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Design and Analysis of Novel Ring UWB Antenna

Kayhan ÇELİK[1,*]

[1]Gazi University, Department of Electrical and Electronics Engineering, Faculty of Technology, Ankara, TURKEY

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Abstract

In this communication, the design and analyses of the novel printed ultra wide band ring monopole antenna is presented. The recommended antenna has a pretty small size of 20 x 26 x 1.6 mm^3 which is designed on the FR4 dielectric material which has the dielectric constant of 4.4 and loss tangent of 0.02. The general geometry of the radiating part of the antenna is composed of the circular ring. The antenna has a defected ground structure which has the circular corner points. The antenna feed is placed in asymmetrical position with respect to the y-axis as a microstrip line. The findings obtained by examining the general antenna performance criteria are presented in a systematic way. The findings of the research prove that the proposed antenna has some suitable performance parameters at the UWB frequency range.

1. INTRODUCTION

With the Federal communication commission (FCC)'s announcement that ultra-wide band (UWB) frequency range from 3.1 to 10.6 GHz can be used without a license for the commercial proposes, the studies to use this band continue to increase until today by the scholars [1]. Depending on the increase in applications in this frequency band, the need for broadband antenna designs that will cover the entire UWB band is also increasing [2-4]. When viewed from this perspective, the microstrip monopole structures are the suitable candidate for designing UWB antennas due to their prominent features such as small size, being cheap, being easy of manufacturing and Omni-directional radiation patterns [5-7]. When the literature is examined that, the many monopole antennas have been presented for the UWB or narrow band applications with the different shaped radiators [8-11]. In addition to this, circular ring radiator is an also popular structure for the UWB antenna designs which ones have the advantages of the improving the antennas performances. The following examples can be given to antennas with ring structure found in the literature in an historical order:

One of the early circular ring antenna was presented by Liang et al. [12]. The designed antenna has a volume of 42 x 50 x 1.5 mm^3 with the bandwidth of the 2.75 - 9.84 GHz. The another circular ring antenna which one has the band-rejection at the WLAN band was presented by Hong et. al. [13]. The band rejection was accomplished by the inserting a U-shaped slot or an inverted Y-shaped stub. The more compact antenna from Ref. [12] was presented by Xiao et al. which one has the size of 33 x 28 x 1.4 mm^3 [14]. In Ref. [15], the printed circular-ring monopole antenna with band notched specification at the 5 GHz has been presented with the help of the C-shaped short-circuited stub by Xiao et al. In Ref. [16], the circular-ring antenna with a size of 26 x 28 x 1.6 mm^3 was presented by Liu et al. which has an impedance bandwidth of more than 132% (from 3.7 to more than 18 GHz). In Ref. [17], the novel UWB antenna with dual-frequency notched was presented by Azim et al. The notching of the WLAN and WiMAX bands were achieved with the dual-slot on the radiator. In Ref. [18], a printed ring shaped UWB antenna was presented by Yang et al. which one has the quarter wavelength stub for notching of the WLAN band. In Ref. [19], the novel UWB antenna which one has a dual frequency-notched property was presented by Shi et al. The notched bands were accomplished by an arc H-shaped slot on the radiating element and by etching narrow slots on the ground

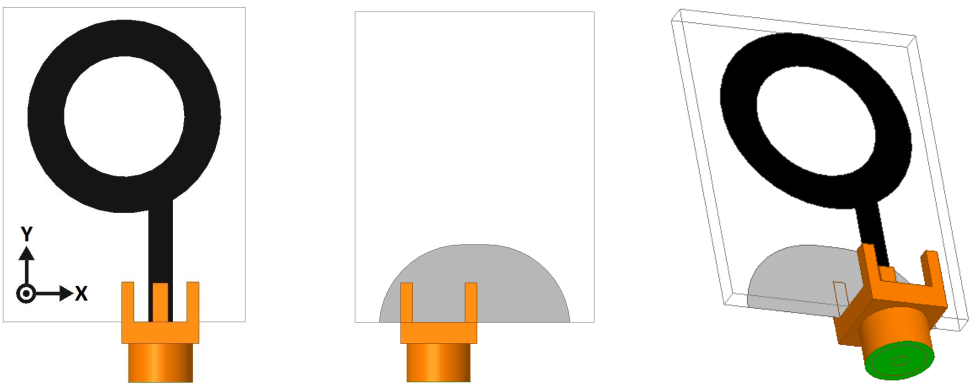
*Corresponding author, e-mail: kayhancelik1923@gmail.com, kayhancelik@gazi.edu.tr DOI:10.29109/gujsc.1078954

plane. In Ref. [20], the ring UWB antenna with the triple band notched was presented by Srivastava et al. by using the elliptical slot and split ring slot in the antenna and a double rectangular single split ring resonators for the notching of frequency bands. In Ref. [21], UWB ring antenna with the triple band notched which were obtained by CSRR and S-shaped slot in feeding line and SSRRP near the microstrip feed line was presented by Yadav et al. In Ref. [22], the novel SWB ring antenna with dual band rejection was presented by Manohar et al. The notching bands of the system were utilized by a U-shaped piece and a T-shaped stub inside the radiation element structure and U-shaped slot. In Ref. [23], a miniaturized ring UWB antenna with tunable notched band was presented by Sharma et al. by the help of setting the coupling between T-shaped strips which were located inside radiation element. In Ref. [24], the rectangular monopole with circular ring antenna for UWB was reported by Lamultree et al. which one works in the frequency bandwidth of 2.56-13 GHz.

In this paper, the design and analyses of the original circular ring antenna is presented. In section 2, the construction of the antenna is presented. In section 2.1 the investigation of the antenna performance is presented. In section 2.2. the parametric analyses of the antenna are accomplished and the obtained results are given. Lastly in section 3, the paper is finished with the conclusion.

2. CONCEPT OF THE ANTENNA

In this part of the paper, the design concept of the antenna is performed. The general form of the intended antenna is given in Figure 1. As seen from the figure, it is easily understanding that the shape of the radiating part of the antenna is a mutated version of the classical circular monopole antenna which one has a circular slot inside it for the aim of decreasing the resonance frequency of the antenna. The outer (R1) and inner (R2) radius of the radiating rings are 8 mm and 5 mm, respectively. In the ground plane, the partial or defected ground is used at the bottom side of the dielectric substrate which one has a circular corners for increasing the antenna performance. The width and length of the ground plane are 16 mm and 6.5 mm respectively. In addition to this, the radius of the circles at the corners of the ground plane is 7 mm. The feeding of the antenna is made with the microstrip transmission line with the size of 2 mm width and 9 mm length. At the same time, the feeding line is shifted 3 mm to the right with respect to the y-axis. In terms of the substrate material, the FR4 is assigned for construction of the antenna which has a dielectric constant of 4.4 and loss tangent of 0.02 with the thickness of 1.6 mm.



a) Top view *b) Bottom view* *c) Perspective view*

Figure 1. *The general shape of the proposed antenna*

The design stages of the recommended antenna are given in Figure 2 which one starts with the classical circular shaped monopole antenna. The formula, which is commonly found in the literature and provides the fundamental resonance frequency of the circular monopole antenna is given by Equation 1 [25-27]:

$$f_L = \frac{7.2}{(l+r+p)} = \frac{7.2}{(2.25R+p)} \quad \text{GHz} \tag{1}$$

In the given formula, R and p represent the radius of the radiating circular and gap between the radiating part and the ground part, respectively.

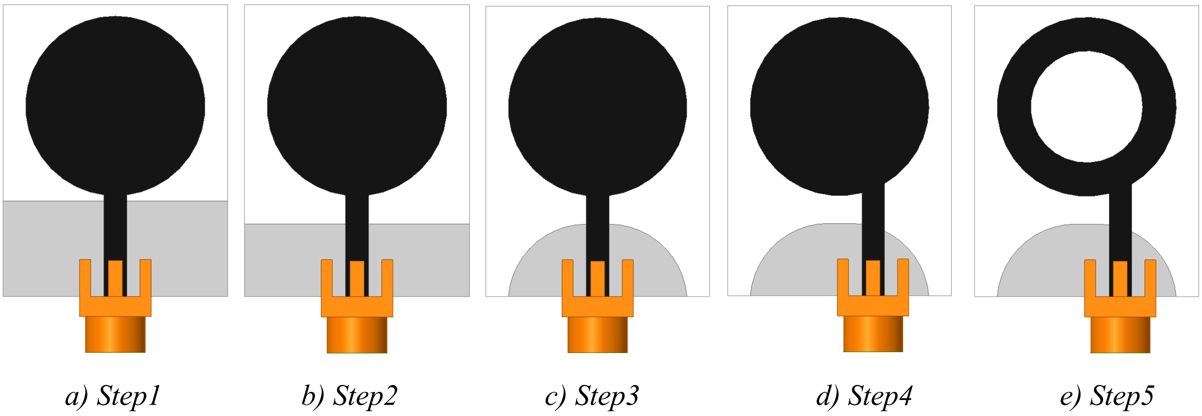


Figure 2. *The design stages of the proposed antenna*

Considering that the R-value is 8 mm and the p value is 0.3 mm in step1, the lower operating frequency of the step1 can be calculated as 3.93 GHz which one verifies the simulated value of the reflection coefficient of the step1 as seen from the Figure 3 (the red line). In the second step, the p value was increased from 0.3 mm to 2.5 mm as seen from Figure 2(b) in order to reduce the antenna lower operating frequency. As a result of this process, the lower operating point of the antenna decreases to 3.3 GHz as it is seen with the green line in Figure 3. For the 2.5 mm value of p, the operating frequency calculated with Equation 1 is approximately 3.5 GHz which one shows that there is a difference between values obtained from equation and the simulation. In the third step, ground structure of the antenna is altered which can be seen in Figure 2(c) in order to boost the antenna impedance range. According to the Figure 3, as a result of this process, there is a decrease of 100 MHz in the lower operating frequency of the antenna and it is seen that the impedance bandwidths improves, especially in the frequencies at the 8 GHz - 10 GHz band.

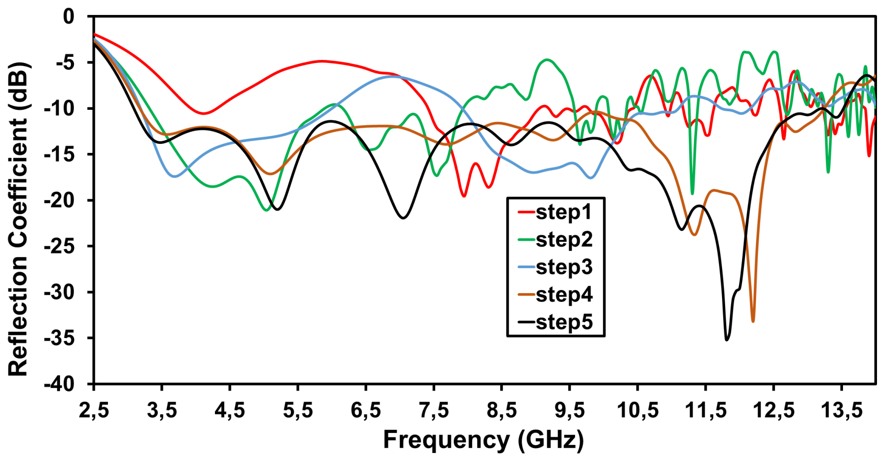


Figure 3. *The reflection coefficient values of the design steps*

In the fourth step, the feeding line, which is symmetrical with respect to the y-axis, is shifted to the right by 3 mm. This process improves the impedance range of the antenna in the 4.5 GHz - 8 GHz and 10.5 GHz - 13 GHz frequency range. Finally, by adding a circular slot inside the circular patch, the lower operating frequency is further reduced by 100 MHz. As a result, the proposed antenna has a suitable bandwidth from 3.07 GHz to 13.6 GHz with covers the UWB band.

2.1. The Investigation of the Antenna Performance

In this part of the paper, the performance parameters of the antenna such as S11, gain, radiation patterns are presented. The crosscheck of the reflection coefficient of the designed structure which are obtained from the different electromagnetic analyses programs are given in Figure 4. According to the figure, it is reality that the files obtained from CST and HFSS programs support each other and prove that the antenna runs on the whole UWB frequency range.

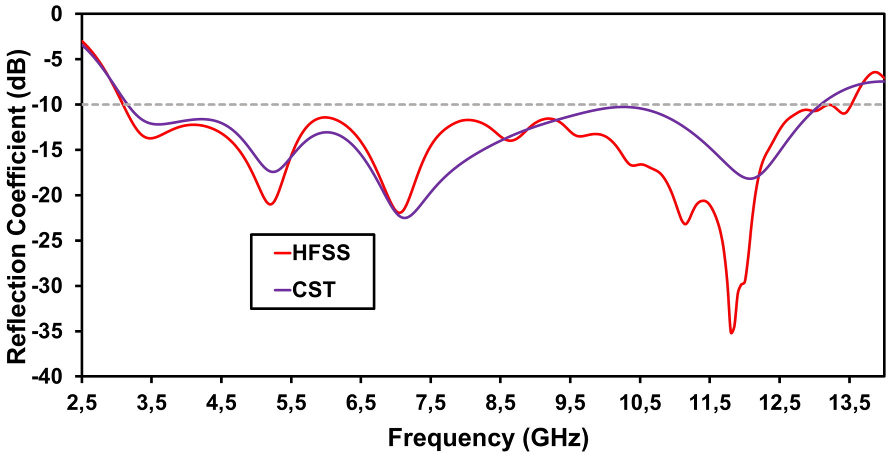
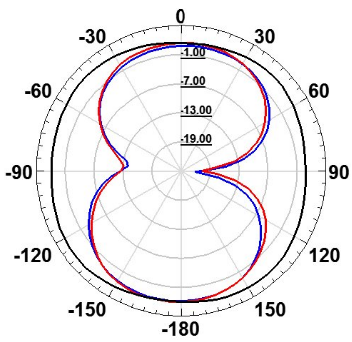
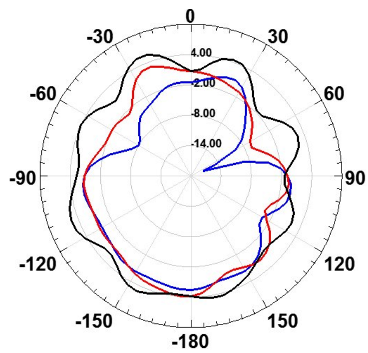


Figure 4. *The simulated reflection coefficient values of the antenna*

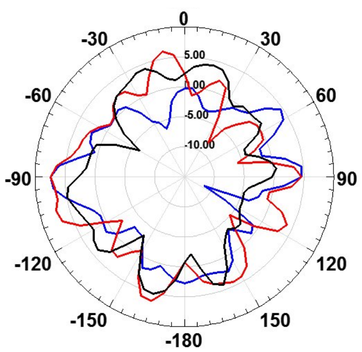
The radiation pattern graphs of the antenna at the various frequencies are illustrated in Figure 5. Since the designed antenna is a monopole, it has an Omni-directional radiation pattern as expected. While it has a more uniform radiation pattern in the low frequency region, however, it is seen that there is a deterioration in the radiation patterns with the increasing of the frequency according to the figures.



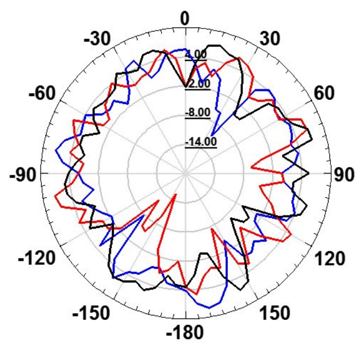
a) 3 GHz



b) 5 GHz



c) 7 GHz



d) 9 GHz

Figure 5. *Radiation patterns of the designed antenna (phi=0 (x-z), phi=90 (y-z), theta =90(x-y))*

The gain of the antenna versus the frequency is examined and given in Figure 6. The antenna has a nearly maximum gain of 3.7 dBi at the frequencies of 6 GHz, 10.5 GHz and 13.4 GHz and it has a minimum gain value of the 1.82 at the 3 GHz band.

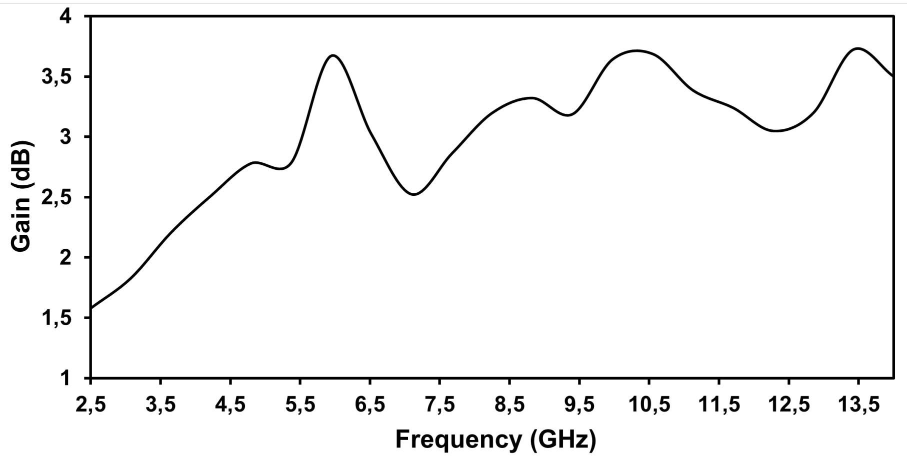


Figure 6. *The gain of the antenna versus frequency*

2.2. The Parametric Analyses of the Antenna

In this part of the paper, the parametric analyses of the antenna are investigated. Analyzes are carried out over the antenna parameter variables given in section 2. By taking these values as a constant, only the analyzed parameter is changed.

Firstly, the length of the ground plane is examined in the range of 5 mm – 7 mm and the reflection coefficient results of the antenna are submitted in Figure 7. According to the figure that, the optimum value of the ground length is 6.5 mm. The value of the ground length for the 7 mm increases the lower operating frequency. In addition to this, for the values especially from 6.5 mm to 5 mm, the bandwidth of the antenna deteriorates.

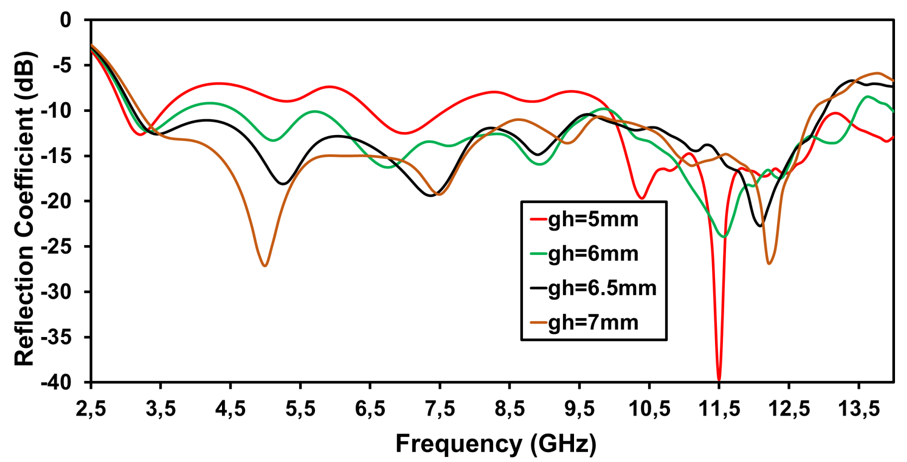


Figure 7. *The reflection coefficient of the antenna depending on the ground length*

The fluctuation of the reflection coefficient of the antenna versus the ground width is depicted in Figure 8. It can be said that increasing of the ground width from 12 mm to 16 mm, effects the reflection coefficient positively. After the 16 mm, it makes the reflection coefficient of the antenna worse.

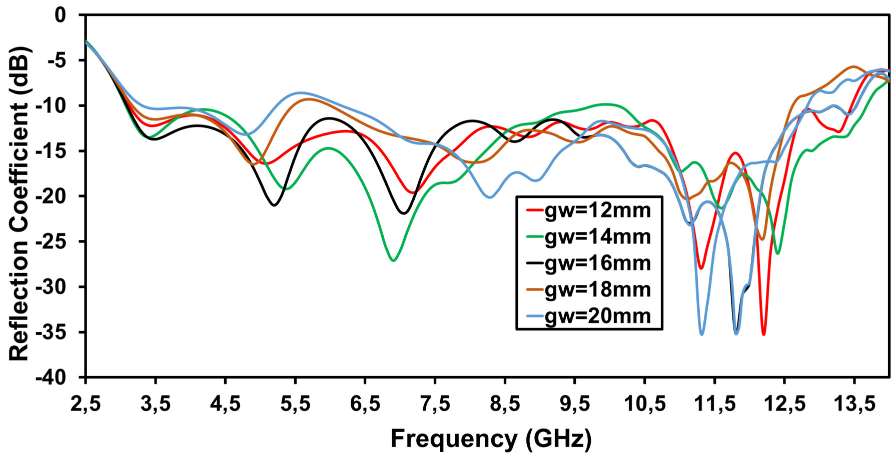


Figure 8. *The reflection coefficient of the antenna depending on the ground width*

The fluctuation of the reflection coefficient of the antenna versus the outer radius of the circular ring is depicted in Figure 9. The main result can be concluded form this figure is that; the changing of the outer radius mainly effects the lower operating frequency.

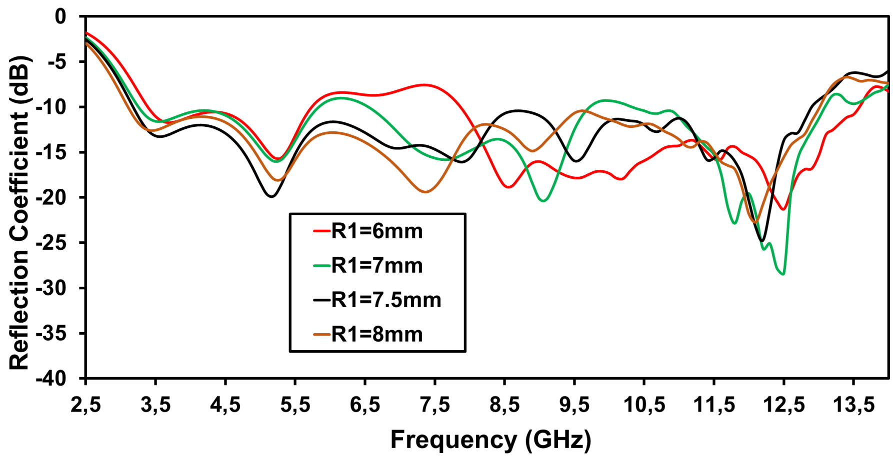


Figure 9. *The reflection coefficient of the antenna depending on the outer radius of the ring*

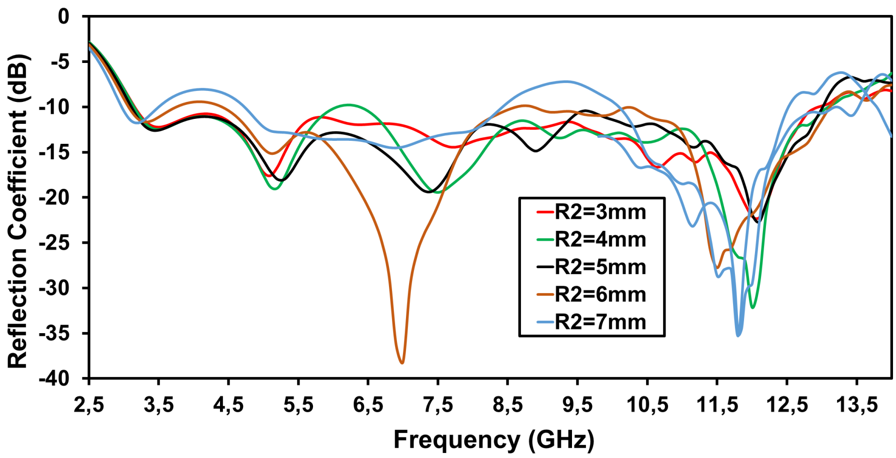


Figure 10. *The reflection coefficient of the antenna depending on the inner radius of the ring*

In Figure 10, the increasing of the inner radius of the ring monopole from 3 mm to 5 mm does not cause a significant change in the impedance bandwidth of the antenna at the frequencies above 3.5 GHz, however, it decreases the lower operating frequency. As the radius continues to increase, the lower operating frequency continues to decrease. The impedance matching appears to be distorted in some frequency domains for instance in the 3.5 GHz - 4.5 GHz and 7.5 GHz - 10 GHz bands.

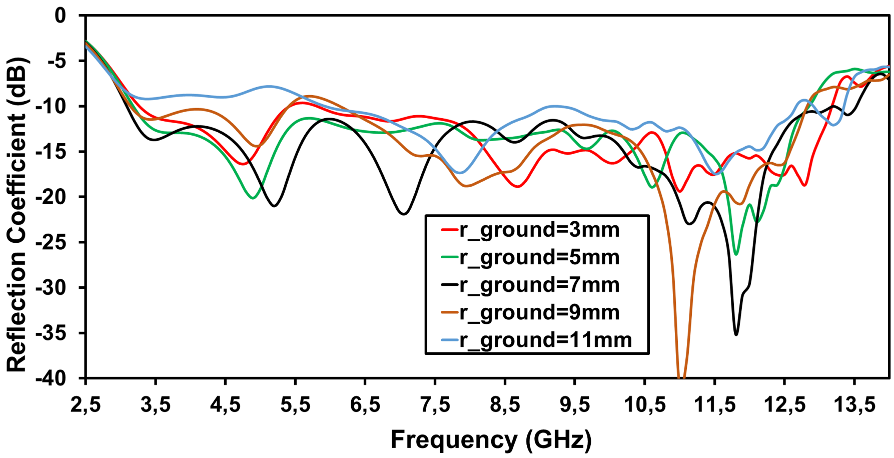


Figure 11. *The reflection coefficient of the antenna depending on the radius of the ground's corner*

Lastly, the radius of the circles at the ground plane corners is examined and given in Figure 11. Increasing the radius from 3 mm to 7 mm influences the impedance bandwidth of the antenna positively, while increasing it from 7 mm to 11 mm affects it negatively.

The performance similarities of designed antenna with its counterparts in the literature is also tabulated and addicted in Table 1. It is clearly seen that Ref. [13, 23] are the most compact antennas. According to the table, the recommended antenna is nearly as compact as Ref. [16,17, 21] and the size of the proposed one is not so bad. In term of the bandwidth and gain, it has a satisfactory value.

Table 1. The comparison chart of the designed antenna

Reference	*Size (mm^3)*	*Bandwidth (GHz)*	*Gain (dBi)*
[12]	*42 x 50 x 1.5*	*2.75 - 9.84*	*N. A.*
[13]	*18 x 20 x 1.6*	*3.1 - 10.6*	*2 – 8*
[14]	*33 x 28 x 1.4*	*3 - 12*	*N. A.*
[15]	*33 x 28 x 1.4*	*3 - 12*	*2 – 7*
[16]	*26 x 28 x 1.6*	*3.7 - 18*	*2 – 7*
[17]	*26 x 24 x 1.6*	*2.79 to 11*	*average 2.9*
[18]	*20 x 30 x 0.8*	*3.06 -10.8*	*2.1- 4.2*
[19]	*35.5 x 30 x 1.6*	*2.9 - 10*	*N. A.*
[20]	*35 x 30 x 1.6*	*2.5 to 11.85*	*4 – 9*
[21]	*26 x 30 x 1.6*	*3.10 to 10.60*	*3 – 7*
[22]	*24 x 30 x 0.787*	*1.6–25*	*-6 – 5.8*
[23]	*12 x 18 x 1.6*	*3.5 to 10.6*	*-16 – 4*
[24]	*40 x 40 x 1.6*	*2.56 -13*	*maximum 2.8*
Proposed	*20 x 26 x 1.6*	*3.07 -13.6*	*1.8 – 3.7*

3. CONCLUSION

In this study, the design and analyses of the novel printed ring monopole antenna was presented. The antenna performance parameters were investigated. In addition to this, the parametric analyses on the antenna variables were investigated. The analyzed antenna has a compact size of 20 x 26 x 1.6 mm^3, which has the impedance bandwidth of nearly 10.5 GHz from 3.07 GHz to 13.6 GHz covering the entire UWB range. In addition to this, the proposed antenna has an Omni-directional radiation patterns as expected. While it has a more uniform radiation patterns in the low frequency region, it is seen that there is a deterioration in the radiation patterns with the increasing of the frequency according to the figures. The antenna has a nearly maximum gain of 3.7 dBi at the frequencies of 6 GHz, 10.5 GHz and 13.4 GHz and it has a minimum gain value of the 1.82 dBi at the 3 GHz band. As a result, it can be concluded that the designed antenna has a satisfactory performance values for the UWB applications.

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