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Investigation of Origami Inspired Sub-6 GHz Accordion Monopole Antenna for 5G Applications

Duygu Nazan GENÇOĞLAN[1], Şule ÇOLAK*[1]

Abstract

This study presents an origami inspired sub-6 GHz accordion monopole antenna for 5G applications. Parametric study is performed by varying monopole height, fold width and bevel angle to examine the antenna performance in the 1 GHz - 6 GHz frequency range. The proposed antenna is designed with the values that yield the best performance in accordance with the results of parametric study. Antenna behavior is then evaluated in terms of Return Loss, gain and radiation pattern. The proposed antenna operates in 1.22 GHz - 6 GHz frequency range which covers almost the entire sub-6 GHz range with an approximate impedance bandwidth of 132%. Hence, the designed antenna structure has a good performance in the sub-6 GHz and it is a promising design for 5G applications.

Keywords: Accordion monopole antenna, communication systems, origami, sub-6GHz, 5G

1. INTRODUCTION

The millimeter-wave (mm-Wave) bands provide large bandwidths which contribute higher data transmission rate via Fifth Generation (5G) applications. Therefore, new challenges and demands have emerged by up to date applications [1-16]. The main purpose of 5G communication systems is to assure people's interaction, device interconnection, and connection of people to devices [17-19].

5G services are generally categorized as enhanced mobile broadband, mission-critical control, and massive Internet of Things (IoT) [3]. The IoT phenomena are generally associated with smart devices such as wireless communication systems, sensors and RFID systems [20]. Wireless communication systems with 5G applications consist of several components including batteries, sensors, actuators, interconnections and antennas [3-10, 14, 20]. Due to the compactness of IoT structure and high-speed data rate for wireless communication, antennas should be miniaturized with improved performance. Ramos et al. designed multilayer Yagi with compactness for IoT sensors whose operating frequency is 24 GHz. The proposed structure has been compared with the conventional planar type of Yagi-Uda version. The results showed that the prototype provided higher gain and larger bandwidth as compared to the conventional planar type [3]. Sanam et al. proposed a basic SRR loaded, dual-band UWB MIMO antenna for IoT applications with miniaturized antenna size. Additionally, SRR has been performed as a decoupling element

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for creating notch band feature between C-band and X-band range. The simulation and experimental results were compatible with each other [4]. Hassan et al. proposed dual band-notched structure with large bandwidth and compact size for IoT applications [5]. Similarly, there are many such studies on antenna design for 5G/IoT applications in the literature [6-15].

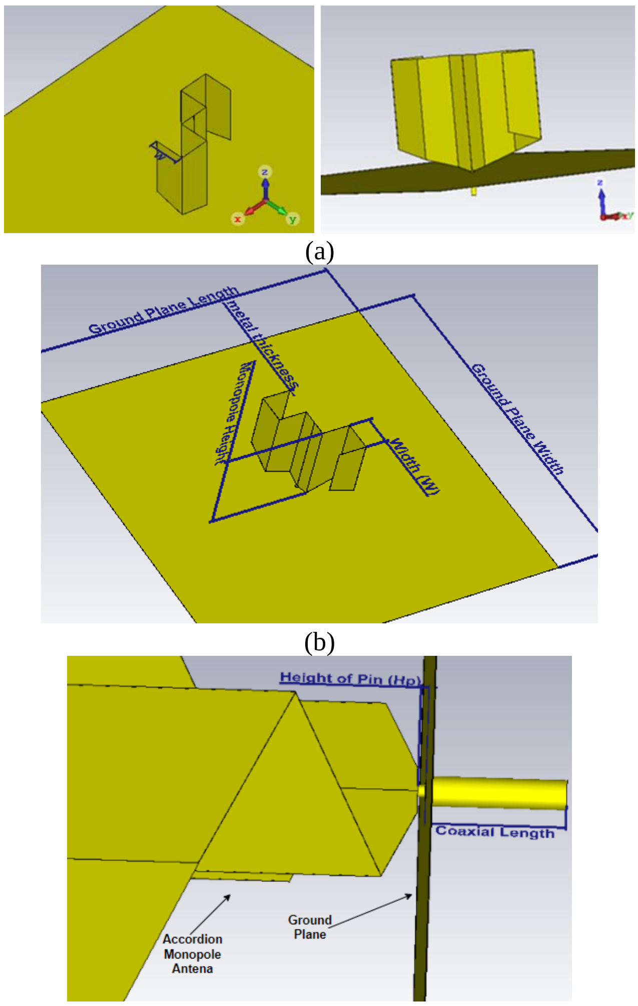
Origami is a kind of art which provides to fold the paper to obtain a shape corresponding to an object. This popular folding technique has recently been getting attention by the scientists and mathematicians [21-27]. This miracle work of art has also provided insight into electromagnetic system designers for a variety of applications as antennas [28-43] and absorbers [44], in the last few years.

Recently, implementation of smart devices such as electro-textiles and wearable antennas with IoT kits has been getting attention due to the advantages as small dimensions, lightweight, and flexibility [45-54]. Telecommunication operators generally prefer to employ their base station sites at the 3.5 GHz frequency band in order to employ 5G technology easily. Hence, the sub-6 GHz band by using the frequency of 3.5 GHz has been allocated as a candidate band for communication technology of 5G since 2018 [55-59].

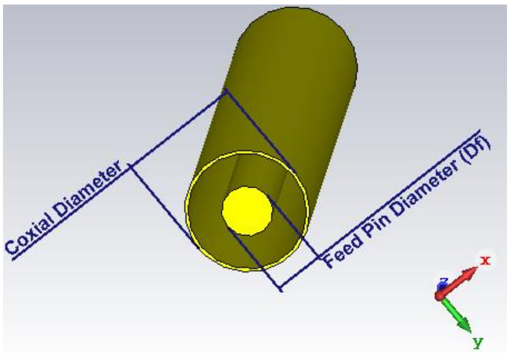
In this study, an accordion monopole antenna is presented and analyzed in the sub-6 GHz frequency range for 5G applications. Section 2 depicts the design of the antenna by using Antenna Magus [60] and CST Microwave Studio Programs [61]. Additionally, parametric study is carried out by means of monopole height, fold width and bevel angle to obtain the best performance in the related frequency range. Then, in Section 3, proposed antenna is designed with selected values in accordance with the results of parametric study. Antenna performance with these specified dimensions is evaluated in terms of Return Loss, gain and radiation pattern in the 1 GHz - 6 GHz range. Finally, concluding remarks are discussed in the last part.

2. ANTENNA DESIGN

The accordion monopole antenna is analyzed by using Antenna Magus [60] and CST Microwave Studio Program [61]. Initially, broadband characteristic is considered for selecting the antenna structure via extensive database of Antenna Magus so to speed up the design [60]. Antenna physical dimensions are calculated considering the frequency range of sub-6GHz [60]. Then, the obtained antenna structure with its parameters is exported to CST MWS to determine the best antenna parameters. The proposed structure is obtained by folding a beveled metal plate into accordion shape, and placing it vertically on metal ground plane. The geometry of the designed structure is shown in Fig. 1. The proposed antenna is fed by 50 Ω coaxial cable. Copper is selected as the conducting material. Dimensions of antenna parameters are tabulated in Table-1.



(a) (b) (c)



(d)

Figure 1 Geometry of origami inspired accordion monopole antenna with different views

Table 1 Physical Dimension Parameters of the Antenna

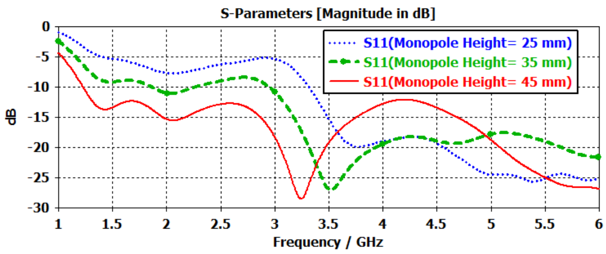
Parameters	Dimension and Units
Monopole fold width(W)	16 mm to 20 mm
Height of pin (Hp)	0.5 mm
Monopole height (Hm)	25 mm to 65 mm
Metal thickness	50 µm
Ground plane width	194.8 mm
Ground plane length	194.8 mm
Feed width	1 mm
Feed pin diameter (Df)	0.8 mm
Coaxial length	9 mm
Coaxial diameter	1.84 mm
Bevel angle (θ)	5° to 28°
Base width	4 mm

2.1. The Effect of Monopole Height on Antenna Performance

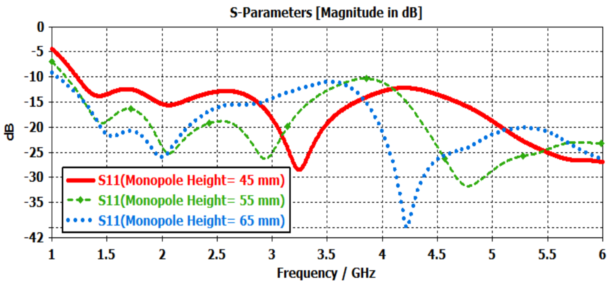
Due to the origami inspired structure, the designed antenna may show different performances with different monopole heights. That's why, the monopole height effect on the antenna characteristics is examined by using parameter sweep tool in CST MWS program. Parametric analysis of Return Loss for different heights are illustrated in Fig. 2. It is apparent from Fig.2 that the monopole height is changed, the resonance frequencies are shifted.

In Fig. 2a, when the monopole height is 25 mm, the bandwidth covers only a fraction of the sub 6 GHz range. As the monopole height is increased to 35 mm, the bandwidth increases slightly too. However, it still covers some part of the range. However, when monopole height is increased to 45 mm, the bandwidth is improved significantly and it covers almost the entire sub-6GHz band. In fact, the bandwidth in this case is 4.77 GHz, ranging from 1.22 GHz to 6 GHz.

In Fig. 2b, bandwidth increases slightly when the monopole height is increased gradually from 45 mm to 65 mm. The minimum Return Loss is achieved when monopole height is 65 mm. On the other hand, with 65 mm monopole height, the antenna has a larger size, which is a disadvantage for applications that require compact structures. Therefore, it is a trade-off that should be considered when designing the antennas. In other words, to achieve larger bandwidth, monopole height needs to be increased. Likewise, with a more compact antenna, the bandwidth is reduced. Considering this trade-off, monopole height is selected as 45 mm to obtain wideband characteristic and more compact size in the study.



(a)



(b)

Figure 2 Return Loss plots for monopole heights of a) 25 mm, 35 mm, 45 mm, b) 45 mm, 55 mm, 65 mm

2.2. The Impact of Monopole Fold Width (W) on Antenna Characteristic

In this section, the fold width (W) impact on the proposed structure is examined by means of parametric study in CST MWS. Return Loss plots for different widths are illustrated in Fig. 3. In these figures, although there are slight differences in the bandwidths, 16 mm fold width yields better bandwidth with more compact size. Therefore, this value is selected for the proposed antenna.

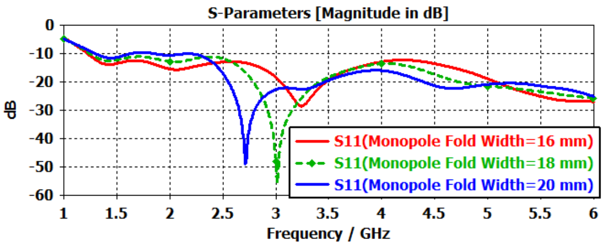
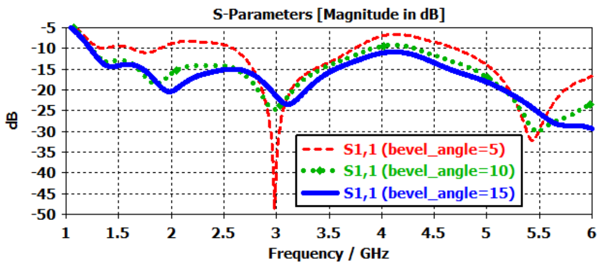


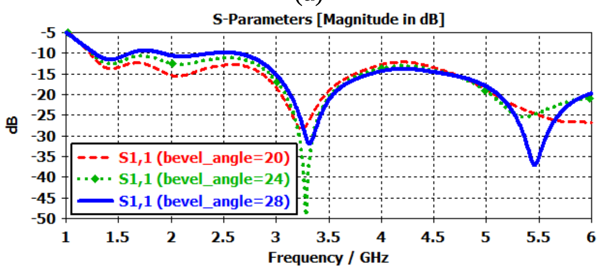
Figure 3 Antenna Return Loss plots for W= 16 mm, 18 mm, 20 mm

2.3. The Effect of Bevel Angle on Antenna Performance

Fig. 4 illustrates Return Loss graphs for six different bevel angles. According to the figures, the antenna with 15° and 20° bevel angles accomplish the -10 dB Bandwidth characteristics. However, the best Return Loss characteristic is achieved by the bevel angle of 20°. Therefore, bevel angle is selected as 20° for the proposed antenna.



(a)



(b)

Figure 4 Antenna Return Loss plots for bevel angles of a) ——— 5°, ------ 10°, ······· 15°, b) ——— 20°, ------ 24°, ······· 28°

3. CHARACTERISTICS OF DESIGNED ANTENNA WITH PROPOSED DIMENSIONS

According to the results of parametric study, proposed antenna is designed with selected values, that is, monopole height of 45 mm, fold width of 16 mm and bevel angle of 20°. The Return Loss plot of the proposed structure, simulated by CST MWS is illustrated in Fig. 5. It is apparent from this figure that the bandwidth is 4.78 GHz ranging from 1.22 GHz to 6 GHz. Hence, it covers almost the entire sub-6 GHz band with an impedance bandwidth of 132%. The minimum Return Loss value is -28.20 dB, which occurs at the resonance frequency of 3.25 GHz.

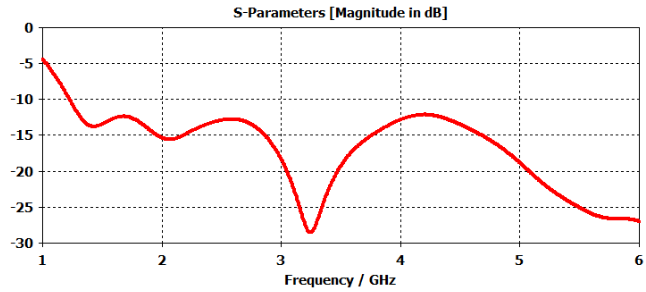
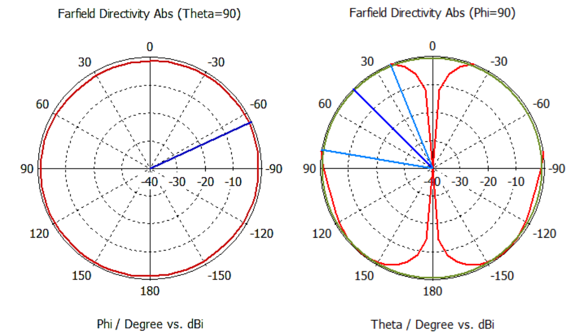
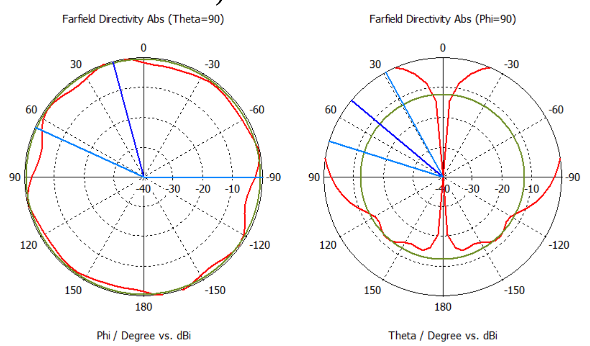


Figure 5 The Return Loss performance analysis of the proposed structure with determined dimensions

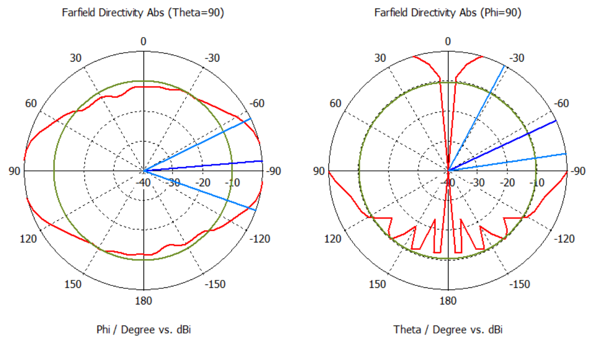
Radiation pattern characteristics of the proposed structure are depicted at different frequencies including the resonance frequency of 3.25 GHz, the lower frequency (1.22 GHz), and 6 GHz. Fig. 6 illustrates the far field 2D polar pattern and Fig. 7 shows 3D Gain of the antenna. It is seen from the figures that at lower frequencies, the antenna has omnidirectional radiation pattern. However, this characteristic tends to deteriorate with increasing frequency.



a) f = 1.22 GHz

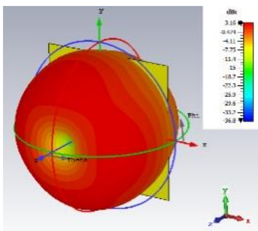


b) f= 3.25 GHz

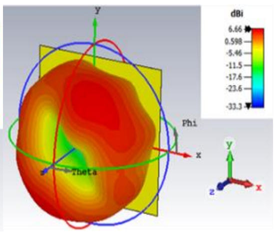


c) 6 GHz

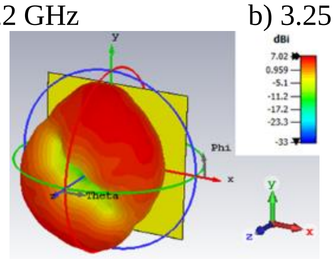
Figure 6 2D Polar Pattern of the designed antenna at a) 1.22 GHz b) 3.25 GHz and c) 6 GHz



a) 1.22 GHz



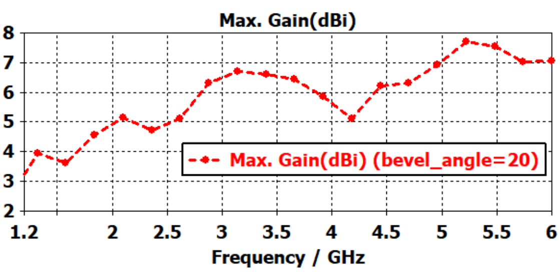
b) 3.25 GHz



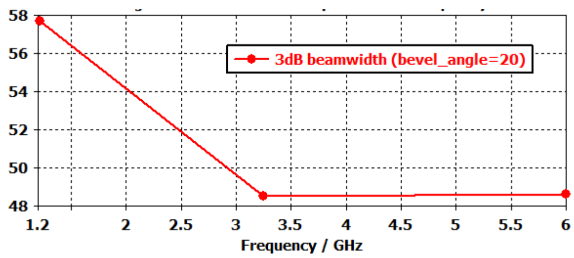
c) 6 GHz

Figure 7 3D Gain of the designed antenna at a) 1.22 GHz, b) 3.25 GHz, and c) 6 GHz

Fig.8 depicts the gain (dBi) and 3-dB beamwidth plots of the proposed antenna structure over the frequency range from 1.2 GHz to 6 GHz. It is deduced from the graphs that the gain increases while the 3 dB-Beamwidth decreases with increasing frequency.



a)



b)

Figure 8 a) Max Gain and b) 3 dB width of the proposed antenna versus frequency

This proposed antenna structure is compared with other origami based antenna structures in terms of operating frequency, bandwidth, and gain parameters as tabulated in Table 2. It is apparent from Table 2 that the proposed structure has broader bandwidth and higher gain. It is worth noting that the proposed design has promising performance as compared to the literature. Additionally, it has also acceptable characteristic for sub-6 GHz 5G communication systems.

Table 2 Origami Based Antenna Structures

Ref.	Origami Based Structures	Operating Frequency	Bandwidth	Max Gain
[28]	Bi-Directional Loop Antenna	1.29 -1.54 GHz 1.31 -1.45 GHz 1.32 -1.48 GHz	250 MHz 140 MHz 160 MHz	2.91 dBi 5.14 dBi 5.91 dBi
[29]	Quasi-Yagi Monopole Antenna	1.65-2.05 GHz	400 MHz	7.3 dBi
[42]	UWB Planar Monopole Antenna	689 - 3460 MHz	2.77 GHz	NA
[43]	Metal-Plate Monopole Antenna	2.18 - 6.59 GHz	4.41 GHz	<3 dB
This Work	Accordion Monopole Antenna	1.23 -6 GHz	4.77 GHz	7.72 dBi

4. CONCLUSIONS

In this research, an origami inspired accordion monopole antenna is examined in the sub-6 GHz range for 5G applications. A parametric study is performed by means of monopole height, fold width and bevel angle to achieve the best antenna performance in the related frequency range. According to simulation results, as the monopole height increases, bandwidth also increases.

However, since antenna size increases with height, it becomes a disadvantage for applications requiring compact structures. On the other hand, the bandwidth is slightly reduced with a more compact antenna. Therefore, there is a trade-off in terms of antenna size and bandwidth. Accordingly, the antenna with monopole height of 45 mm is proposed in this study that achieves a wider bandwidth and more compact size for 5G applications. Then, the effect of fold width of the monopole is examined on antenna characteristics. According to obtained results, bandwidth is decreased as the fold width is increased, and a better bandwidth is achieved with 16 mm fold width. Lastly, antenna behavior is examined by varying the bevel angle and it is seen that 20^0 bevel angle gives the best Return Loss characteristics. Finally, the performance of the proposed antenna with these specified dimensions is evaluated in terms of Return Loss, gain, and radiation pattern in the 1 GHz - 6 GHz range by using CST MWS Program. According to obtained result, the designed antenna covers almost the entire sub-6GHz band from 1.22 GHz to 6 GHz with an impedance bandwidth of 132%, and it has a good performance in the sub-6GHz range for 5G applications.

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The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

Authors' Contribution

The authors contributed equally to the study.

The Declaration of Ethics Committee Approval

The authors declare that this study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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