Highly Miniaturized Triple Band Classical Patch Shaped Antenna for WLAN and WiMAX Applications

Kayhan Çelik
Gazi University, Department of Electrical and Electronics Engineering,
Faculty of Technology, Ankara, Turkey,
kayhancelik1923@gmail.com, kayhancelik@gazi.edu.tr, ORCID: 0000-0003-0371-0473

Abstract: This communication presents the novel triple-band monopole antenna in the shape of a traditional patch antenna, which is made up of a rectangular radiator with a slot and double stub loaded defected-ground structure. The antenna works on the triple bands of *2.4, 3.5, and 5.8 GHz*, respectively, and it is made on the standard FR-4 dielectric material. The volume covered by the antenna is relatively small, which is $20 \times 20 \times 1.6\ mm^3$ or $0.16 \times 0.16 \times 0.0128\ \lambda^3_0$ (λ_0 is the wavelength in free space at *2.4 GHz*). The data obtained from the measurements prove that the antenna has bandwidths of *100 MHz* at *2.4 GHz, 100 MHz at 3.5 GHz, and 300 MHz at 5.8 GHz* bands, respectively. It has maximum gain values of *2.91*, *0.5*, and *5.5 dBi*, and the antenna works efficiently on the proposed WLAN and WiMAX frequency bands. It can be posited that the suggested antenna system is a suitable option for WLAN and WiMAX band wireless applications.

Keywords: Triple-band antenna, Multiband monopole antenna, WLAN, WiMAX.

1. Introduction

It is observed that the need for multi-frequency antennas has risen in the last few years for use in Worldwide Interoperability for Microwave Access (WiMAX) and Wireless Local Area Network (WLAN) frequency bands due to the excessive increase in wireless systems [1]. The multiband planar monopole antennas are the promising and emerging structures to meet this increasing need [2, 3]. The reasons for this include their small size, low production costs, high-performance parameters, simple structure, and ability to be integrated into other circuits [4].

It is evident by searching the literature that a wide variety of triple-band antennas were presented for various applications. Application types can be listed shortly as WLAN/WiMAX [5-7], internet of things [8, 9], the fifth generation of wireless cellular technology (5G) [10, 11], satellite, C, X, K, Ku bands [12, 13], Bluetooth [14], Internet of medical things [15], vehicle communication [16], long-term evolution (LTE) [17] and personal communication [18].

In terms of geometric shape or form, the authors presented many various structures for obtaining triple-band. M-shaped antennas [7], antenna featuring an E-shaped parasitic strip [19], and antenna with C-shaped strips [20] are examples of WLAN/WiMAX applications for the letter-shaped antennas. Besides these instances, an E-shaped antenna for Multiple-Input-Multiple-Output systems [21], a Y-shaped antenna for use in the personal communication system and WLAN [18], a Y-shaped antenna for WLAN and 5G applications [11], and a C-shaped antenna for vehicle communication [15] are the other examples for letter-shaped antennas. In addition to these examples, triple-band antennas with metamaterial structures [1, 22-26], and meandered-shaped triple-band antennas [27-31] have also been presented by the authors.

The following triple-band antennas use the slot structure in the radiation element or ground element. A CPW-fed antenna has two inverted L and V-shaped slots [32], an antenna with a radiator printed on a modified substrate with two inverted-L slots in order to produce three distinct resonant modes [33], a slotted antenna consisting of Pi-shaped and inverted-L slot elements in the beveling rectangular patch [34], the antenna which has the radiating element with a pentagonal shape and two bending slots [35], the inkjet-printed U-slot antenna [36], CWP-fed antenna featuring inverted L-shaped slots and split-ring resonator [37], the miniaturized antenna [38] are the leading examples. In addition to these examples, the triple-band antennas for WLAN/WiMAX in Refs. [39-44] have similar shapes, which are made up of different-shaped stubs or strips inside the rectangular or circular radiating elements with the defected ground planes.

A triple-band antenna for the WLAN/WiMAX with a dual-ring resonator [5], and a stub-matched circularly polarized antenna for the C and X bands [6] were implemented by the authors. The common point of these two articles is that they have a ground structure with significant gaps inside them.

In Ref. [45], the proximity-coupled microstrip two-layer antenna, which has a V-shaped patch with a rectangular strip, was presented by Bakariya et al. for WiMAX, Bluetooth, and WLAN applications. Park et al. constructed a triple-band antenna with a folded architecture in Ref. [46] for use with USB dongles. Additionally, a large number of antennas capable of operating in multiple bands have been proposed by academics [47-49].

A unique monopole antenna made of L-shaped strips and two semicircles [50], the antenna with the novel crinkle fractal structure with resonance frequencies of *1.780/3.520/5.260 GHz* [51], novel antenna, which is made up of stub, patch, and strip in different shapes [52] are triple-band antennas found in the scientific papers and designed for the WLAN/WiMAX. Additionally, the innovative antenna features a ring resonator, an inverted U-shaped slot, a rectangular radiator with an arc-shaped edge [53], the novel antenna with toothbrush-shaped and inverted U-shaped patches and a meander line [54], a claw-shaped monopole antenna with three arms for generating independently adjustable frequencies [55], the ACS-fed antenna with the open-ended slots [56], a microstrip-fed antenna that has a defected ground, a Y-shaped patch, and a modified circular monopole [57], the CPW-fed antenna consisting of T and L shaped monopole [58] are the other triple-band antennas for the WLAN/WiMAX bands.

This communication proposes the design and analysis of a novel, highly miniaturized triple-band antenna for WLAN and WiMAX systems in the *2.4, 3.5,* and *5.8 GHz* bands. In the next section, the information about the concept of the antenna is addressed. In section 3, the analyses of the antenna according to the design variables are addressed. The experimental findings and comments are presented in Section 4. Lastly, the presentation concludes with a summary.

2. The Proposed Antenna

In this section of the document, the conceptual design of the recommended antenna system is submitted step by step. The design variables of the antenna and its views from different angles are presented in Table 1 and Fig. 1. For the implementation of the antenna, a widely used insulating material, FR4, with a thickness of *1.6 mm*, relative permittivity of *4.4,* and loss tangent of *0.02,* was chosen. The intended antenna is a modified variant of the rectangular patch antenna, as observed in the drawings, particularly in the ground. Unlike the patch antenna, it has a monopole structure, which means that it has a defected ground plane. At the same time, at the left and right edges of the ground plane, it has a double stub structure with different lengths. Apart from the stubs, there is a slot in the middle of the ground, which is placed symmetrically to the y-axis. Lastly, the antenna has a slot in the radiating patch. Through the use of a SMA connector, the antenna is fed via a *1 mm* feeding line. Commercial electromagnetic program Ansys-HFSS is used for the antenna's simulations and analyses.

The process steps that make up the design of the novel antenna and the *S(1,1)* values of these steps are stated in Figs. 2 and 3, respectively. The initial design of the antenna is accomplished with the rectangular monopole antenna, as seen in Fig. 2(a), which means that it has a defected ground plane for obtaining the wideband operation. The general design equation of the rectangular monopole antenna is expressed by *Equ. 1* [59]:

$$f_L = \frac{7.2}{l + r + p} = \frac{7.2}{L + \frac{W}{2\pi} + p} \quad GHz \qquad (1)$$

In this equation, *W* and *L* represent the width and length of the patch, and *p* represents the gap between the radiating element and the ground. Based on the antenna specifications listed in Table 1 (*W = 17 mm, L = 10 mm, and p = 1 mm*), the antenna's minimum operational frequency at step 1 is roughly *5.2 GHz*. However, as illustrated in Fig. 3, the impedance of the antenna is not well matched at this frequency, and the *S(1,1)* value is around *3 dB*.

In the second step, the stub is inserted into the left edge of the ground plane, which has a length of *d1 (12 mm)*. The effect of this stub is that it creates a resonance at the *3.25 GHz* frequency band. In step 3, the other stub is inserted to the right edge of the ground. At the end of this process, a second resonance occurred at nearly *6.2 GHz*. However, the impedance matching of the antenna is not very suitable, especially at the new frequency band. In step 4, a slot that has a thickness of *0.5 mm* is etched into the middle of the patch to attain the *3rd* resonance frequency at *3.5 GHz*. The following deduction can be obtained from Fig. 3; the addition of this slot reduces the minimum frequency from *3.26* to *2.83 GHz* and minimizes the upper operating frequency from *6.2* to *6 GHz*.

In step 5, a new slot is inserted at the bottom of the feeding line, bisecting the ground plane to increase the antenna's electrical length while decreasing its working frequency. With this process, the primary frequencies are reduced from *2.83* to *2.52*, from *3.55* to *3.5*, and from *6* to *5.7 GHz* respectively. Finally, inset slots have been added between the radiating patch and the feeding line for further reduction in operating frequencies and to get better impedance matching. Consequently, the designed antenna works on the triple bands of *2.4*, *3.5*, and *5.8 GHz*, respectively. The stubs and slots utilized in the antenna design assure triple-band functioning; also, these features increase the electrical length of the antenna while decreasing the antenna's working frequency. As a result, a highly miniaturized antenna is obtained.

3. Parametric Analyses of the Antenna Parameters

In the present design, since the antenna provides the ability to work in all three frequencies with the help of the dual stubs on the ground plane and the slot on the patch, the parametric analyses of the antenna are done according to the parameters of these structures. In addition to this, the length and width of the antenna are also considered for the parametric analyses, and the analyses are made using the final design parameters. Firstly, the effect of the patch width on the antenna resonance frequencies is examined, and it is given in Figure 4. The patch width of the antenna is increased from *15* to *19 mm*. According to the figure, increasing the patch width directly affects the resonance frequencies. It is seen that when the patch width is increased, it affects the lower band the most, which decreases from *2.6* to *2.1 GHz*. In the upper band, it causes a shift of *200 MHz* from *5.9* to *5.7 GHz*. For the middle band, it is seen that *±1 mm* change shifts the frequency downward from the optimum value of 17 mm, while *±2 mm* change has no effect.

The effect of the antenna height on the resonances is given in Figure 5. The changing of the patch height from *8* to *11 mm* has no considerable impact on the *2.4 GHz* band. However, the increase in patch height causes a *150 MHz* decrease in the middle band and a *300 MHz* decrease in the higher-frequency band.

The outcome of shifting the length of the first stub (d1) on the resonance frequencies is given in Fig. 6. When the variable is moved from *2 mm* to *12 mm* and when the shifting process is examined graphically, it is easily understandable that the first resonance at the *2.4 GHz* originates especially for the value of *8*, *10*, and *12 mm*. For the values of d1 below *8 mm*, no resonance occurs at this frequency value. A similar effect is also observed in the upper working band. Similarly, at values of d1 greater than 6 mm, resonance occurs in the upper band. The values of d1 for *8, 10*, and *12 mm* resonance occur at *6.7, 6.1,* and *5.8 GHz* bands, respectively. Furthermore, since the resonance is generated at the middle band with the slot on the patch, the alteration of the d1 has a minimal impact on it.

The effect of the width of the first stub (d2) on the resonances is given in Fig. 7. When the width is shifted from 1 to 3 mm, it is easily understandable that it mainly affects the upper band. When d2 is boosted from *1* to *3 mm*, the upper frequency increases from *5.5* to *6 GHz*. Furthermore, it results in a shift in the lower and middle operational frequencies. While the lower operating frequency decreases from *2.6* to *2.3 GHz*, the middle frequency increases from *3.5* to *3.6 GHz.*

The effect of the length of the second stub (d7) on the resonances is given in Fig. 8, and it is shifted between *2 mm* and *5 mm*. According to the information obtained from the figure, the increase of the d7 from *2* to *5 mm* diminishes the lower resonance frequency from *2.55* to *2.2 GHz*. The rise in the d7 from *2 mm* to *4 mm* does not have much effect on the upper band. However, when d7 is *5 mm*, the upper frequency is lower by about *150 MHz*, which has no considerable impact on the middle band.

The effect of the width of the second stub (d8) on the resonances is given in Fig. 9. When the variable is shifted from *1 mm* to *3 mm*, the following result can be obtained: it mainly affects the lower operating band. When d8 is shifted between *1 mm* and *3 mm*, the lower frequency declines from *2.5* to *2.2 GHz*. Additionally, the device exhibits a nearly *150 MHz* shift in the middle operating frequency. And lastly, it can be said that it causes very little change in the upper band.

4. Experimental Results and Discussion

The prototype of the suggested antenna is depicted in Fig. 10, and the simulated and measured reflection coefficients of the structure are also given in Fig. 11. The measured values entirely agree with the values obtained from the simulation; however, it is also a fact that there are minor differences in the measurement values. In the band of *2.2 GHz - 2.3 GHz*, there is a peak value in the measurement, which is not shown in the simulation. The implemented antenna has bandwidths of *100, 100, and 300 MHz* at the frequencies of *2.4, 3.5,* and *5.8 GHz*, respectively.

The image of the antenna for getting the gain values in the anechoic chamber is given in Fig. 12. The radiation patterns of the designed antenna at the *2.4, 3.5,* and *5.8 GHz* bands are shown in Fig. 13. According to Fig. 13(b), it has a nearly Omni-directional radiation pattern at the *Y-Z* plane. On the other planes, it can be said that it has non-uniform patterns. In the middle band, the antenna has bidirectional patterns at all planes. At the upper operating band, the antenna also has a directional pattern at the *X-Z* and *X-Y* planes. Lastly, The radiation pattern is nearly bidirectional at the *Y-Z* plane.

The resonances of the recommended antenna are analyzed with the help of parametric analysis data and the current distributions at the interested frequency bands given in Figure 14. The length of the antenna at the resonance frequencies could be calculated with Equation 2. In this formula, c, λ_g, and ε_{eff} denote the speed of the light, the guided wavelength at the desired frequency band, and the effective dielectric constant of the material.

$$f = \frac{c}{\lambda_g \sqrt{\varepsilon_{eff}}} \qquad (2)$$

For the band of *2.4 GHz*, the resonance is mainly accomplished by the stub lengths of the antenna, which has a length of nearly quarter wavelength ($d1+d7 = 15.5\ mm \approx \lambda_g/4 = 15mm$). For the middle operating band (*3.5 GHz*), the resonance is mainly accomplished by the slot, which has a quarter wavelength of nearly *s1+s2+s3 = 9 mm* $\approx \lambda_g/4$ *=10.2 mm*. For the upper operating band (*5.8 GHz*), the resonance is mainly accomplished by the first stub on the ground plane, which has a quarter wavelength of nearly *d1/2 = 6 mm* $\approx \lambda_g/4 = 6.165$ *mm*. The current distribution and parametric analyses of the antenna prove the given calculations.

The recommended structure is contrasted with the related triband antennas in the literature and categorized in Table 2. The dimensions of the antennas are calculated according to their minimum operating frequencies. The data presented in the table indicates that the proposed antenna has the smallest volume, except Ref. [51], and it suggests that the recommended antenna structure is sufficiently compact. Regarding bandwidth, the recommended antenna has bandwidths of *100 MHz* at *2.4, 100 MHz* at *3.5,* and *300 MHz* at *5.8 GHz* bands, respectively. When the bandwidths of the antenna are compared with others, it has the smallest values at all frequencies; however, thanks to this feature, the recommended antenna can be used in narrow-band wireless applications. Regarding the maximum gain, the antennas in the table have different values, and the values of the proposed antenna are not very low when compared to the other ones, except for the middle band. It has the minimum gain value at the middle band. This constitutes a negative aspect of the designed antenna.

5. Conclusion

The design, simulation, and implementation of the novel classical patch antenna-shaped triple band antenna for the WLAN / WiMAX applications were presented. The antenna was made up of a rectangular radiator with a C-shaped slot and a double stub loaded defected-ground structure, which works on the triple bands of *2.4, 3.5,* and *5.8 GHz*, respectively. The antenna has a very compact volume of *20 x 20 x 1.6* mm^3. The measurement results prove that it has bandwidths of *100, 100, and 300 MHz* at the *2.4, 3.5,* and *5.8 GHz* bands, respectively. It has maximum gain values of *2.91, 0.5,* and *5.5 dBi*. The parametric analyses were done, and the working principles of the antenna were analyzed. The obtained experimental results support the simulations and they also prove that the antenna works efficiently on all three bands.

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Appendices:

Figure List:

Table List:

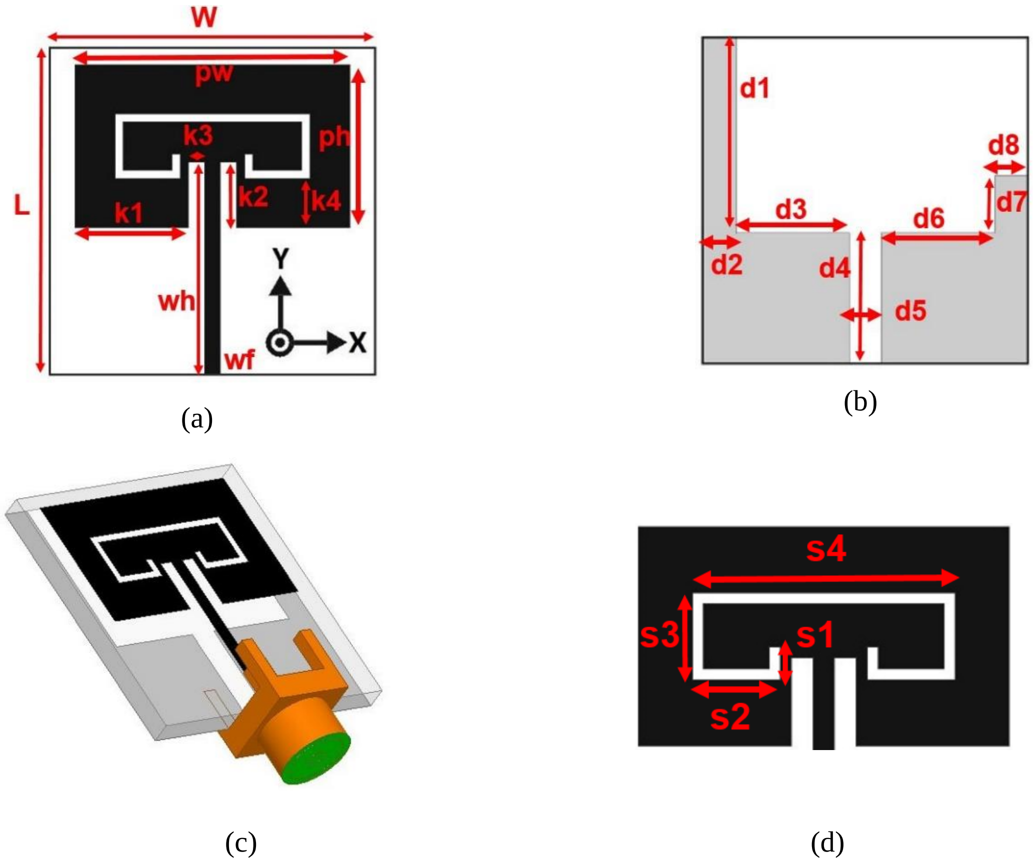
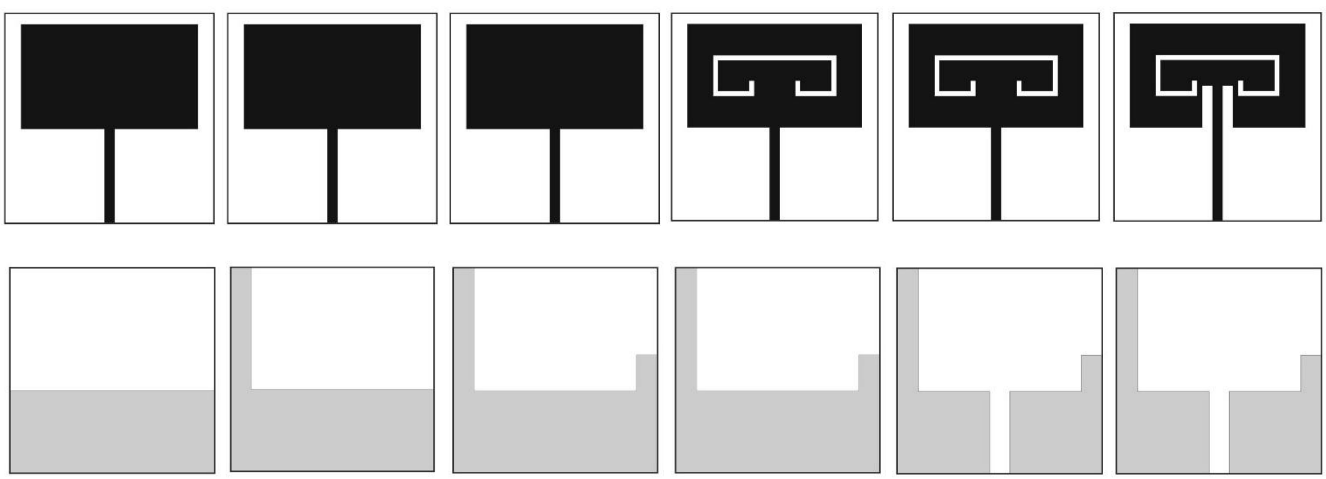


Figure 1. The configuration of the antenna.



(a) step1 (b) step2 (c) step3 (d) step4 (e) step5 (f) step6

Figure 2. The suggested antenna's design stages.

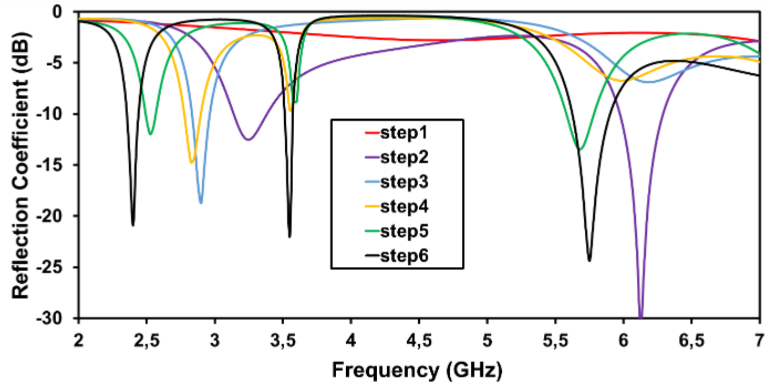


Figure 3. S(1,1) values for each design stage.

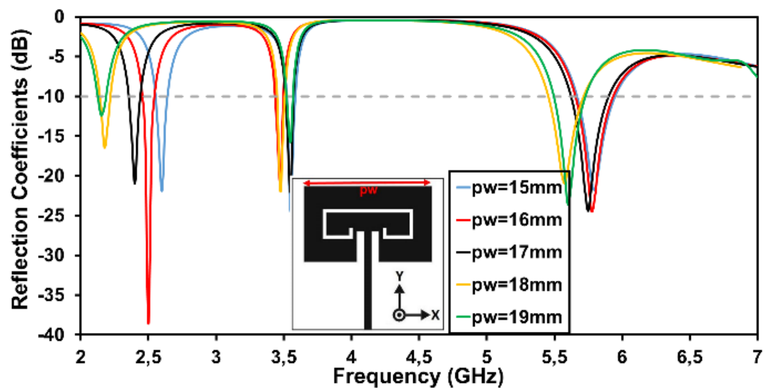


Figure 4. The examination of the antenna in terms of patch width.

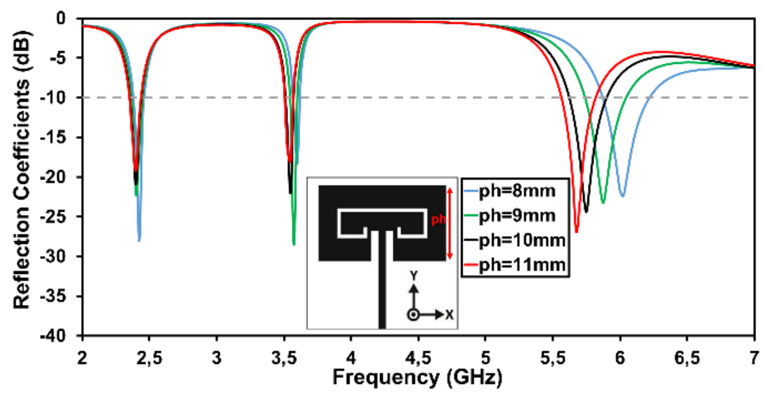


Figure 5. The examination of antenna in terms of patch height.

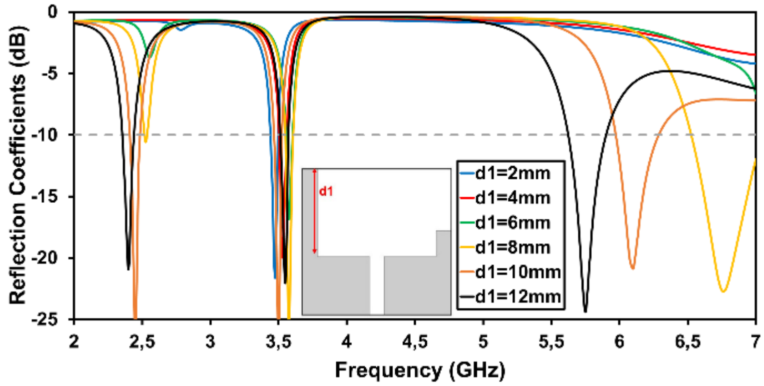


Figure 6. The examination of the antenna based on the d1.

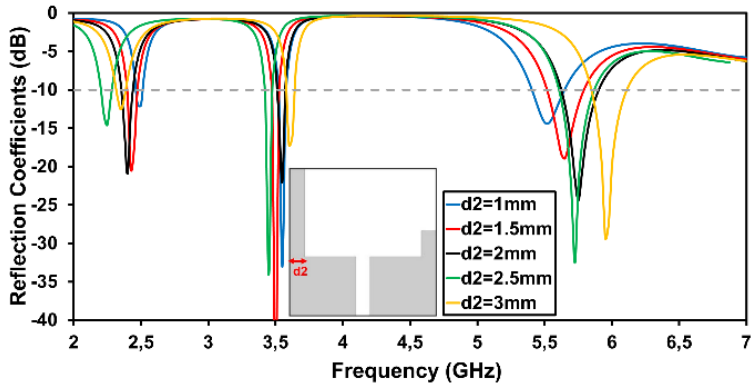


Figure 7. The examination of the antenna based on the d2.

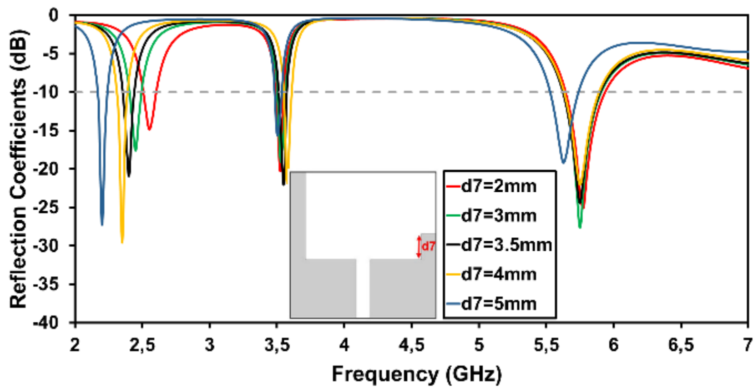


Figure 8. The examination of the antenna based on the d7.

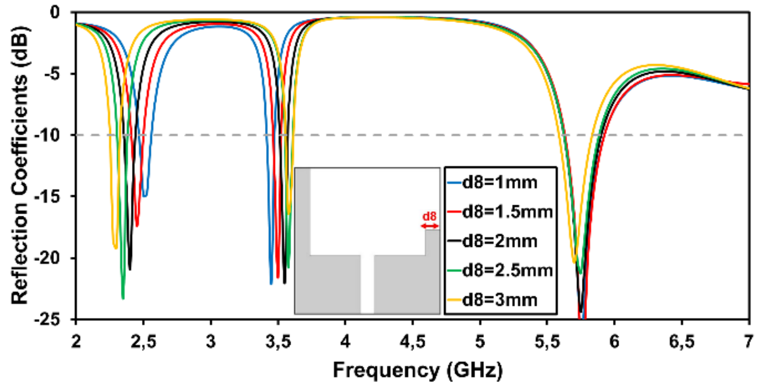


Figure 9. The examination of the antenna based on the d8.

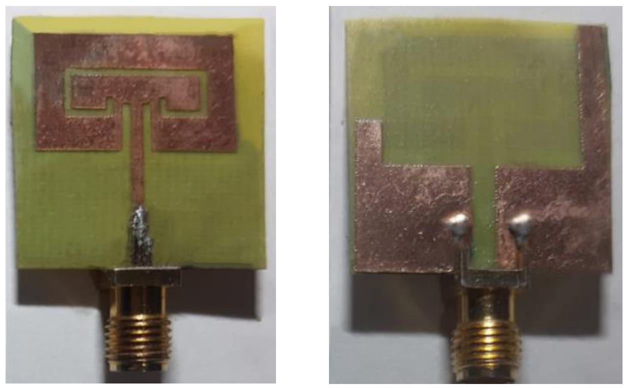


Figure 10. The recommended antenna.

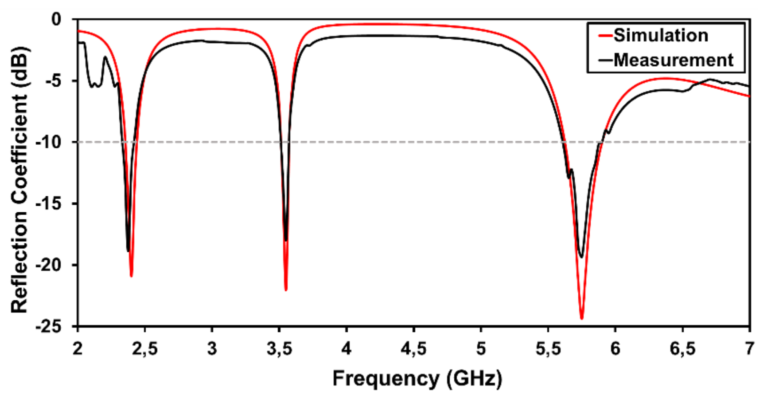
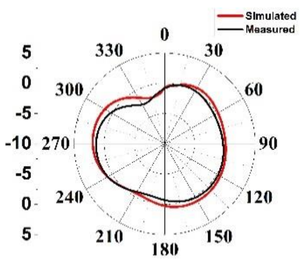
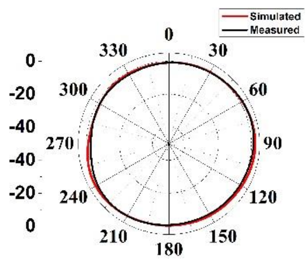


Figure 11. S(1,1) graphics of the antenna.

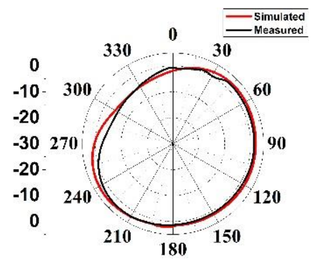
Figure 12. The antenna in the anechoic chamber.



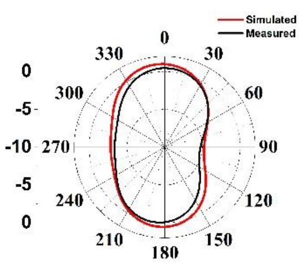
(a) 2.4, X-Z



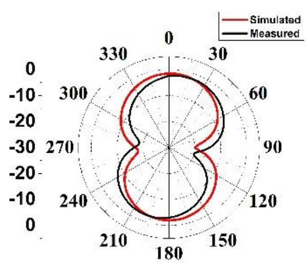
(b) 2.4, Y-Z



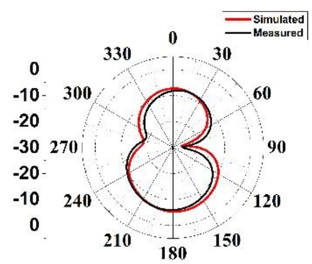
(c) 2.4, X-Y



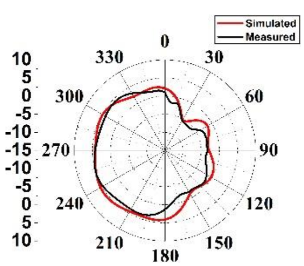
(d) 3.5, X-Z



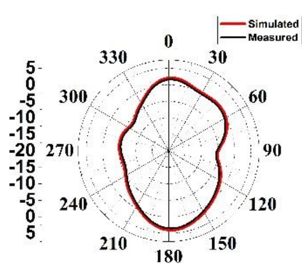
(e) 3.5, Y-Z



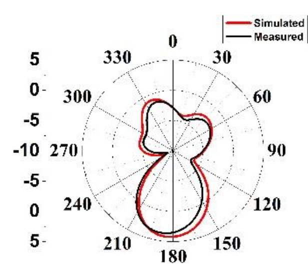
(f) 3.5, X-Y



(g) 5.8, X-Z

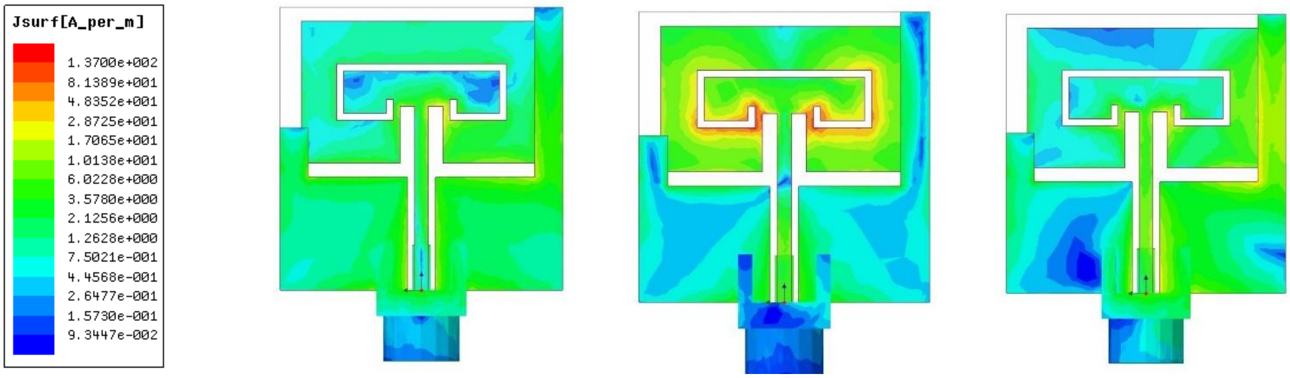


(h) 5.8, Y-Z



(i) 5.8, X-Y

Figure 13. The radiation patterns of the antenna



(a) 2.4 (b) 3.5 (c) 5.8

Figure 14. Current distributions at varying frequencies.

Table 1. The variables of the designed antenna

Parameter	Value (mm)	Parameter	Value (mm)
W	20	k4	3
L	20	d1	12
pw	17	d2	2
ph	10	d3	7
wh	13	d4	8
wf	1	d5	2
k1	7	d6	7
k2	4	d7	3.5
k3	1	d8	2
s1	1.5	s3	3.5
s2	4	s4	12

Table 2. The crosscheck process of the recommended antenna with similar ones.

Ref.	Minimum frequency (GHz)	Size (λ^3_0)	Bandwidth (%)	Bandwidth (MHz)	Operating range (GHz)	Peak Gain (dBi)	Year
This work	2.325	0.16 x 0.16 x 0.0128	4.211 2.837 5.217	100 100 300	2.325-2.425 3.475-3.575 5.60-5.90	2.91 0.5 5.5	2024
[1]	2.02	0.303 x 0.269 x 0.007	25.862 26.866 4.207	600 1080 220	2.02–2.62 3.48–4.56 5.12–5.34	2.23 2.81 1.91	2022
[41]	2.35	0.319 x 0.294 x 0.013	6.982 26.087 13.455	170 960 740	2.35–2.52 3.2–4.16 5.13–5.87	1.22 2.15 4.06	2021
[6]	4.67	0.498 x 0.498 x 0.025	11.504 3.022 2.819	570 220 310	4.67-5.24 7.17-7.39 10.84-11.15	6.23 2.07 2.11	2020
[23]	2.18	0.300 x 0.267 x 0.013	7.930 18.657 6.286	180 500 270	2.18–2.36 2.43–2.93 4.16–4.43	2.89 3.26 4.08	2020
[34]	2.37	0.217 x 0.158 x 0.012	6.135 15.172 44.930	150 550 288	2.37-2.52 3.35-3.90 4.97-7.85	3.9 4.1 3.8	2020
[51]	1.691	0.079 x 0.079 x 0.006	10.585 6.026 5.709	189 212 302	1.691–1.880 3.412–3.624 5.139–5.441	2.7	2016
[5]	2.29	0.214 x 0.244 x 0.008	22.824 17.367 37.109	590 620 190	2.29–2.88 3.26–3.88 4.17–6.07	3.8 - 4.4 4 - 4.65 1.9 - 3.5	2016
[37]	2.28	0.175 x 0.289 x 0.012	11.570 24.533 15.693	280 920 860	2.28–2.56 3.29–4.21 5.05–5.91	1.48 - 1.96 2.1 - 3.22 2.63 - 3.56	2015
[54]	2.4	0.160x 0.240 x 0.006	5.833 8.857 15.272	140 310 840	2.4 3.5 5.5	1.3 2.2 3	2015
[52]	2.4	0.160x 0.240 x 0.006	13.230 9.497 11.511	340 340 640	2.4-2.74 3.41-3.75 5.24 -5.88	2.08 1.93 2.48	2014
[19]	2.33	0.163 x 0.241 x 0.012	19.380 19.337 43.209	500 700 2370	2.33 - 2.83 3.27 - 3.97 4.3- 6.67	2.02 1.69 2.52	2012
[53]	2.37	0.198 x 0.332 x 0.008	13.752 18.231 19.780	350 680 1080	2.37-2.72 3.39-4.07 4.92-6.0	2.65 - 2.93 2.69 - 3.49 4.50 - 4.22	2010

Biography:

KAYHAN CELIK was born in Kayseri, Turkey, in 1990. He received a B.S. degree in Electrical and Electronics Engineering from Erciyes University, Kayseri, Turkey, in 2011. He earned his M.S. and Ph.D. degrees from Gazi University, Ankara, Turkey, in 2015 and 2021, respectively. In 2023, he was assigned to the position of Assistant Professor at the Electrical and Electronics Engineering Department, Faculty of Technology, Gazi University in Ankara. His research interests include energy harvesting, antenna design, chaotic circuits, and image encryption algorithms.