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1.4 ve 2.4 GHz RADAR UYGULAMALARI İÇİN REFLEKTÖR MİKROŞERİT DİZİ ANTENİ

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Anahtar Kelimeler	**Öz**
Mikroserit anten, Radar, Yansitici, Yuksek kazanc, HPBW.	Bu calışmada kısa menzilli radar calışmaları icin kazancı yuksek olan, reflektorlü E-şekilli dizi mikroşerit anten tasarımı sunulmaktadır. Substratın üst yüzeyindeki E-şekilli dipoller, FR-4 substratının tabanı olan duzensiz bir mikroşerit hattı ile temas ettirilmektedir. Anten kuaksiyel besleme ile uyarılmıştır. Alt tabaka malzemesi ve krom yansıtıcı birbirine Teflon malzeme ile tutturulmuştur. Önerilen anten, 1.4 ve 2.4 GHz rezonans frekanslarında sırasıyla 7.85 ve 9.62 dBi kazanç sunmaktadır. Bu anten ayrıca 15 dB'in uzerinde F/B oranına ve kısa mesafeler icin kullanılabilecek bir HPBW (half power beam width) değerine sahiptir.

REFLECTOR MICROSTRIP ARRAY ANTENNA for 1.4 AND 2.4 GHz RADARS APPLICATIONS

Keywords	**Abstract**
Microstrip antenna, Radar, Reflector, High gain, HPBW.	This study presents an E-shaped array microstrip antenna design with a reflector, which has a high gain for short-range radar studies. E-shaped dipoles at the top of the substrate are brought into contact with an irregular microstrip line, which is the bottom of FR-4 substrate. The antenna feed is excited using a coaxial cable. The substrate material and the chrome reflector are attached to each other with Teflon material. The proposed antenna provides 7.85 and 9.62 dBi gains at resonance frequencies of 1.4 and 2.4 GHz, respectively. This antenna also has an F/B ratio of over 15 dB and an HPBW (half power beam width) value able to be used for short-ranges.

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Highlights (At least 3 and maximum 4 sentences)

- This study presents an E-shaped dipole array microstrip antenna design with a reflector
- This study has a high gain that can be used for short-range radar studies.
- This antenna also has an F/B ratio of over 15 dB and 38^0 HPBW value
- The antenna operates at 1.4 and 2.4 GHz resonant frequencies with 7 and 9.5 dBi gains.

Graphical Abstract

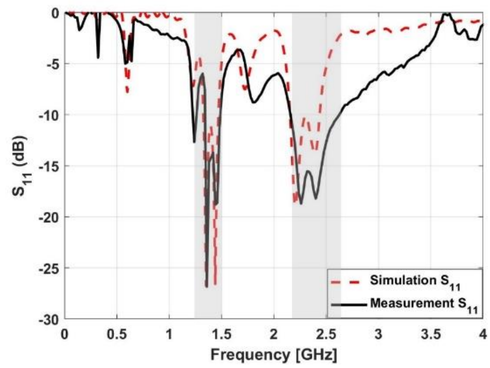

Figure. The return loss parameters of the proposed antenna

Purpose and Scope

Recommended for short-range radar applications, this antenna can be used in different application areas with its low cost, small dimension, and high gain.

Design/methodology/approach

The array antenna constructed with dimensions of 19×15×11.8 mm^3 has been designed and simulated in CST studio. At the same, this design has been fabricated using PCB techniques.

Findings

The design has gains of 9 and 9.5 dBi at the resonance frequency of 1.4 and 2.4 GHz, respectively. It has also a 17 dB F/B ratio value and 38^0 HPBW value

Research limitations/implications (if applicable)

The array antenna constructed with dimensions of 19×15×11.8 mm^3 has gains of 9 and 9.5 dBi at the resonance frequency of 1.4 and 2.4 GHz, respectively. It has also a 17 dB F/B ratio value and 38o HPBW value that make it easier signal processing.

Practical implications (if applicable)

In future research endeavors, there is potential to broaden the bandwidth even further. Exploring the possibility of achieving a more compact structure could also be pursued.

Originality

This study presents an E-shaped dipole array microstrip antenna design with a reflector that has a high gain that can be used for short-range radar studies. The proposed antenna provides 7 and 9.5 dBi gains at resonance frequencies of 1.4 and 2.4 GHz, respectively

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1. Introduction

Doppler radar has enabled studies in many areas, from non-contact weather forecasting, vehicle speed detection, vehicle traffic monitoring, smart homes, baby monitoring, heartbeat, and breathing monitoring to tumor detection (Benchetrit, 2000; Gu, He, & Zhu, 2019; Huang, Hayward, & Lin, 2016; Javaid, Noble, Rosenberg, & Weitnauer, 2015; C. Li, Lubecke, Boric-Lubecke, & Lin, 2013; M. Li & Lin, 2017; J. Lin & Li, 2007; J. C. Lin, 1992; Naishadham, Piou, Ren, & Fathy, 2016; Soldovieri et al., 2012; Suryadevara & Mukhopadhyay, 2012; Watson-Watt, 1945).

Doppler radar has an active role in the non-contact monitoring of vital signs by being applied in healthcare areas. For this purpose, many studies observed in the literature the heartbeats and respirators for monitoring people's daily activities with Doppler radar (Benchetrit, 2000; Gu et al., 2019; Huang et al., 2016; Javaid et al., 2015; Karatay, Orcan, Özkal, & Yaman, 2019; Klavestad, Assres, Fagernes, & Grønli, 2020; M. Li & Lin, 2017; J. Lin & Li, 2007; Naishadham et al., 2016; Neebha & Nesasudha, 2018; Suryadevara & Mukhopadhyay, 2012). In one study, the movements of four different old people were followed with radar at the frequency of 2.4 GHz. This radar method eliminates the need for a health caregiver (Suryadevara & Mukhopadhyay, 2012).

Antennas are one of the most fundamental parts of radars that consist of many circuit elements. Different antenna types can be preferred according to the usage areas of radars. Among these antenna types, microstrip patch antennas are frequently used in short-range Doppler radars, especially in health following and observing with their advantages such as lightness, ease of production, and low production cost (Gu et al., 2019; Karatay et al., 2019; M. Li & Lin, 2017; Neebha & Nesasudha, 2018). In a study, respiratory and heartbeat, which are people's vital signs, were detected with radar measurements in the range of 60 cm at the frequency of 2.4 GHz. Also, a circular microstrip antenna with 2.6 dBi gain was used in this study (Gu et al., 2019). In a different study, two antenna designs were presented to increase the range and capability of the MIT-Coffee Can Doppler radar. In this study, the designs of an aperture-coupled Vivalti-type transmitter patch antenna and a microstrip array patch antenna were proposed operating at the frequencies of 2.45 GHz. FR-4 substrate material was used in the production of these antennas, and they had gains of 3.23 and 5.63 dBi, respectively (Karatay et al., 2019). In another study, four different microstrip patch antennas were designed for radar applications in the 5-8 GHz span, and these antennas were compared to their reflection coefficients (Neebha & Nesasudha, 2018).

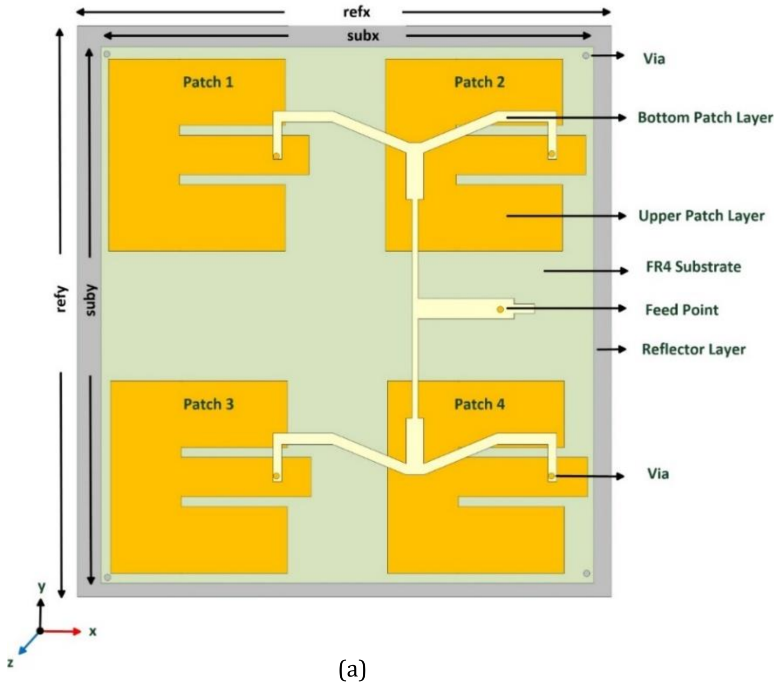
The disadvantages of microstrip antennas are that they have an average of 5% bandwidth and present low gain (Balanis, 2015). There are different studies on microstrip arrays (Kim & Kim, 2021; Y. Li & Luk, 2015; Midasala & Siddaiah, 2016; Yang, Geyi, & Sun, 2017) and microstrip reflectors (Debbarma & Bhattacharjee, 2019; Fernandes et al., 2019; Kim & Kim, 2021; Krishna, Shirisha, Isfahani, & Manisha, 2023; Mohammadi Shirkolaei & Engineering, 2020; Zhou, Cheng, Chen, & Luo, 2021) antennas to increase the gain and bandwidth of these antennas. Among the studies, E-shaped broadband microstrip antennas are one of them (Ge, Esselle, Bird, & Propagation, 2004; Rajagopalan, Kovitz, & Rahmat-Samii, 2012). There are different studies on reflector microstrip patch antennas in the literature. One of these studies presented a band-stop reflector antenna design and optimization for directivity and front-to-back (F/B) ratio. The designed antenna offered a bandwidth of 7 % at the resonance frequency of 2.4 GHz and 18.8 % at the resonance frequency of 5.8 GHz. Reportedly, gains of 7.54 dBi and 7.46 dBi were achieved at these respective frequencies (Fernandes et al., 2019). Another research study introduced a C-shaped reflector antenna design that showcased a gain of 5.5 dBi across the frequency span ranging from 1.5 to 2.8 GHz, as well as a gain of 5.7 dBi within the frequency span from 5 to 5.9 GHz (Rezvani & Mohammadi, 2018).

Antenna gain, F/B ratio and HPBW (half-power bandwidth) are among the important parameters in the antenna types used in short-range Doppler radars. (Chuang et al., 2011). However, it has been known that narrow HPBW has been preferred in different antenna types. In a study, the HPBW value of the microstrip array antenna operating in the 2.28-2.49 GHz frequency band is 26^{o} (T. Tang, 2012). The HPBW value of another microstrip patch antenna designed for Doppler radar used at short ranges is 43^{o} (Park, Li, & Lin, 2009). In a different study performed with a 10×16 microstrip patch array antenna, the HPBW is equal to 12^{o} (Lan et al., 2016).

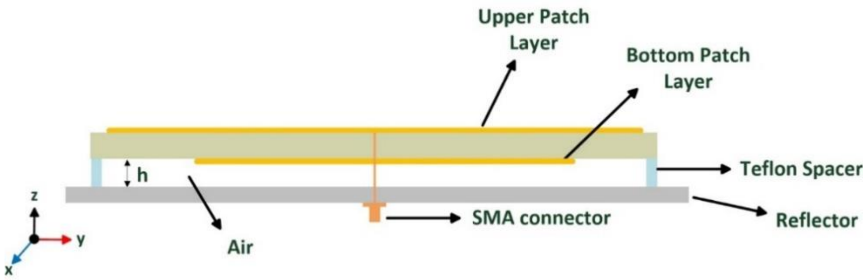
In this study, an E-shaped dipole microstrip array patch antenna with a reflector has been designed and manufactured. In this antenna design, it is aimed to obtain an E-form broadband frequency. Antenna gain is also desired to be increased with the array structure and reflector. This paper will present the structural design and analyses, followed by the presentation of its results and conclusions, in that order.

2. Antenna Design and Analysis

In Figure 1, the bottom patch, upper patch, FR4 substrate, vias, reflector layer, and feed point of the antenna placed across x- and y-axes are shown together. In the antenna design, FR4 substrate material with ε_r: 4.3, tanδ: 0.025, dimensions of 142*187*1.6 mm^3 has been used. This antenna's upper and bottom layers have been designed with lossy copper and united with the vias. Meanwhile, a 1 mm thick lossy chrome metal reflector has been used in this design.

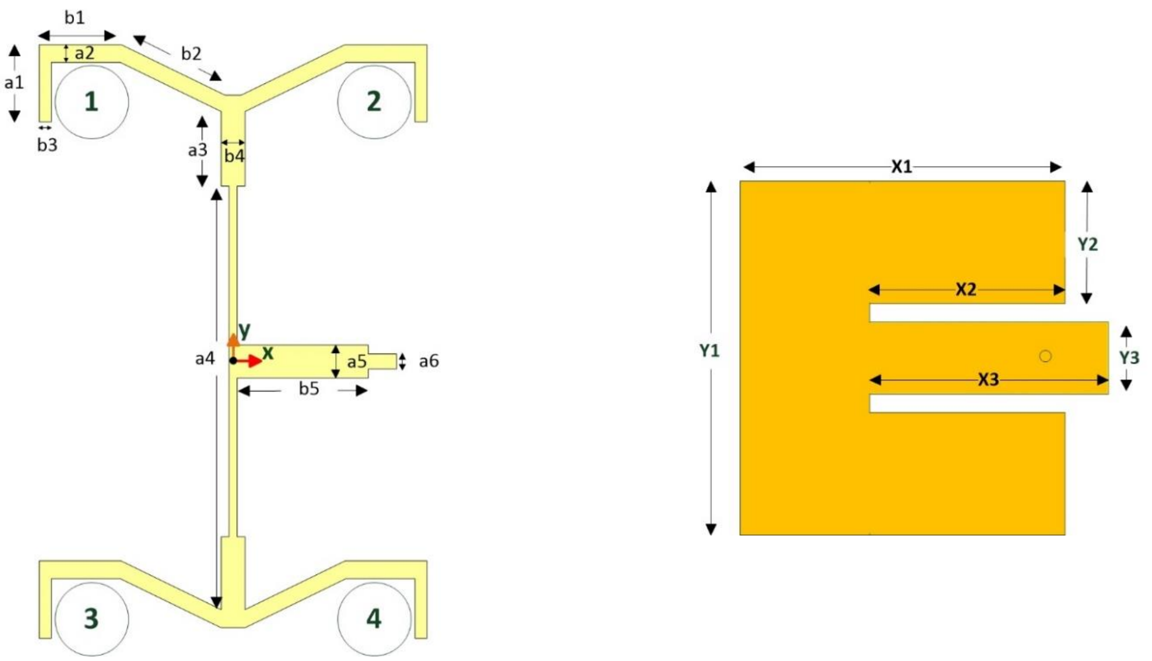


(a)



(b)

Figure 1. The proposed antenna is depicted in the following ways: (a) Front surface schematic diagram, (b) Side transparent diagram



(a) (b)

Figure 2. (a) Bottom schematic diagram, and (b) Geometry of the upper layer
Dimensions are refx: 192, refx: 153, subx: 142, suby:187, h: 9.2, a1: 16.7, a2:3.8, a3: 16.1, a4: 76, a5: 7.1, a6: 3.2, b1: 17.7, b2: 25, b3:2.5, b4: 5.1, b5:28.3, X1: 43.5, X2: 25, X3: 35, Y1:60.5, Y2: 22 (all in mm)

The side view of the designed antenna is given in Figure 1 (b). The geometry of the bottom patch layer is shown in four parts in Figure 2(a) in detail. Firstly, the part 1 geometry of these parts has been formed. Patch 2 has been constituted by getting the symmetrical y-axis of part 1. Patch 3 and Patch 4 have also been formed by the symmetry of the x-axis of Patch 1 and Patch 2.

All E-shaped on the upper patch layer have been designed in equal dimensions. An E-shaped geometry to belong to the upper patch layer is given in Figure 2(b) in detail.

The equivalent circuit of the proposed antenna is shown in Figure 3. As seen in this circuit, four L-C-R circuit elements of four E-shaped are given on the antenna. L inductances show the current detour on the antenna, R resistors indicate radiation resistors on the antenna, and C capacitances indicate fringing effects on the antenna (Garg, Bahl, & Bozzi, 2013). Cs represents the fringing effects of the Bottom patch layer and reflector, and Ls represents the current detours in the current detour of the bottom patch layer and reflector.

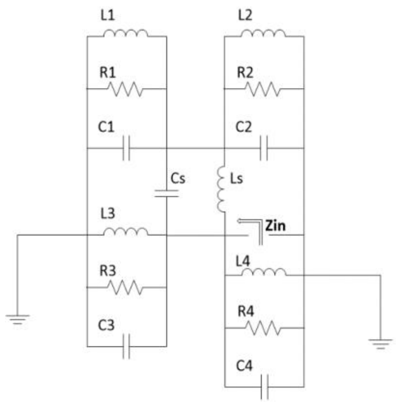


Figure 3. Antenna Circuit Equivalent

3. Results of Analysis and Discussion

The cross view of the performed antenna with its dimensions is given in Figure 4. S11 return loss measurements of the fabricated antenna have been performed with a Rohde and Schwarz FSH spectrum analyzer (Schwarz, 2007).

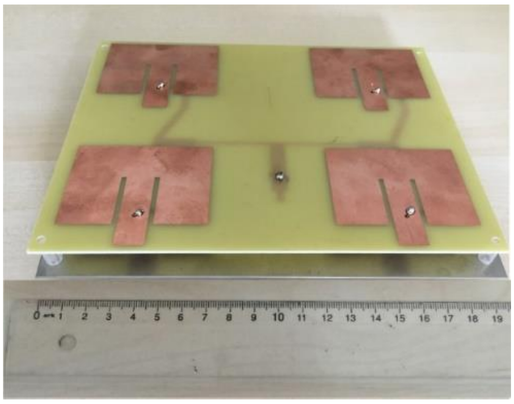
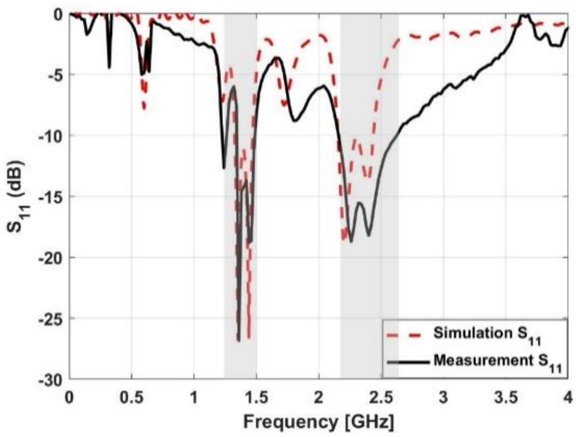


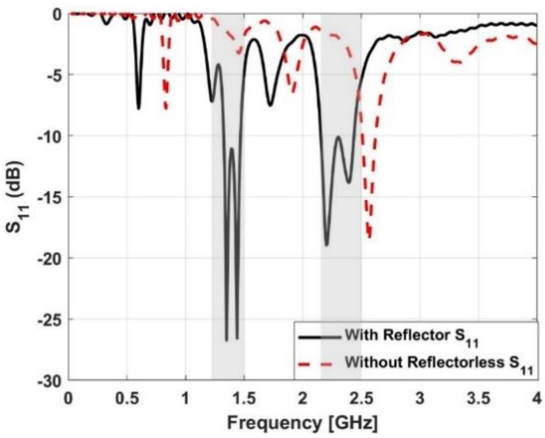
Figure 4. The cross view of the perfomed antenna

Return loss results of the simulation and measurement are given in Figure 5(a). This antenna works in two different frequency band spans, 1.3-1.5 GHz and 2.2-2.6 GHz. It is seen in Figure 5(a) that the results of the simulation and the measurement overlap with each other.

Figure 5 (b) displays the impact of the reflector on the return loss outcome in the designed antenna. It is understood from Figure 5 (b) that the proposed antenna works in two different broad frequency bands, while the antenna without the reflector operates in a narrow and single band.



(a)

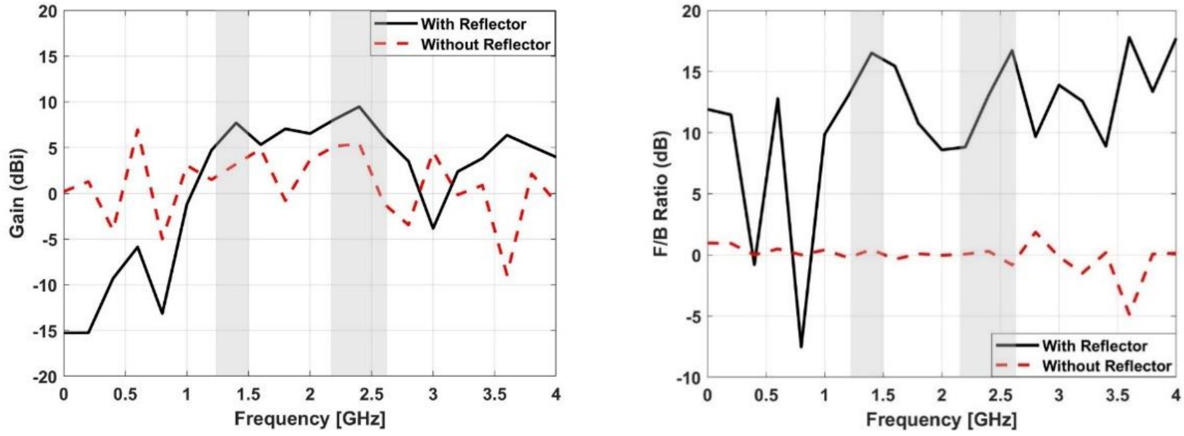


(b)

Figure 5. The propoesed antenna: (a) The return loss parameters of the proposed antenna, (b) S11 simulations results of the antenna with reflector and without reflector

Figure 6 (a) illustrates the impact of the reflector on the gain of the presented antenna. As seen in these results that the antenna gain has been increased from 5 dBi to 10 dBi with the reflector structure.

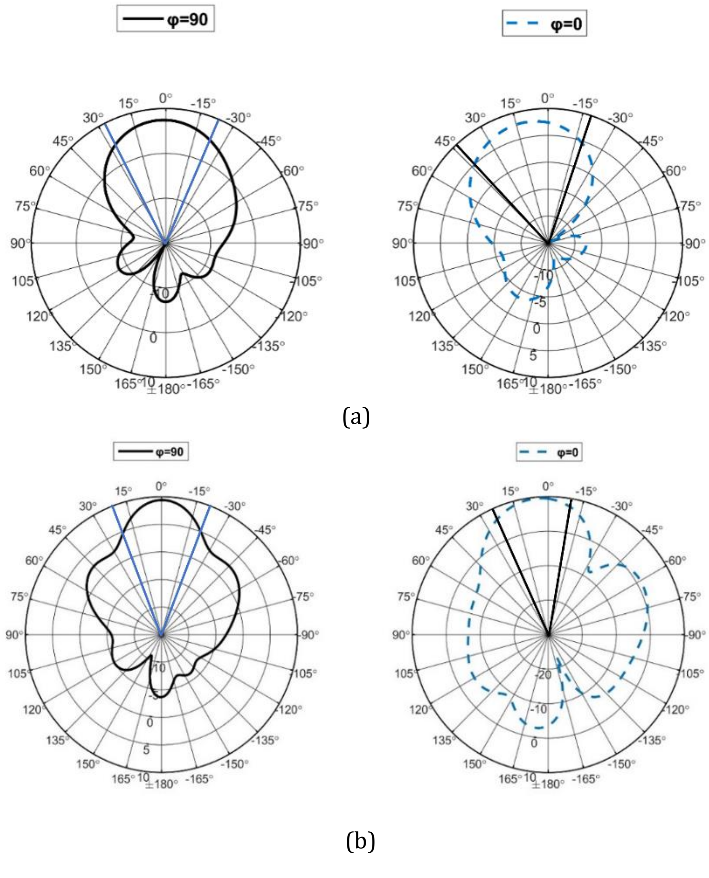
Figure 6(b) presents the simulation values of the Front-to-Back (F/B) ratio for both the proposed antenna and the antenna without a reflector. The F/B ratio value with a reflector result has been increased from 0 dB to 15-20 dB span.



(a) (b)

Figure 6. (a) Gain simulations of the antenna with reflector and without reflector, (b) The F/B ratio is being analyzed for both the antenna that includes a reflector and the one without a reflector.

The antenna pattern results of the designed structure are shown in Figure 7. In this figure, the main planes of φ=90 and φ=0 are given together at 1.4 and 2.4 GHz. These figures show that the proposed antenna has a radiation pattern focused in one direction and stability. The main radiation patterns are apparently better than the backward radiation thanks to the usage of a reflector plate. Also, the HPBW values of this antenna are 61^0 and 38^0 at the 1.4 GHz and 2.8 GHz frequencies, respectively. As seen in Figure 7, the main lobe magnitudes of the antenna change between 9-10 dB. This HPBW value proves that this antenna is directional.



(a)

(b)

Figure 7. Simulation results of the proposed antenna pattern at (a) 1.4 GHz, (b) 2.4 GHz

Table 1 provides a comparison between the findings of this study and those of prior research. These antennas in this table have been examined in terms of frequency, substrate material, dimension, gain, and HPBW. In these comparisons, it has been paid attention to select the studies, which are similar in the resonance frequency and the substrate material. Thus, these antennas can be easily compared in terms of gain, size, and HPBW. It is also seen from Table 1 that this study has an ideal dimension and a good HPBW value for Doppler radar at short ranges. In the 2nd study, the antenna designed for the Doppler radar has 36^0 HPBW and shows that narrow HPBW values are enough for Doppler radar studies. Narrow HPBW values facilitate signal processing. However, there are studies with high HPBW values such as the 5th and 7th studies. Since the antennas in these studies are designed for LTE base stations, it is normal for them to have high HPBW.

It is seen from Table 1 that the proposed antenna is superior to many other studies in terms of gain. This paper has a sufficiently high gain, approaching 10 dBi. higher gains are obtained, it is necessary to use better quality substrate material or increase the number of arrays as in the 6th study. However, it is taken into consideration that the substrates with less tangent loss require larger budgets.

Table 1. Comparison of the presented antenna with the previous studies in the literature

References	Freq. (GHz)	Substrate	Gain (dBi)	HPBW (deg)	Dimension (mm^3)
This Study	1.4 2.4	FR4 ε_r: 4.3, tanδ: 0.025 Thickness: 1.6 mm	9.5 7.5	61 38	191×153×11.8
1. (Gu et al., 2019)	2.4	FR4 ε_r: 4.4, tanδ: 0.025 Thickness: 3 mm	2.6	-	50×50×3
2. (Karatay et al., 2019)	2.45	FR4 ε_r: 4.3, tanδ: 0.025 Thickness: 1.5 mm	0	36	100×220×1.5
3. (Fernandes et al., 2019)	2.4 5.8	FR4 ε_r: 4.4, tanδ: 0.025 Thickness: 1 mm	7.54 6.8	-	40×12×1
4. (Zhou et al., 2021)	7 9 13	FR4 ε_r: 4.4, tanδ: 0.025 Thickness: 3 mm	4.5	-	24×20×1.6
5. (Rezvani & Mohammadi, 2018)	1.58-2.89 1.5-2.8 5-5.9	FR4 ε_r:4.4, tanδ: 0.02 Thickness:0.8 mm	~9 ~5.5 ~5.7	257 166 192 60	120×120×40
6. (Kaboutari, Zabihi, Virdee, & Salmasi, 2019)	9.97-11.9	Rogers RO4003 ε_r: 3.55, tanδ: 0.0027 Thickness: 0.8 mm	14.95	60.91	106×34×0.813
7. (Govindanarayanan & Rangaswamy, 2015)	1.7-2.7	FR4 ε_r:4.4, tanδ: 0.02 Thickness:0.8 mm	~7.5	>65	120×120×40

4. Conclusion

In this paper, a microstrip patch antenna study and chrome reflector have been performed in two different frequency bands. An array has been formed E-shaped on the substrate and these dipoles have been connected by an irregular microstrip layer bottom of the substrate. The array antenna constructed with dimensions of 19×15×11.8 mm^3 has gains of 9 and 9.5 dBi at the resonance frequency of 1.4 and 2.4 GHz, respectively. In these resonance frequencies, the design has also 17 dB F/B ratio values and 61^0, 38^0 HPBW values, respectively. This study distinguishes itself through its notable high antenna gain and front-to-back (F/B) ratio values. Suggested for short-range radar applications, this antenna holds potential for diverse usage in various application domains with its low cost, small dimension, and high gain.

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