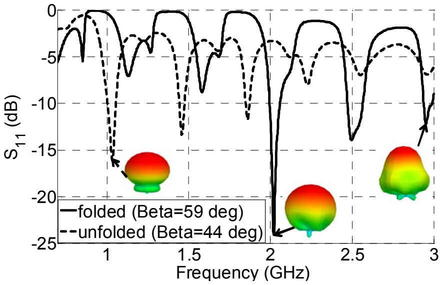


Fig. 6. S11 and radiation patterns of QHA at unfolded and folded states.

TABLE III. REALIZED GAIN OF QHA AT FODLED AND UNFODLED STATES AT RESONANT FREQUENCIES

| $\beta$ (°) / $f_r$ (GHz) | 59 | 44 |
|---|---|---|
| **2.95** | **7.1 dB** | 1.8 dB |
| **2.02** | **7.4 dB** | -6.1 dB |
| **1.03** | -11 dB | **7.0 dB** |

## REFERENCES

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