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Design and Experimental Verification of an Origami Based Compact Helix Antenna with High Gain Characteristics

Fatih Özkan ALKURT [1,a]

[1]*Iskenderun Technical University, Electrical-Electronics Engineering Department, Hatay, Türkiye*

[a]***ORCID**: 0000-0002-9940-0658*

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Corresponding Author

Fatih Özkan ALKURT
fozkan.alkurt@iste.edu.tr

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ABSTRACT

This research presents origami folding technique based novel compact helix antenna design and experimental verification. The study begins by detailing the origami technique to design and construct helical structure using a thin paper. A 1.5 mm wide copper layer is then longitudinally integrated onto the prepared paper layer which is aimed to fold to form a helical configuration. This folded helical strcure then combined a fully copper ground layer to create an helix antenna configuration that aims to operate at sub-6 GHz 5G frequencies between 4 GHz and 8 GHz. The helical structure has flexible characteristics which allows for volume reduction and frequency reconfiguration through adjustment in the flexion angle. The flexion angle parametrically examined to obtain optimum operating frequency and the optimum operating frequency is obtained at 6 GHz with 2 GHz bandwidth and 8.32 dBi gain. Proposed antenna structure was manufactured and numerical results were supported experimentally. This antenna is well suited for applications in next generation wireless communication systems, including 5G networks, Internet of Things (IoT) devices, and portable communication technologies such as satellite communication.

Yüksek Kazanç Özelliklerine Sahip Origami Tabanlı Kompakt Heliks Anten Tasarımı ve Deneysel Doğrulaması

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Sorumlu Yazar

Fatih Özkan ALKURT
fozkan.alkurt@iste.edu.tr

Anahtar Kelimeler

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ÖZ

Bu araştırma, origami katlama tekniğine dayalı yeni kompakt heliks anten tasarımını ve deneysel doğrulamasını sunmaktadır. Çalışma, ince bir kağıt kullanarak heliks yapıyı tasarlamak ve üretmek için origami tekniğini ayrıntılı olarak açıklamaktadır. Ayrıca, 1,5 mm genişliğinde bir bakır tabaka, heliks bir yapılandırma oluşturmak üzere katlanması amaçlanan kağıt tabakasına uzunlamasına entegre edilmiştir. Bu katlanmış heliks yapı daha sonra, 4 GHz ile 8 GHz arasında 6 GHz altı 5G frekanslarında çalışmayı amaçlayan bir heliks anten oluşturmak için tamamen bakır bir toprak tabakası ile birleştirilmiştir. Heliks yapı, esneme açısının ayarlanması yoluyla hacim azaltımına ve frekans yeniden yapılandırmasına izin veren esnek özelliklere sahiptir. Optimum çalışma frekansını elde etmek için esneme açısı parametrik olarak incelenmiştir ve optimum çalışma frekansı 2 GHz bant genişliği ve 8,32 dBi kazançla 6 GHz'de elde edilmiştir. Önerilen anten yapısı üretilmiştir ve sayısal sonuçlar deneysel olarak desteklenmiştir. Bu anten, 5G ağları, Nesnelerin İnterneti (IoT) cihazları ve uydu iletişimi gibi taşınabilir iletişim teknolojileri dahil olmak üzere yeni nesil kablosuz iletişim sistemlerindeki uygulamalar için oldukça uygundur.

1. INTRODUCTION

Nowadays, the necessity for compact, high performance antennas has significantly increased with the rapid development of wireless communication technologies. As communication systems advanced towards higher frequencies, such as the sub-6 GHz 5G frequency applications, antenna design needs the compelling requirements for bandwidth, gain, and miniaturization [1,2]. In traditional antenna design, these requirements face some challenges when aiming to achieve compactness without any functionality [3]. Origami based engineering technique, which is aimed to fold flat sheets into complex three dimensional structure, has gained attention what provides novel approach to develope compact and reconfigurable structures especially antennas [4,5].

By using origami technique approach, it is possible to create flexiable and adaptable structures that can be easly tuned for different frequency bands for applications [6]. The origami principle have been applied various fields such as aerospace engineering, robotics, and deployable structures, that aimed to provide innovative solutions to combine mechanical flexibility with functional performance [7-10]. In the field of antenna design, origami techniques have opened new possibilities for developing antennas with adjustable geometries that allows dynamic reconfiguration of operating frequencies and radiation patterns [11,12]. In previous studies, it is presented that the feasibility of using origami based design to create compact antenna with enhanced gain and bandwidth parameters [13,14]. For example, origami inspired antennas can be easly adaptable in foldable and deployable systems that makes them ideal solutions for space or volume constrained environments [15,16]. Helix antennas are widely used by their suitability in various communication systems, including satellite communications, wireless networks, and radar systems [17-20]. However, traditional helix antenna configurations are rigid and limiting their integration into compact or portable devices [21,22].

This research focuses to address this gap by introducing an origami inspired approach to the design of a compact helix antenna, which is optimized for the sub-6 GHz 5G frequency bands. The proposed design creates a flexible, accordion-like configuration that allows for significant volume reduction while providing high gain characteristics. By using a copper layer into a thin origami folded substrate, the antenna can be reconfigured through adjustments in the flexion angle of helix structure, that enables frequency tuning 4 GHz and 8 GHz frequency band. The study combines both numerical simulations and experimental validation to demonstrate the effectiveness of this design approach.

2. DESIGN AND ANALYSIS

In each step of the design and numerical analysis, Finite Integration Technique (FIT) based microwave simulation software is utilized. Before the numerical analysis, origami folding technique has been approached which is illustrated in Figure 1 with design and folding processes. As shown, origami technique paves the way for accordion-like flexible structure by various geometric manupilation of a thin paper, the geometric design parameters were aimed to operate at sub-6GHz 5G frequencies between 4 GHz and 8 GHz. Firstly, 1x8 paper is folded in horizontal, vertical and diagonal lines, and then it bended vertically to create a curvature which is also illustrated in Figure 1, then that forms a spiral like structure with accordion-like shape.

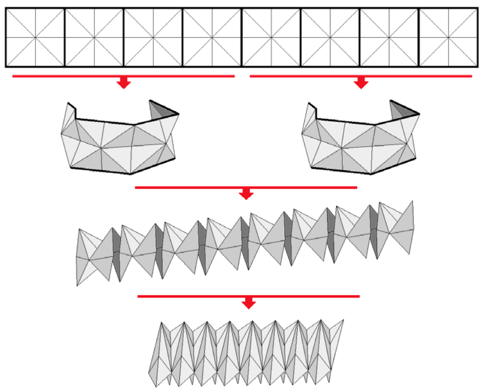

Figure 1. Origami folding technique to design helical accordion

Moreover, a copper line is integrated vertically to 1x8 cell that aims to create an antenna element which is illustrated in Figure 2. The origami approach given in Figure 1 provides the integrated copper line to form a spiral like helix configuration which is also illustrated in Figure 2. This accordion-like helix line with copper material is also integrated to a square metallic plate to create a helix antenna configuration as illustrated below. The advantage of this novel antenna configuration is to have flexible characteristics with its accordion-like shape as shown. The connected discrete port is a 50 ohm standart feeding line to obtain numerical return loss and radiation patterns.

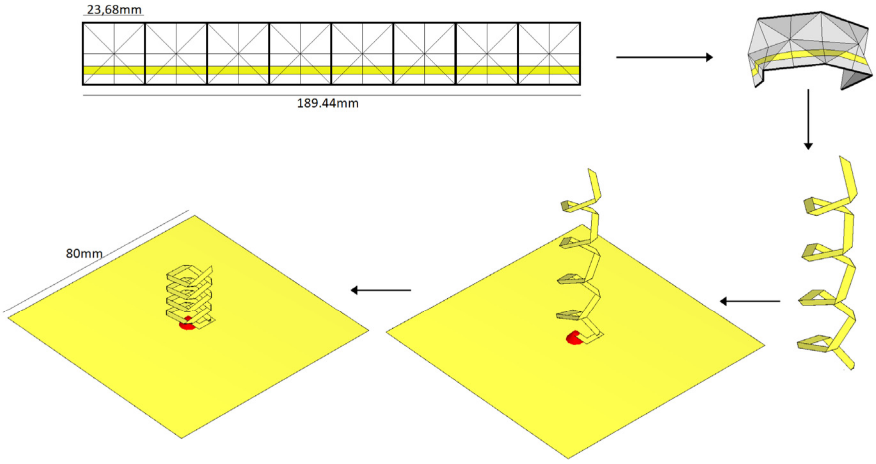

Figure 2. Origami folding based helix antenna design

Furthermore, the flexibility of the proposed accordion-like helix antenna configuration is illustrated in Figure 3. The physical variations of helix antenna versus flexion angle have been examined as illustrated in this figure. The antenna effective length, which affects the operating wavelength, is increased when the flexion angle increase that shown clearly. Figure 3 clearly explains effect of origami technique on helix antenna design, the advantage of this design is to provide lightweight, cheap and compact structure for applications.

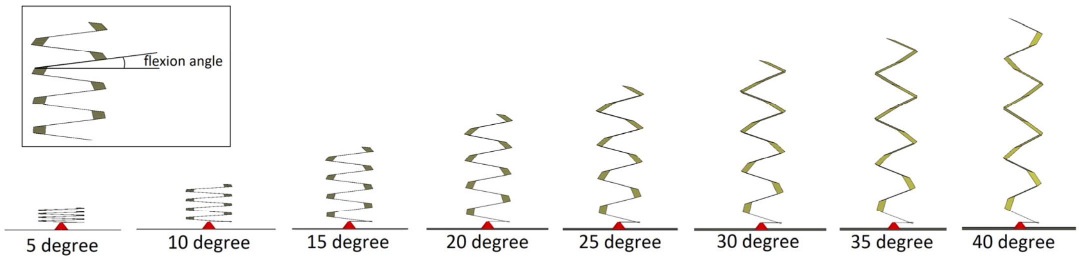

Figure 3. Helix antenna variations versus various flexion angle

To see the effect of flexion angle on antenna S11 return loss parameter, a parametric study was conducted. Figure 4 plots the obtained S11 parameter distributions by the examined parametric study. As shown, designed helix antenna has various resonance band characterictics under different flexion angle condition. The numerical simulations were conducted for the frequency band between 4 GHz and 8 GHz which is sub-6 GHz 5G frequency region for telecommunication applications. For the 5˚ flexion angle, two resonance peaks occur around 5.75 GHz and 7.75 Ghz with -12 dB and -17 dB S11 parameter, respectively. For the 10˚ flexion angle, two resonance peaks occur around 6.2 GHz and 7.45 Ghz with -11 dB and -12 dB S11 parameter. For the 15˚ flexion angle, a single resonance peak observed at around 5.3 GHz with -20 dB S11 level. For the 20˚ flexion angle, two resonance peaks observed, first one is narrow band with -20 dB S11 parameter at 5 GHz and the second one has wide band width with centre at 6 GHz with -17 dB S11 parameter. For the 25˚ flexion angle, a single resonance occurs at 5.1 GHz with -13 dB S11 parameter. For the 30˚ flexion angle, no resonance peak occurs. For the 35˚ flexion angle, a single and narrow resonance peak occurs at 4.8 GHz with -42 dB S11 parameter. Finally, for the 40˚ flexion angle, an ultra wide band resonance obtained from 5 GHz to7 GHz with 2 GHz bandwidh, the S11 parameter is -17 dB at 6 GHz central frequency.

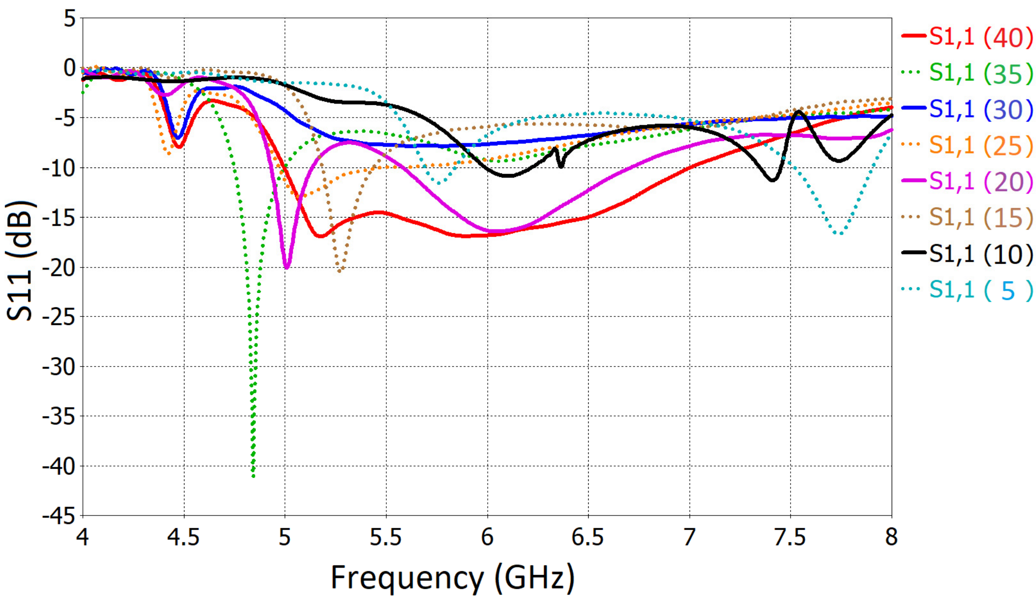

Figure 4. S11 characteristics of proposed helix antenna under different flexion angle conditions

In addition, the farfield radiation pattern distribution of proposed helix antenna is calculated and depicted as shown in Figure 5. This pattern diagrams obtained at 6 GHz with 40 degree flexion angle because the antenna has ultrawide bandwidth at this configuration. Figure 5a and 5b shows proposed antenna structure in side and perspective views with radiation pattern, and the main lobe with a peak gain of 8.32 dBi, indicating a highly focused energy transmission along the axis of the helix. The polar plot of the antenna supports this analysis, showing a main lobe direction at 0 degrees with a 3 dB beamwidth of 68.6 degrees, which indicates a moderate spread of the main lobe that is suitable for applications for precise targeting. Besides, the side lobe level of -9.4 dB shows minimal energy loss in undesired directions.

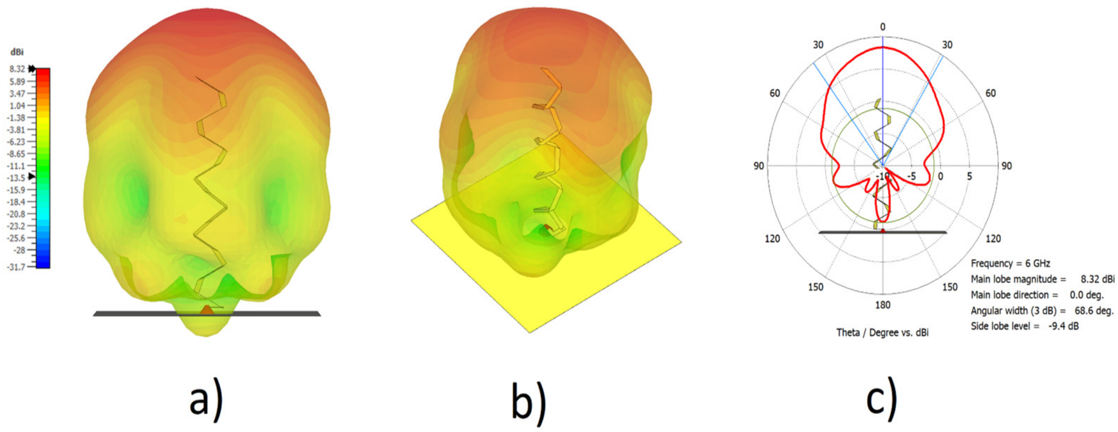

Figure 5. Radiation pattern configuration at 6GHz

3. EXPERIMENTAL RESEARCH

Designed accordion-like origami helix antenna was professionally fabricated by hand which is depicted in Figure 6. In the fabrication processe, a thin origami paper is prepared by some folding steps to locate bending lines, firstly. Afterwards, a thin copper tape is integrated as illustrated in figure, which creates a metallic helical configuration in application. To create helical configuration, prepared paper folded by using origami approach as illustrated in figure. Prepared helical structure is then integrated to a square ground plane which has 50 ohm SMA connector for feeding.

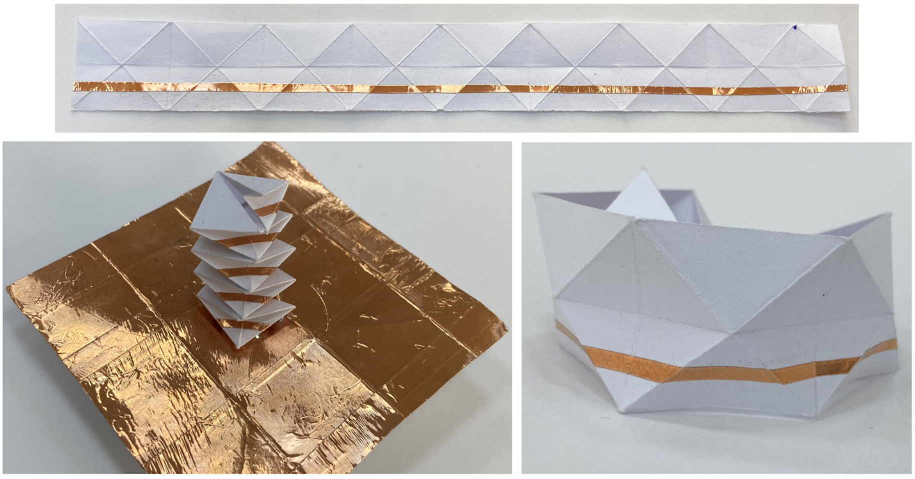

Figure 6. Fabricated accordion-like origami helix antenna

Fabricated accordion-like origami helix antenna was measured in a microwave laboratory by using a vector network analyser as shown in Figure 7a. Before the measurement, some calibration steps were done to minimize losses and noises. Measurement was done at the frequency region between 4 GHz and 8 GHz which is the same frequency band with simulations. Figure 7b and Figure 7c shows the measured S11 parameter characteristics and radiation pattern under 40˚ flexion angle condition.

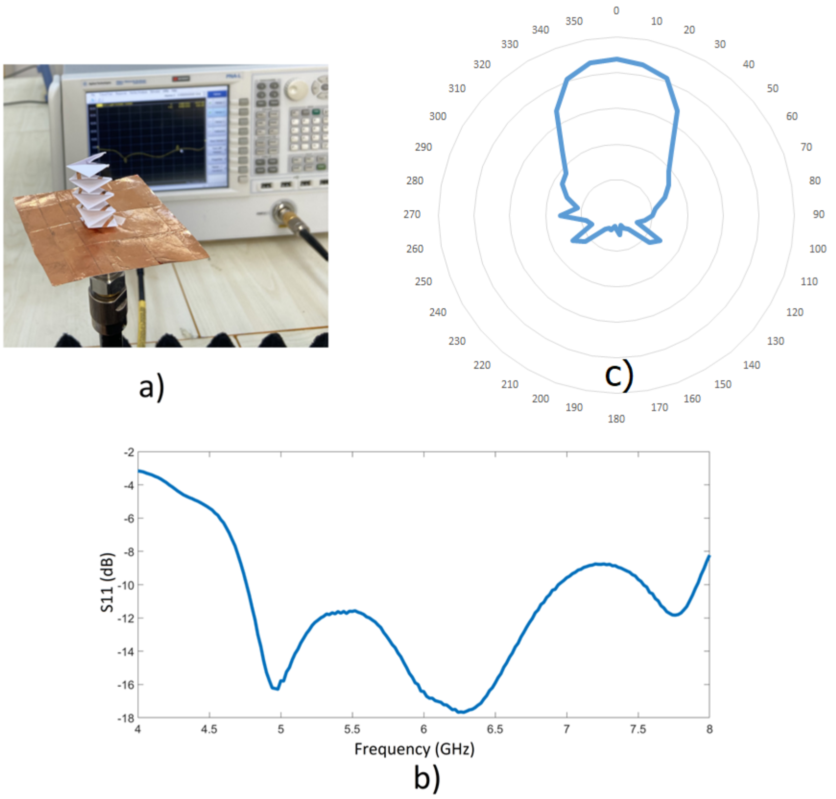

Figure 7. a) measurement setup, b) measured S11 parameter and c) measured radiation pattern of accordion-like origami helix antenna under flexion angle of 40˚

Obtained S11 parameter characteristics has nearly the same resonance band with simulation results. As shown, this antenna configuration has resonance band between 4.8 GHz to 6.8 GHz with a wide bandwidth. The small amount of resonance differences caused by laboratory conditions and fabrication imperfections. It is clearly shown that the proposed antenna structure has a huge poteltial for sub-6 GHz 5G applications by using origami approach in design.

4. RESULTS

This research demonstrated the design, fabrication and experimentally verification of an origami based accordion-like helix antenna structure with high gain characteristics for sub-6 GHz 5G applications. By using the origami technique, a flexible, lightweight and compact helix structure was modelled which is suitable for volume reduction and frequency reconfigurability application by the change of flexion angle. The proposed antenna structure is well optimized to operate at 6 GHz with 2 GHz bandwidth, which has 8.32 dBi gain under 40˚ flexion angle condition. The proposed helix antenna is suitable for next generation sub-6 GHz 5G applications such as 5G networks and IoT. Both numerical and experimental results show a strong agreement that confirms the effectiveness of the origami based design approach. As shown in this study, the innovative use of origami techniques in antenna design opens new perspective for developing adaptable and efficient communication devices as where space, weight, and frequency reconfigurability are important.

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