A 2.45 GHz microstrip patch antenna design, simulation, and analysis for wireless applications

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ABSTRACT

This paper designs, simulates, and analyzes the S-band microstrip patch antenna (MPA) for wireless applications. FR-4 (lossy) and Rogger RT/duroid, whose dielectric permittivity is 4.3 and 2.2, respectively, have been used as substrate materials. Simulation is done by computer simulation technology (CST) suite studio 2019 software. Simulations with FR-4 material showed that the return loss was -20.405 dB, the gain was 2.592 dB, the directivity was 7.47 dBi, the voltage standing wave ratio (VSWR) was 1.221, the bandwidth (BW) was 0.0746 GHz, and the efficiency was 34.69%. Also, Rogers RT/duroid material gives results of a return loss of -12.542 dB, a bandwidth (BW) of 0.0349 GHz, a gain of 8.092 dB, a directivity of 8.587 dBi, and an efficiency of 94.24%. The main goal of this antenna is to have a low return loss while getting as close as possible to a VSWR of 1. This will improve the antenna's gain, directivity, and efficiency compared to other antennas. Copper was used to make the patch and the ground, which were 0.35 mm and 0.0077 mm thick, respectively. The results obtained from the proposed antenna were better than those previously published in various in modern scientific journal and conference papers.

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1. INTRODUCTION

In this age of information technology, people are increasingly becoming interested in wireless technology. Wireless technology is essential to people's lives throughout the modern world and affects everyone. No matter what we do, we can't escape the fact that wireless technology is integral to our lives. Many different kinds of equipment can be used for wireless technology applications. One of these is the development of 5G mobile applications. For 5G applications, a microstrip patch antenna (MPA) might be the best choice. It could have a wider bandwidth (BW), be more efficient, use less power, and have a high gain.

A new design structure patented in 1955 was the microstrip antenna, also known as the patch antenna. In a microstrip antenna, there is a layer of conductive material on each side of the substrate and insulating material. The term "ground plane" refers to the lower conducting surface, while "patch" refers to the upper conducting plate. Both of these surfaces are conductive. Because the manufacturing process of printed circuit boards and microstrip antennas is similar, the microstrip antennas are also referred to as "printed antennas." The size and shape of the patch are two of the most important things that affect how well the microstrip antenna works. The length, width, and thickness of the substrate, the dielectric constant of the substrate material, and where the feed line is placed all affect how well the MPA works [1]. An antenna device is connected to a source and a load terminal. The antenna matches the characteristic impedance of the two terminals. An impedance-matching device is a term that's used to refer to this piece of equipment. The antenna converts the electrical signals into electromagnetic waves to be transmitted. At reception time, it turns electromagnetic waves into electrical impulses, which is the opposite of what it did to send the signal. The term "transduction" refers to the process that is being discussed here [2]. The rising demand for wireless communication devices and the downsizing of these systems have made it more challenging to design antennas in today's world. This demand has completed the design of antennas more challenging [3]. However, these antennas have several limitations, the most notable of which are their narrow BW and weak gain.

The BW limits are needed for many applications, including some that the government uses for security. The rectangular MPA can also take on a variety of other shapes, such as those shown in Figure 1, which include Figures 1(a) rectangle, 1(b) square, 1(c) circular, 1(d) triangle, 1(e) donut, and 1(f) dipole [4]. Figure 2 illustrates the MPA actual construction [5]. The MPA is formed consisting of three layers of metal and substrate material. Copper is one example of a material used to build the ground structure layer at the base of the building. The substrate layer, also called the intermediate layer, can be made from any dielectric material, such as air, FR4, and Rogers [6].

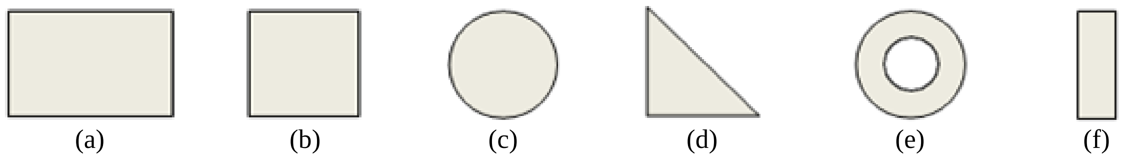

Figure 1. Representative shapes of microstrip patch elements (a) rectangle, (b) square, (c) circle, (d) triangle, (e) donut, and (f) dipole

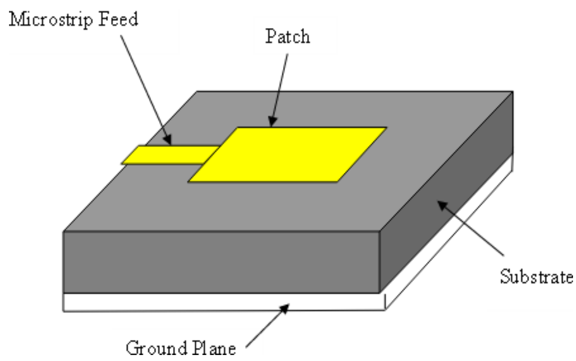

Figure 2. Patch antenna geometry

In order to better arrange the information that is being provided, the document has been split into four parts. In addition to this, the following components make up the organization of the paper: section 1 is dedicated to the presentation of the introduction; section 2 is dedicated to the presentation of a literature review; section 3 is dedicated to the discussion of antenna design and simulation; section 4 is dedicated to the discussion of results analysis and section 5 is dedicated to the presentation of the conclusion. The complete list of references for this part can be found in the following chapter.

2. LITERATURE REVIEW

In the modern world of wireless communication networks, patch antennas serve a purpose that is of the utmost importance and is, therefore, essential to how they work. The construction of a MPA is not overly complicated and uses a microstrip fabrication technology that is more frequently applied. The patch can be configured in about any shape imaginable; however, the rectangular and circular patterns are the ones that are used the most daily. These patch antennas are put to use in the simplest way possible for the most diverse range of applications, which also happen to be the ones that have the highest degree of demand for their services [7].

Nowadays, the use of MPA is increasing day by day. It has also been used in wireless communication, vehicle-to-vehicle communication, biomedical applications, networked machine learning, artificial neural networks, and other wireless applications. Researchers have published numerous high-quality international journals and conference papers through their research on this patch antenna. This section discusses various technical works on MPA published in S-band.

According to Aneesh *et al.* [8] a S-shaped MPA for wideband operation, utilizing a circuit theory idea based on a modal expansion cavity model. The authors developed this concept. The theoretical and simulated results for the S-shape MPA, which has a centre frequency of 2.62 GHz and is suitable for broadband operation with sufficient BW and moderate gain, show that this antenna can be utilized in various wireless communication systems.

Research by Kaur and Parkash [9] shows an example of a MPA, which has a rectangular shape and is made for wireless applications. The signal's gain, directivity, and BW can all be improved using this MPA. It functions accurately on the S and C frequency bands. Research by Rana and Rahman [10], discusses a MPA that operates at 2.4 GHz. This antenna works at this frequency. It was made and studied as a possible wireless communication device for the future. Within the limitations of their research publication, they discuss the MPA. This study aimed to get a low voltage standing wave ratio (VSWR), a noticeable increase in gain, and a low return loss.

Research by Güler *et al.* [11] shows how to make a MPA that works in the industrial, scientific and medical (ISM) 2.4 GHz band and has a wide frequency range. The research consists of a phase of simulation, a phase of construction and measurement, and a phase of modelling a three-dimensional antenna. The small volume of microstrip antennas has cheap manufacturing costs and is easy to fabricate, accelerating the work in this area. Using the transmission line model and a series of math calculations, the feed line length and the rectangular patch size were figured out. In the research study, four different designs are shown. When the results are compared, the authors conclude that the proposed antenna has a rational BW, return loss, and directivity gain of -10 dB at the resonance frequency of 2.316 GHz.

Research by Ezzulddin *et al.* [12] different patch configurations of microstrip antennas are looked at. These configurations include rectangular, circular, and triangular patches. In real life, it is possible to make these patch shapes, and the two ways described here have been tested to see which one works better by looking at the parameters of the microstrip antenna. In addition, it has been discovered that the outcomes of the proposed antenna parameters agree with those of earlier studies carried out at the same frequency. This research was carried out in the past. This is suitable for applications that use wireless communication networks of the 5G generation.

Research by Kumar *et al.* [13] used MATLAB's Simulink and the antenna Toolboxes to build and simulate a 2.45 GHz square patch microstrip antenna. This article will discuss the pros and cons of using MPA. It will then give a brief history of how antennas used in wireless communication systems have changed over time. This collection of work talks about the rectangular MPA, how it is coded, and what happens when a MPA is made. The prerequisites for this method include a smaller antenna in terms of both size and weight and a more affordable price tag while maintaining a high-performance level and a low return loss.

Research by Abdulhussein *et al.* [14] talks about how the MPA for 2.4 GHz applications is designed and made to have a shallow return loss and a perfect voltage standing wave ratio. Both of these characteristics were achieved through careful consideration during the manufacturing process. The processes of designing and simulating are carried out in computer simulation technology (CST) studios. The flame-resistant material called FR-4 is used as a base to make the proposed MPA. The suggested antenna has a lower return loss and a lower VSWR compared to existing references. Also, the gain and BW are about the same as in earlier studies. As a result, the MPA's findings show whether applications that use Wi-Fi, Bluetooth, or ZigBee are suitable.

Research by Kashif *et al.* [15] presents the system-level architecture for a future multifunctional radio over a fiber network. When fiber to the home (FTTH) technology is implemented, it will be possible to use applications that operate at multiple frequencies on a single fiber medium. At first, there were horn antennas for the S-band and circular patch antennas for the Ka-band. Estimates of the performance of circular patch antennas are provided for various substrate heights. Following the acquisition of S parameters and far-field findings, we proceeded to model the radio over fiber system over a distance of 10 kilometres using the same parameters as the antenna results.

Research by Duman *et al.* [16] an inset-fed rectangular MPA is created using the CST design studio program. After this, measurements are acquired utilizing a nano vector network analyzer (VNA) device with an SMA connection at a centre frequency close to 2.46 GHz. On the antenna, four different grounding methods that are different from each other in the published research were tested with a total of five tests. The outcomes from the nano-VNA device are presented below. In the study, return loss values of -27.5 dB (random, according to the author method), -22.5 dB (random, according to the default substrate dimension method), -13.8 dB (2 times the W, L method), -23.8 dB (6 times the h plus W, L method), and -27 dB (12 times the h plus W, L method) are obtained, respectively, according to the various dimensions of the ground.

According to Demirbas *et al.* [17] an antenna has been built with a frequency of 2.4 GHz. This antenna could be used in the next generation of wireless communication systems, which are in high demand now because technology is improving. IEEE 802.11 standards say that the antenna's Wi-Fi operating frequency range meets their requirements. Copper was chosen for the antenna's grounding and patching parts when it was decided that this would be the best choice. Most goals that were supposed to be reached because of the invention have been met. The results of the tests show that the 2.4 GHz antenna built for this research can be used for Wi-Fi research. According to Devi *et al.* [18] the proposed work is checked, and the antenna works in the ISM frequency band at 2.45 GHz. The designed antenna is often used in wireless sensor networks with a short range. The proposed antenna reduces the return loss and improves the radiation pattern. To enhance the performance of wireless sensor communication systems that use 2.4 and 5.3 GHz frequencies, a new MPA with a limited range, low power output, and good directional abilities has been made.

Research by Mahbub *et al.* [19] shows how the software that comes with the CST studio suite 2016 was used to make a rectangular MPA. This was done since the future of wireless local-area network (WLAN) systems would require improved gain and efficiency. The suggested model possesses both an improved return loss and an efficient behaviour attribute. The working frequency, 2.3025 GHz, was taken from one of WLAN systems' most important frequency bands. This makes it a better WLAN system when its good features are considered. Considering these things, the antenna that was made could be a good upgrade for WLAN systems shortly. An omnidirectional MPA (OMPA) is designed, built, and tested during this study [20]. The antenna's operational BW is well suited to the many various applications. Compared to other research, the antenna has a small BW, a good omnidirectional pattern, a low return loss, and a VSWR value that is as close to 1 as possible. The operating frequency is 2.405 GHz, which meets the requirements of various wireless communication uses.

3. SIMULATED ANTENNA DESIGN AND RESULTS

With the help of a MPA, electromagnetic waves are often sent into space when wireless communication occurs. A MPA four most important parts are the ground, substrate, patch, and feed [21]. Microstrip antennas have been in development for a long time, and the number of ways to use them is continually growing. One of these is the field of wireless communication. Figure 3 presents the results of the MPA simulation run using the CST software. The CST program was used to simulate the design of the antenna. It can show different statistics about the antenna. The following section uses these characteristics to rate how well the suggested antenna design works.

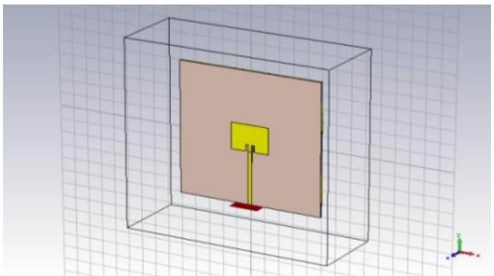

Figure 3. The antenna structure developed for the CST

To compute the parameters of this study, the following are utilized. The width of the MPA:

$$Wp = \frac{c_0}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

The dielectric constant of effective potential:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12*\frac{h}{w}\right)^{-0.5} \tag{2}$$

Extended length:

$$L_{ext} = \frac{c_o}{2f_r\sqrt{\varepsilon_{reff}}} \quad (3)$$

The following is applied in order to eliminate the fringing effect, and as a result, the accurate length of the patch may be determined:

$$\Delta L = 0.824h \frac{\left(\frac{w}{h}+0.3\right)(\varepsilon_{reff}+0.264)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.8\right)} \quad (4)$$

3.1. Antenna parameter

Table 1 gives the parameters of the MPA, where there is patch length, width, ground length, width, substrate depth, thickness, and other parameters that help create the complete design. The parts do not show the values of the many features that make up the total. Instead, the deals are offered based on other parameters.

Table 1. Given the dimensions of the antenna

	FR-4 substrate	Roggers RT 5880
Parameter	Value (mm)	Value (mm)
W_g	100	100
L_g	100	100
W_p	40	70
W_L	28.44	39.5
H_g	1.5	1.5
T_x	2.94	4.66
ε_r	4.3	2.2
t	0.035	0.077
$Inset_w$	1.5	1.5
$Inset_l$	6	5.16

3.2. Return loss

In communication devices, the radiation that bounces off the antenna is called "return loss," and the term "return loss" is used in communication devices. Return loss happens when the coaxial cable or the system for sending power does not fit well. This can take place when there is a mismatch in the impedance [22]. The S-parameter tells you how much power is reflected from the antenna have input port and how much energy it gives off after reflecting specific signals [23].

The reflection coefficient is one of the most important things to consider when figuring out how much power an antenna can send out in all directions. If you have a good patch antenna, need a return loss value of less than -10 dB for effective communication. The S-parameter says what the antenna's resonance frequency is and how wide its BW is. It also determines the antenna's BW. Figure 4 shows several values of S-parameter. The patch antenna constructed with FR-4 and Roggers RT duroid 5,880 substrate material has a return loss of -20.40 dB, a BW of 2.4142 GHz–2.4888 GHz, and an operating frequency range of 2.4354 GHz-2.4703 GHz with a return loss of -12.542 dB while it is operating at its resonance frequency of 2.45 GHz.

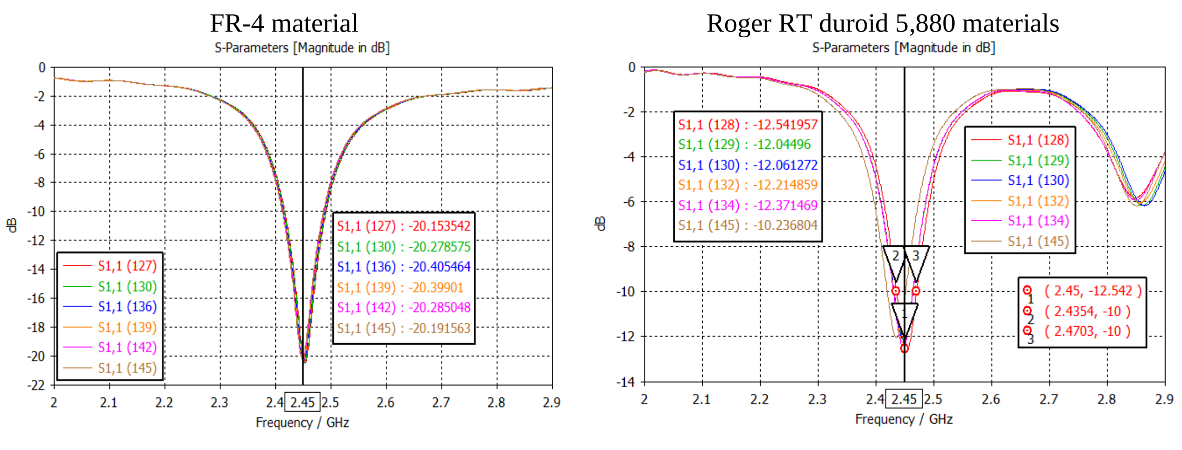

Figure 4. Return loss vs frequency of the antenna

Figure 5 depicts a return loss vs frequency graph. This graph shows that the recommended patch antenna has a return loss of -20.40 dB (FR-4) and -12.542 dB (Roggers RT droid) at 2.45 GHz, the solution frequency. This value is far higher than what is desirable to achieve increased performance. The antenna's BW is demonstrated to be 0.0746 GHz (FR-4) and 0.0349 GHz, as shown in Figure 5. Figure 4, which can be viewed by clicking this link, depicts a plot of the return loss of the suggested antenna vs frequency.

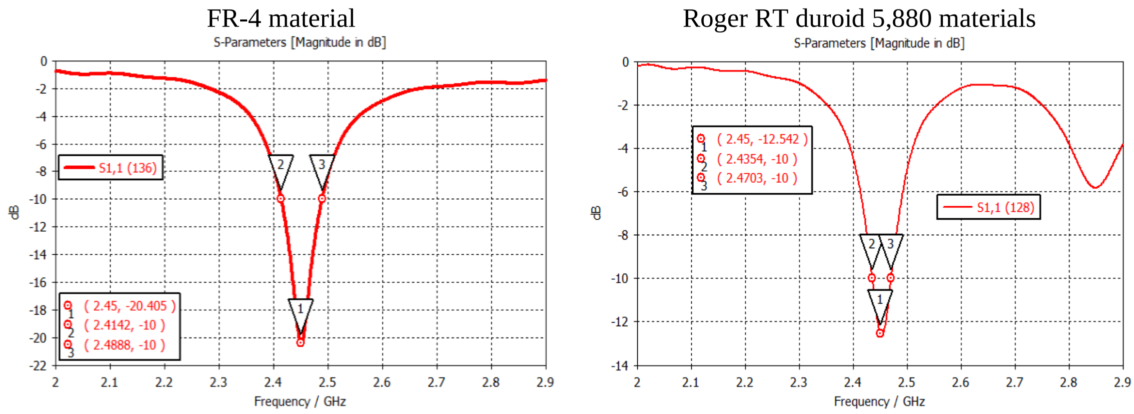

Figure 5. A graph showing return loss versus frequency is presented

3.3. Voltage standing wave ratio and bandwidth

The VSWR is a way to measure how well radio frequency (RF) power is sent from a power source to a load along a transmission line. For the most effective communication [24], the VSWR value should fall somewhere between 1 and 2. When the impedance matching value is close to one, it is optimal. Figure 6 shows the calculated value for the antenna's VSWR at 2.45 GHz. The VSWR for FR-4 material comes in at 1.211 and frequencies spans is 2.4119 GHz to 2.4913 GHz, while the VSWR for Rogers RT/duroid material is 1.617 and frequencies spans of 2.4333 GHz to 2.4724 GHz.

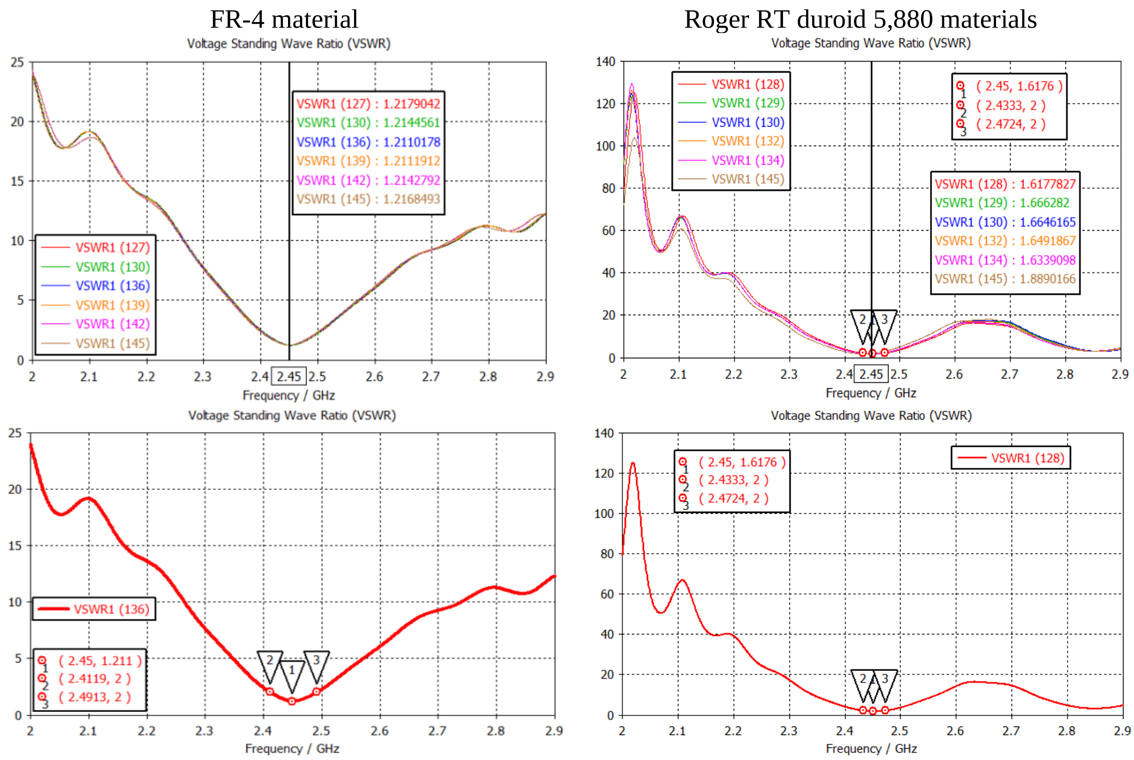

Figure 6. Create a graph showing frequency versus VSWR based on the results of the simulation

3.4. Gain and radiation pattern

Gain is defined as the difference between the power density of a directional antenna at every place and the power density of an isotropic antenna at the same point when both antennas are fed by the same power source [24]. When figuring out how well an antenna works, gain and directivity are two things to pay a lot of attention to. Directivity can measure the quantity of radioactivity along a particular path. In contrast, the amount of energy transferred to the main lobe can be measured by the gain [25]. Figures 7 and 8 show how well the suggested antenna model works regarding gain and directivity. As can be seen in Figure 7, the gains of the rectangular patch antenna in at 2.592 dB and 8.092 dB by using FR-4 and Roggers RT/duroid substrate materials, respectively. The gain of the proposed design is 8.092 dB at 2.45 GHz.

FR-4 material Roger RT duroid 5,880 materials

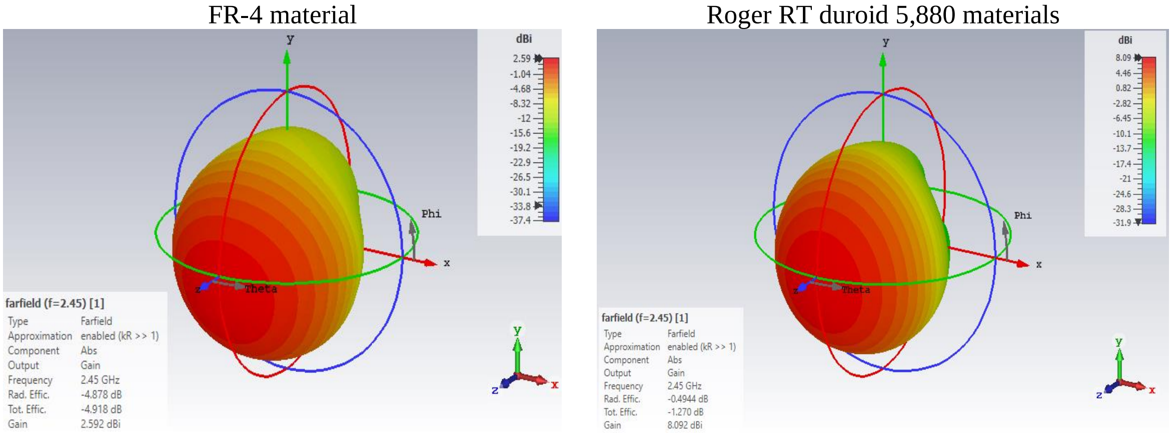

Figure 7. 3D gain field configuration of the MPA

The term "directivity" refers to the ratio of the strength of an antenna's radiation in one particular direction to the average strength of its radiation across all directions [24]. Figure 8 show that an antenna's directivity represents its far field. This can be noticed while looking at an antenna. While operating at a frequency of 2.45 GHz, the directivity ranges between 7.471 dBi and 8.587 dBi, with the proposed design achieving a directivity of 8.57 dBi.

FR-4 material Roger RT duroid 5,880 materials

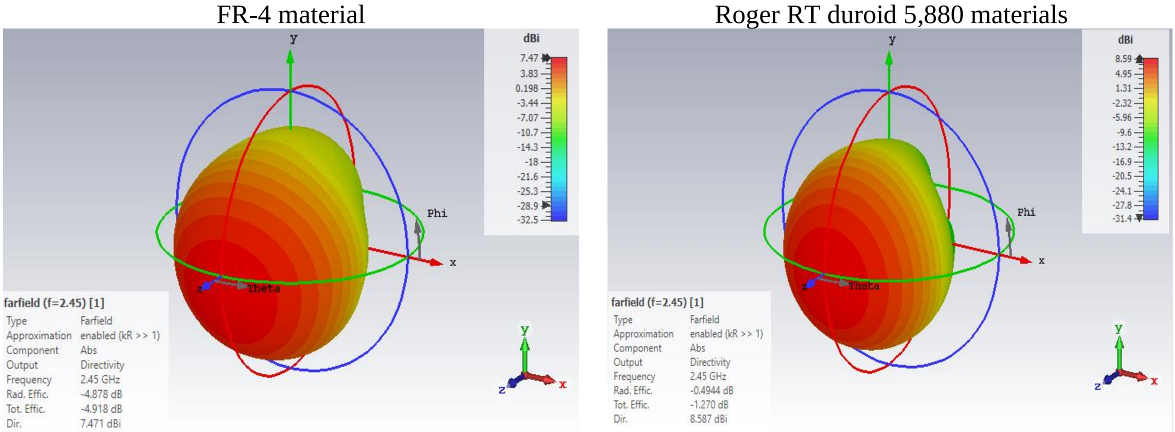

Figure 8. 3D radiation pattern

Figure 9 provides a visual illustration of the polar radiation pattern. The primary lobe of the FR-4 substrate material has an intensity of 2.6 dBi, and its angle of incidence is 9.0 degrees. The angle that corresponds to a value of 3 dB is 77.8 degrees. This antenna has a sidelobe level of -16.8 dB on the sidelobe scale. To reiterate, the magnitude of the primary lobe is 8.09 dBi for the Rogers RT duriod material, and the angle is 4 degrees. A figure of 72.9 degrees represents the 3 dB angular value. Also, their side lobe level is -22.1 dB.

Figure 10 illustrates the polar directivity. When measured for an FR-4 substrate, the primary lobe has a strength of 7.47 dBi and an angle of incidence of 9.0 degrees. The 3 dB angular value was calculated to be 77.8 degrees, as was previously mentioned. This antenna has a sidelobe level of -16.8 decibels lower than the norm for producing them. For Roggers RT/duriod, the main lobe magnitude was 8.59 dB, the main lobe direction was 4 degrees, the angular width was 72.9 degrees, and the side lobe level was -22.1, respectively.

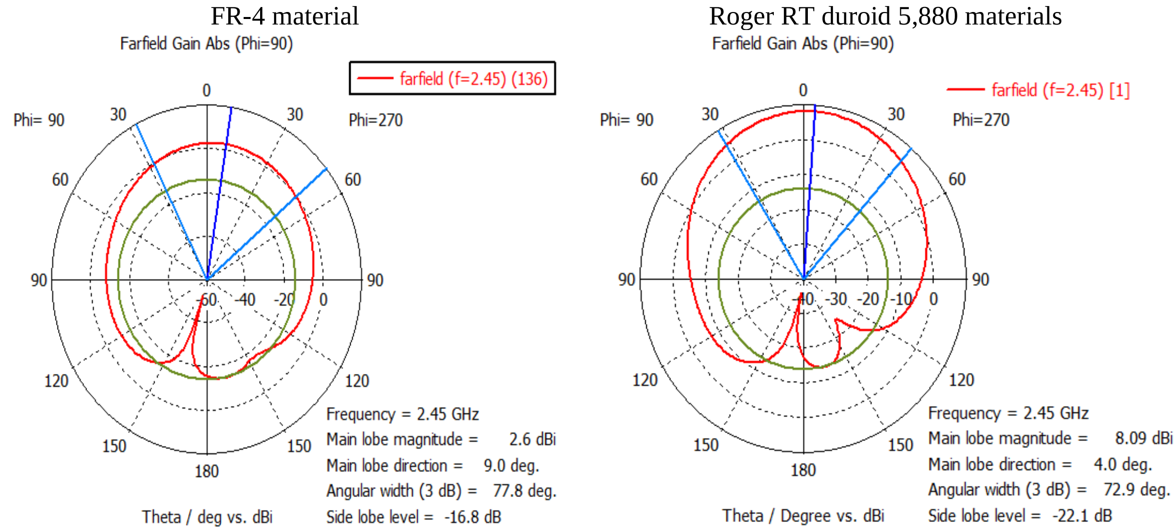

Figure 9. Farfield gain

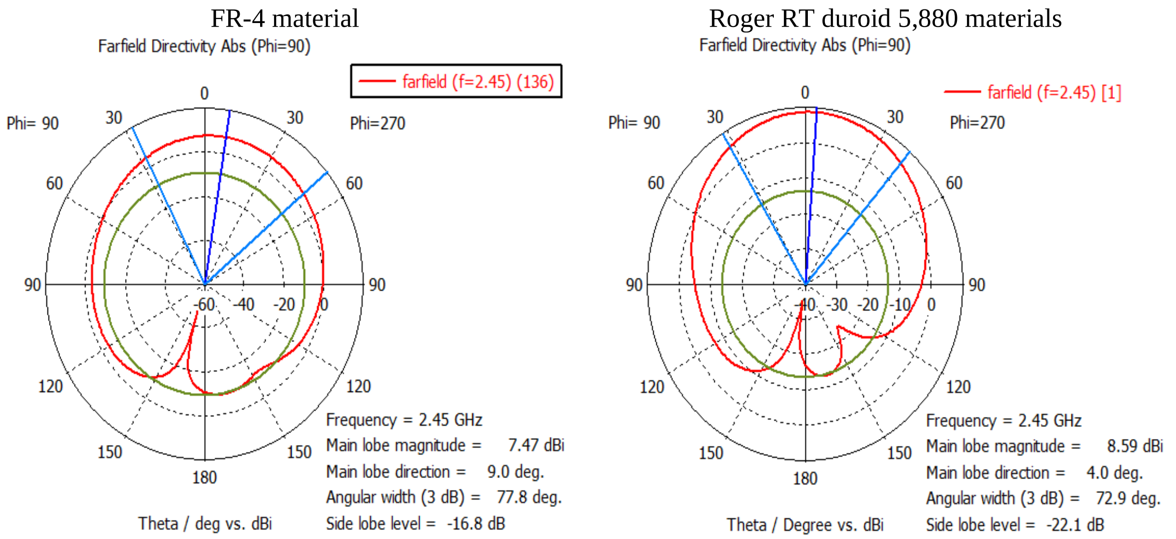

Figure 10. Farfield directivity

3.5. Radiation efficiency

The ratio of the total power that the antenna sends out to the net energy it receives from a linked transmitter is equal to the antenna's radiation efficiency. Radiation levels are 34.69% for FR-4 and 94.24% for Roggers RT droid 5,880. At a frequency of 2.45 GHz, the proposed device has a radiation efficiency of 94.24%. The design works much better than papers that have been published before, and it can be used for wireless applications. By making the antenna in the future, the results from the simulation can be compared to the results from making the antenna.

4. RESULT ANALYSIS

In this investigation, the FR-4 and the Roggers RT durioid 5,880 substrate materials are put to work. Simulations for use in wireless applications with an operating frequency of 2.45 GHz are carried out here. The simulations evaluate the functionality of two different substrate materials and compare their results. Following the simulation, the gain of the FR4 material is 2.592 dB, the directivity is 7.471 dBi, the return loss is -20.405 dB, the BW is 0.0746 GHz, the bear loss is 1.221, and the efficiency is 34.69%. On the other hand, the return loss, gain, directivity, BW, VSWR, and efficiency for the material that was utilized in the Rogers RT Duroid are, respectively, -12.542 dB, 8.09 dB, 8.587 dBi, 0.0349 GHz, 1.617, and 94.24%. The antenna uses Roggers substrate material to meet its operational goals of increased gain, strong directivity, and a relatively high efficiency of 94.24%. Table 2 displays the findings of the simulation, which are summarized in the following sentence.

Table 2. Provides a synopsis of the results of the simulation

FR-4 substrate		Roggers RT5880
Parameter	Value	Value
Return loss (dB)	-20.405	-12.542
BW (GHz)	0.0746	0.0349
Gain (dB)	2.592	8.092
Directivity (dBi)	7.471	8.587
Efficiency (%)	34.69	94.24
VSWR	1.211	1.617

Table 3 show the proposed MPA compares in several ways, such as its maximum return loss, gain, directivity, and BW. Table 4 also compare additional elements, including efficiency, directivity, and others. The market for wireless communication technology is expected to keep growing, so this could be a good answer.

Table 3. Comparasion between others design

Ref.	S_{11} (dB)	Gain (dB)	VSWR	BW
[8]	-	8.2	-	-
[10]	-13.89	6.6	1.5	0.07 GHz
[11]	-24.529	-	1.17	979 MHz
[13]	-38.86	-	1.002	57 MHz
[14]	-38.86	-	1.02	58 MHz
[16]	-27.5	-	1.08	-
[17]	-30	2.83	-	145.8 MHz
[18]	-16.25	-	-	-
[19]	-40.35	5.93	1.019	75.2 MHz
[20]	-25.26	-	1.12	61 MHz
[26]	-34.21	7.7	-	0.028 GHz
[27]	-31.4	7.3	1	-
[28]	-	4.2	-	83.5 MHz
[29]	-23.18	2.9	-	220 MHz
[30]	-23.8	6.907	1.88	-
[31]	-20.01	6.29	-	36.8 MHz
[32]	-23	3.01		105 MHz
[33]	-26.3558	1.866	1.1052	131 MHz
[34]	-16.20	5.44	1.5	0.160 GHz
	-12.542	8.092	1.617	0.0349 GHz
This work	-20.40	2.592	1.211	0.0746 GHz

Table 4. Comparision between previous published works

Ref	Dielectric permittivi y (ε)	Thickness (mm)	Directivity (dBi)	Efficiency (%)
[8]	1.07	-	-	92.04
[10]	2.2	0.3451	-	-
[11]	4.3	1.6	2.68	-
[16]	4.3	1.6	-	-
[17]	2.2	0.81	-	-
[18]	-	-	-	89
[19]	-	0.035	6.992	84.81
[20]	-	1.59	-	-
[26]	2.2	1.5	-	91.79
[30]	2.2	0.009	-	-
This work	4.3	0.035	7.471	34.69
	2.2	0.077	8.587	94.24

5. CONCLUSION

In the said research paper, a MPA was designed and simulated, where two substrate materials were used separately. One of which is FR-4 material, and the other is Rogers RT/duroid 5,880. After the antenna is fully designed and simulated, return loss, gain, directivity, VSWR, BW, and efficiency are obtained. Among the results designed using the two materials, the results of the Rogers RT/duroid 5880 are better, which may make it a good candidate for wireless communication in the future. Among the results obtained from Rogers' RT/5880 are return loss, gain, directivity gain, VSWR, and efficiencies of -12.542 dB, 8.092 dB, 8.587 dBi, 1.617, and 94.24%, respectively. Furthermore, the FR-4 results include return loss, gain, directivity gain, VSWR, and efficiencies of -20.405 dB, 2.592 dB, 7.47 dBi, 1.221, and 34.69%, respectively. This antenna design is far superior to others in terms of how well it radiates signals, works across a wide frequency range, and picks up signals. So, the antenna built for this article is an excellent example of a candidate antenna that could be used in wireless technology. Due to high demand, the antenna's performance specs are good. The newly developed antenna structure will be employed for wireless applications on remote networks. Simulations demonstrate that the given antenna is suitable for wireless communication. The antenna will be made quickly so measurements can be compared to models.

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