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Microstrip patch antenna design and simulation for S-band wireless applications operating at 3.5 GHz

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ABSTRACT

In the modern world, wireless technology is one way to send information from one place to another. This technology is getting better and better with time, which significantly impacts the activities that make up daily living. This wireless application has the most impact on mobile and other technologies. This research paper shows the design and analysis of a 3.5 GHz microstrip patch antenna (MPA) for wireless applications. The substrate material is Roggers RT/duroid, which has a dielectric permittivity of 2.2 computer simulation technology (CST) software does antenna design and simulation. Some observed parameters are the S-parameter, antenna directivity gain, voltage standing wave ratio (VSWR), and bandwidth. From the simulation, the return loss, VSWR, directivity gain, and bandwidth are -50.4227, 1.0061, 7.43 dBi, and 122.1 MHz respectively. This study aims to find the best return loss, get the most directional gain, and get the VSWR closer to 1. When this antenna was used, the results were better than those in scientific journals and conferences. As a result, this antenna is anticipated to fulfill the requirements of various wireless communication applications effectively.

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1. INTRODUCTION

An antenna is both a static electronic device and a transducer. It changes electrical energy into electromagnetic energy and back again. In many wireless communication technologies, antennas send and receive electromagnetic wave signals. It is used in a variety of applications [1]. There are different antennas for this wireless communication technology, and the patch antenna is one of them. Patch antennas are very popular today because they are used in many electronic systems. They are used in electronic warfare, remote sensing, wireless communication (like cell phones), space exploration, and many other electronic systems. This is mostly because patch antennas are easy to set up, cheap, small, and light. Modern communication technologies have made it harder to make antennas that work with them [2].

In 1955, a patent was granted for the groundbreaking design structure of microstrip antennas, also known as patch antennas. These antennas consist of a substrate sandwiched between layers of conductive and insulating materials. The conductive layer beneath is commonly called the "ground plane," while the upper conducting plate is called the "patch". This design revolutionized the field of microstrip antennas, enabling their widespread use and paving the way for advancements in wireless communication technologies. These surfaces are classified as conducting surfaces due to their conductive properties. Both of these surfaces have some degree of electrical conductivity.

Microstrip antennas are frequently referred to as "printed antennas" due to the similarities between the procedures used in fabricating printed circuit boards and those used in manufacturing microstrip antennas. The interplay of several parameters most often determines a microstrip antenna's performance. The proportions of the patch, in addition to its shape, are two of the most important variables that need to be considered. The effectiveness of the operation of a microstrip patch antenna (MPA) can be affected by several factors, including the substrate's length, width, and thickness; the dielectric constant of the material that makes up the substrate; and the placement of the feed line [3]. As shown in Figure 1, an MPA has a metal patch that radiates and a grounded dielectric substrate. There are many different shapes of MPA, some of which are shown in Figure 2. These shapes include square, circular, triangular, and elliptical [4].

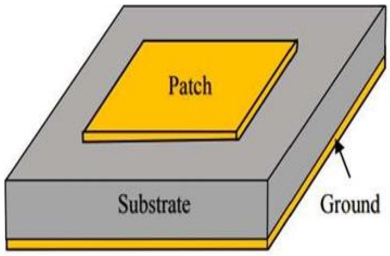

Figure 1. Basic structure of the microstrip patch antenna

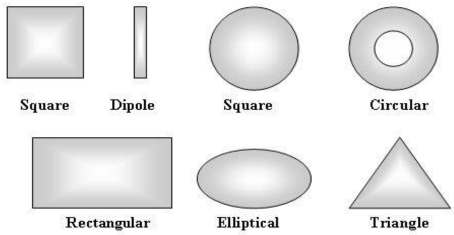

Figure 2. Representative shapes of microstrip patch elements

Figure 3 visually presents the physical construction of the MPA as depicted in [5]. The antenna comprises three layers: metal, substrate, and patch. The metal layer serving as the ground structure can be constructed using various materials, such as copper which provides a stable foundation. The intermediate substrate layer between the metal and patch layers can be composed of different dielectric materials, including air, FR4, and Rogers. The top layer, the patch or design layer is typically crafted from a highly conductive material or is copper based [6].

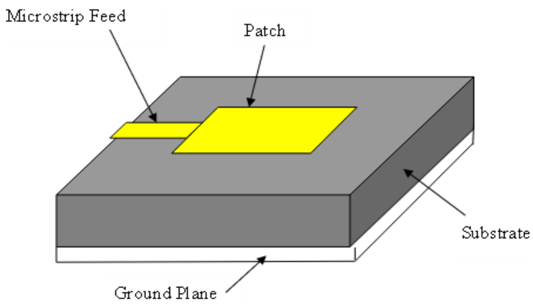

Figure 3. Geometry of microstrip patch antenna

The document has been partitioned into five sections to enhance the clarity of the information presented. Moreover, the paper's organization consists of the following elements: section 1 of this paper is the introduction; section 2 contains a review of the relevant literature; section 3 discusses the antenna design and simulation results; section 4 contains the analysis of the results; and section 5 is the conclusion.

2. LITERATURE REVIEW

Recently, there has been a rise in interest in wireless technology. This is likely because smartphones and other mobile devices are so common. In the modern world, wireless technology has become essential to everyone's life, so its wide use affects everyone. Wireless technology applications can use a wide range of hardware and features. One of these things is developing brand new mobile applications compatible with 5G networks. Besides, regarding 5G applications, the ideal solution is a MPA. It can gain more efficiency, wider bandwidth, and less power.

Patch antennas serve a purpose in today's wireless communication networks that are of the utmost importance. As a result, their use is necessary for the functioning of these networks. Constructing a MPA does not require excessive effort and uses a method for fabricating microstrips that is more frequently utilized. Even though the patch can be put together in almost any shape, the most common ones are square and circle. These patch antennas are used in the simplest way possible for the broadest range of applications, which are also in demand [7].

MPA are experiencing a consistent rise in popularity today. These antennas have found applications in various fields. Researchers have significantly contributed to the understanding and advancement of patch antennas, leading to the publication of numerous high quality articles and conference papers. The extensive body of research reflects researchers' ongoing efforts and dedication to exploring the potential and capabilities of MPA in diverse domains. This section examines several technical consequences of MPA published in the S-band. Singh *et al*. [8], discusses a single-layer arrowhead shaped slotted MPA carefully simulated for use in 3.5 GHz wireless communications systems. The proposed antenna is small and works well with the wireless network, the wireless local area network (WLAN), and the Bluetooth application. It can also be used with other wireless communication systems.

Research by Kaur and Sharma [9], shows how to make a rectangular fractal antenna shaped like an "E" the microstrip line feeding technique is used to feed the antenna. Antenna parameters like gain, return loss, voltage standing wave ratio (VSWR), and bandwidth can be modeled and measured. The simulated data show that the antenna works well at five resonant frequencies, each with a return loss of less than -10 dB. The developed antenna is adaptable and may be utilized for various wireless applications, space communication, and long distance communications.

Research by Amin *et al.* [10], a rectangular MPA design and analysis are done in the said paper. This paper aims to increase the gain by reducing the return loss. When the feed probe of a rectangular antenna is in the right place, the return loss is the least, and the gain is what is needed. So, the rectangular MPA did a great job in terms of reducing the amount of return loss and increasing the amount of gain. These results also show that the rectangular patch antenna works well in wireless communication systems. Ferdous *et al.* [11] showed that a low profile patch antenna was built for 5G communication applications. For the 5G application, the resonating frequency was 3.5 GHz. The main radiating patch is shaped like an ellipse, and a "*line feeding*" method is used. Several parameters, like the S-parameter, antenna gain, directivity, and efficiency, have been observed.

Paragya and Siswono [12] showed that a 3.5 GHz microstrip antenna was designed and built to meet the needs of a 5G application. The needed features were based on Huawei and Qualcomm's views on public policy and an article from the Rel-15 3rd generation partnership project (3GPP). Because microstrip antennas have a small bandwidth, some modifications are carried out. These modifications include proximity coupled feeding and defective ground structures (DGS). In the process's first step, the antenna's starting size is calculated. In the last step, the antenna is simulated and optimized. The simulation starts with a simulation of the first measurement. Next, close coupled feeding is used. Then it continues using the DGS until the target antenna is reached. Research by Ibrahim *et al.* [13], shows how a 5G application could use a rectangular patch antenna array. At 3,500 MHz, the antenna design gives a good return and insertion loss. The array structure demonstrated superior results compared to the single element design's performance. The compensated antenna can work in a frequency range that includes band 78, a commonly used part of the 5G spectrum.

Abdulbari *et al.* [14] describes a small T-shaped microstrip antenna for 5G wireless communication systems. To get around the problems caused by the limited bandwidth of a typical MPA, a T-shaped microstrip patch was designed. This structure's radiation properties are the same over a wide range of frequencies because it has the best impedance at each frequency. The low frequency band can have a broader range of frequencies by putting a rectangular T-shaped hole at ground level. The suggested antenna has, among other things, a more straightforward design, a smaller footprint, and a lower profile. Properties such as radiation pattern, reflection coefficient, gain, current distribution, and radiation efficiency are displayed and analyzed using the computer simulation technology (CST) microwave study when simulating and analyzing. The suggested antenna works well for a wide range of wireless communications, including 5G mobile ones.

According to Sheriba *et al.* [15], the DGS, made up of a ground-level slot in a Y, improves the gain of MPA. The proposed antenna design is a Y-slotted MPA. This type of antenna works well for S-band applications, such as weather radar, ships on the surface, satellites for communication, and Bluetooth. The MPA is one of the most common printed resonant antennas used in communications. This is because it can be used for a variety of wireless applications. Sahoo *et al.* [16] describe a new 5G use for a proximity coupled fed microstrip circular patch antenna (CPA). This particular antenna has a resonance frequency of 3.5 GHz. The impedance matching and return loss characteristics of the proposed antenna are excellent. The VSWR is nearly perfect, and the CPA has both efficiency and capacity. This CPA is good for several 5G applications because it has a simple design, is small, has a high gain, has good radiation properties, has the right impedance matching, and has the right impedance matching.

Research by Al-Gburi *et al.* [17], suggests the hexagonal-shaped slotted array antenna for 5G applications. The "slotted" strategy was used, which led to each design making more money. The established procedure began with creating a single element and progressed to creating 1×8 array element. A microstrip corporate feed line feeds the proposed feed line's 1×8 array antenna. It also had directed radiation, which helped the base station connect to the network in a high-quality and high-capacity way. In addition, the point to point connections that span great distances are the primary focus of this particular form of antenna. The performance of the antenna shows that the suggested hexagonal patch antenna could be a great choice for 5G wireless systems, which need a high gain and a return loss of less than -10 dB. Research by Rana *et al.* [18], shows how an RMPA, or rectangular MPA, is made and how it works. Return loss, VSWR, directional gain, and bandwidth are derived from the simulation. In that research, the primary objective was to boost the return loss, get the VSWR ratio closer to 1, and boost the directive gain. This antenna can be used in many ways, such as in radars, cell phones, and WLANs.

3. PROPOSED ANTENNA DESIGN AND SIMULATION RESULTS

When making a micro-strip antenna, there are three important parts to think about: the ground, the patch, and the substrate. To begin designing the antenna, the first thing that must be done is to create the ground layer, also known as the conducting layer [19]. Copper is used for the antenna's grounding material, and its thickness is 0.0035 mm. This layer is required to have conductive properties. Copper was chosen as the material since it offered the best value for the money. The substrate layer constitutes the second layer. This particular layer is composed of the Rogers RT/duroid 5,880 material. The dielectric coefficient of this material is 2.2. The patch makes up the second layer. The layer the antenna transmits onto is called the patch layer. This component must be conductive. Copper was the material that was determined to be most suitable. It has a thickness of 0.035 mm, as stated. By making adjustments to this layer, the goal is to get the antenna to the appropriate frequency as quickly as possible. Figure 4 illustrates the suggested rectangular microstrip antenna design and a prototype. The patch is attached to a substrate manufactured by Rogers called RT/duroid 5,880. This substrate has a dielectric constant of r=2.2 and a thickness of 0.0035 mm.

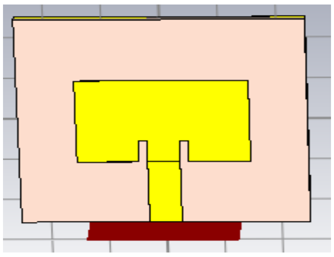

Figure 4. The design of antenna in CST

The following set of equations is used in this investigation so that the parameters can be calculated [14], [20]. Step 1 the width of the patch calculated using (1):

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

where c is the velocity of light in a vacuum and has a value of $3\mathrm{x}10^8$ m/s. The substrate's dielectric constant is represented by ε_r and the design antenna frequency is denoted as f_r. The corrected width is Wp. Step 2 determining the effective dielectric constant of the substrate is a crucial calculation in antenna design.

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

where h is the height of the substrate and and the effective dielectric constant is ε_{reff}.
Step 3 the calculation of the effective length of an antenna is an essential aspect of antenna design.

$$L_{eff} = \frac{c_0}{2f_r\sqrt{\varepsilon_{reff}}} \tag{3}$$

Step 4 computing the length extension of an antenna is a critical calculation in antenna design.

$$\Delta L = 0.412h \frac{\left(\frac{Wp}{h}+0.3\right)(\varepsilon_{reff}+0.264)}{(\varepsilon_{reff}-0.258)\left(\frac{Wp}{h}+0.8\right)} \quad (4)$$

Step 5 the computation of the antenna's length is a fundamental calculation in antenna design.

$$L = L_{eff} - 2\,\Delta L \quad (5)$$

After that, the length and width of the ground plane, in addition to the rectangular microstrip patch, can be determined as (6) and (7):

$$Lg = 6h + L \quad (6)$$

$$Wg = 6h + Wp \quad (7)$$

3.1. Antenna parameter

Table 1 presents the measurement results obtained from the antenna. The parameters are labeled as follows: Wg represents both the breadth and length of the ground; Lg indicates the overall size of the ground; Hs refer to the height of the substrate; t denotes the thickness of the substrate; Wp represents the width of the antenna patch; and Lp represents the length of the antenna patch. The table provides values for these parameters, allowing for a comprehensive understanding of the antenna's dimensions and characteristics.

Table 1. Antenna dimensions

W_g	L_g	W_p	L_{Lp}	H_g	$inset_w$	$inset_l$	Tx_w	ε	t
80	80	30	20	1.67	1.5	5.16	5.64	4.3	0.035

3.2. Return loss

The radiation the antenna reflects in communication devices is called "*return loss*". Return loss happens when the coaxial cable or electrical system isn't connected. This can occur when there is a mismatch in the impedance. Decibels, written as dB are always used as the unit of measurement for volume calculations [21]. The return loss was calculated based on the results of the simulation. The starting point is set at -10 dB, which is a value that is optimal for mobile or wireless technologies. The antenna is tuned to the required frequency for operation [22]. Figure 5 presents several different S-parameter values. While it is running at its resonance frequency of 3.5 GHz, the antenna has a return loss of -50.423% dB, and a bandwidth of 3.4391-3.5612 GHz shown the Figure 6.

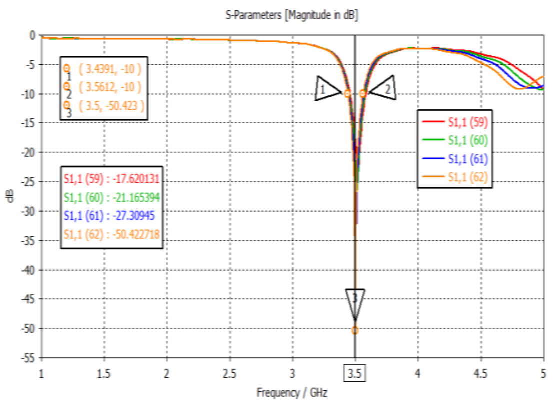

Figure 5. Return loss vs frequency several values of proposed design

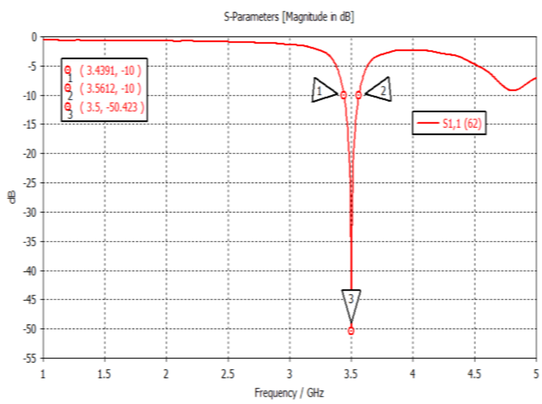

Figure 6. Return loss vs frequency single value of proposed design

3.3. Voltage standing wave ratio and bandwidth

The VSWR, which stands for VSWR, is a way to measure how much power an antenna reflects. The lower the VSWR number, the better the antenna's performance. It explains how the transmission line impedance is set to match [22]. The value of the VSWR should be somewhere between 1 and 2 for the communication to function at its peak level of effectiveness. The lower the value of the VSWR, the more closely the antenna fits the transmission line, which causes more power to be sent to the antenna [23]. Figure 7 illustrates several different VSWR values. At 3.5 GHz; this frequency range goes from 3.4355 GHz to 3.5650 GHz, and the VSWR in Figure 8 is 1.00604.

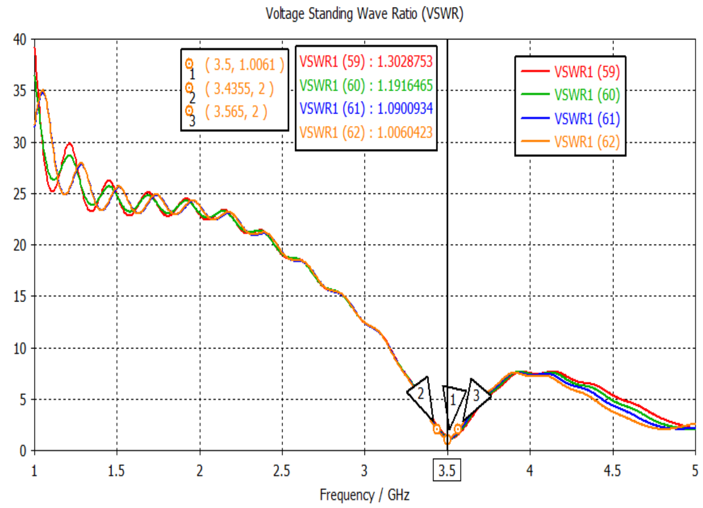

Figure 7. VSWR vs frequency of several values

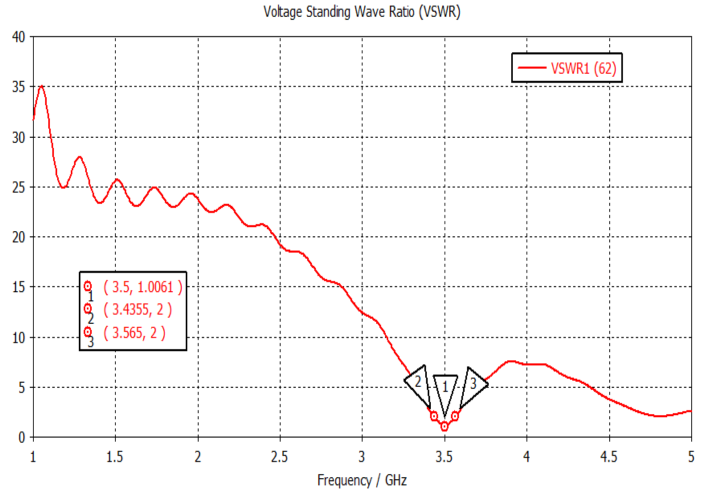

Figure 8. VSWR vs frequency of single value

3.4. Gain and radiation pattern

Directivity refers to the relative strength of an antenna's radiation in a specific direction compared to the average power of its radiation across all directions. It is a measure that quantifies how focused or concentrated the antenna's radiation pattern is toward a particular direction. This ratio is referred to as an antenna's "directional ratio" [24]. The radiation pattern is one of the most significant qualities to look at when evaluating the performance of a MPA. It is one of the most critical characteristics. This statistic is of the utmost relevance since it displays how efficiently the antenna is functioning [25]. At the resonant frequency of 3.5 GHz, the directivity gain of the antenna after the simulation is found to be 7.43 dBi, in Figure 9. The polar radiation pattern is depicted graphically in Figure 10. The intensity of the principal lobe is 7.43 dBi, and the angle of incidence is 39.0 degrees. It takes an angle of 53.3 degrees to equal a value of 3 dB. On the sidelobe scale, this antenna has a sidelobe level of -1.3 dB below the average. Also, Figure 11 shows the 2D farfield directivity gain.

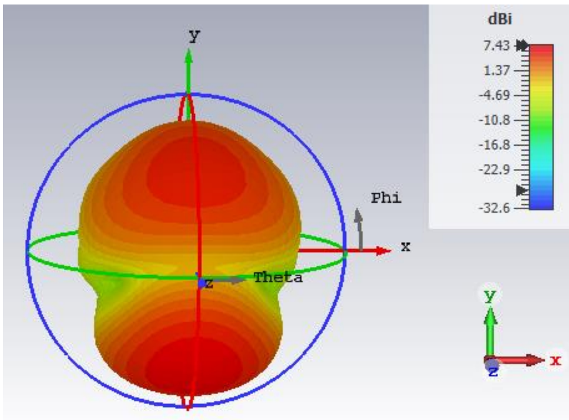

Figure 9. 3D directivity gain

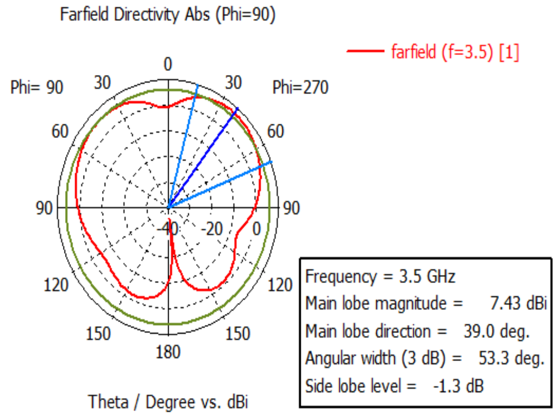

Figure 10. Farfield directivity

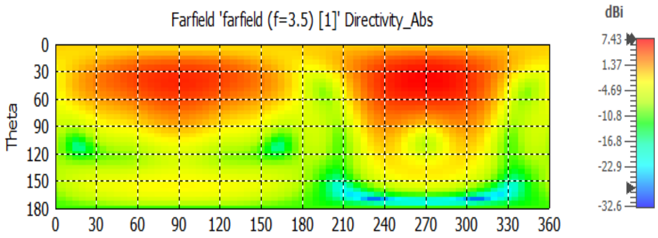

Figure 11. 2D directivity gain

The surface current distribution for the MPA with a microstrip feedline at 3.5 GHz is depicted in Figure 12. An electric current run along the surface, created by an electromagnetic field that originates from the outside. The intensity of the magnetic field can be observed to be 28.9 A/m at the transmission line, as depicted in Figure 10. At 3.5 GHz, the power flow of MPA is 66,300 VA/m^2 as Figure 13.

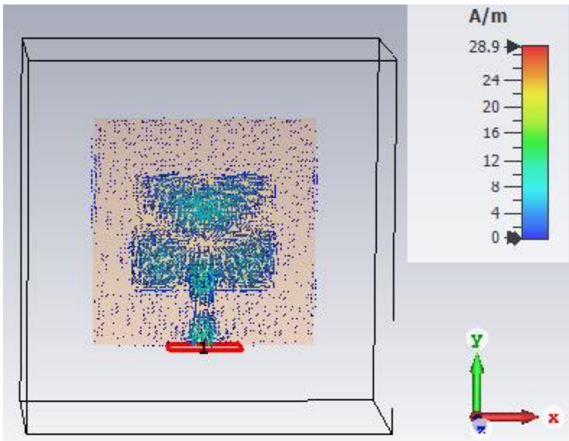

Figure 12. Surface current of MPA

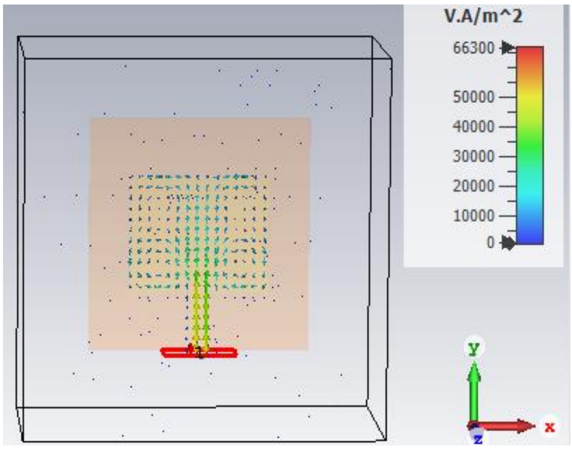

Figure 13. Power flow of MPA

4. RESULT ANALYSIS

At a frequency of 3.5 GHz, the suggested antenna has a directivity gain of 7.43 dBi. This antenna has a return loss of -50.423 dB, a bandwidth of 0.1221 GHz, and a VSWR of 1.0061. As a direct result of this, this antenna has the potential to be a leading contender for use in the following wireless applications: the simulation results in Table 2 provide a comprehensive overview of the findings. To further evaluate the performance of the proposed MPA, Table 3 compares its maximum return loss, directivity gain, and bandwidth with other relevant parameters. Considering the continuous growth of the wireless communication technology market, the research outcomes and comparisons presented in these tables contribute to a valuable understanding of the MPA's potential and its suitability for future applications.

Table 2. Summarizes the simulation results

Parameter	Value
Return loss	-50.423 dB
VSWR	1.0061
Directivity gain	7.43 dBi
Bandwidth	0.1221 GHz
Dielectricity permittivity	2.2

Table 3. Compare return loss, directivity gain, and bandwidth previous published works

Ref.	Operating frequency (GHz)	Dielectricity permittivity (ε)	Return loss (dB)	Directivity gain (dBi)	VSWR	Bandwidth
[8]	3.5	2.2	-31	6	1.5	-
[10]	3.4	2.54	-25	7	-	-
[11]	3.5	4.3	-30	5.15	-	-
[12]	3.5	-	-17.436	6.6	1.31	65.2 MHz
[13]	3.5	2.2	-18.02	-	-	120 MHz
[14]	3.6	2	-28.76	2.52	Below 2	-
[15]	3.98	4.3	-15.67	5.75	1.399	213 MHz
[16]	3.5	2.2	-40.2827	5.82	1.02	200 MHz
[17]	3.5	-	-2.12	5.43	-	-
[23]	3.5	-	-21.8	7.2	1.117	0.210 GHz
[26]	3.55	-	-44	6.695	1.0238	-
[27]	3.5	4.6	-19	7	-	20 MHz
[28]	3.5	4.3	-12.54	5.5	1.6	66.5 MHz
[29]	3.5	2.2	-26.385	-	1.09	72 MHz
[30]	3.5	2.2	-13.772	-	1.5152	0.0236 GHz
This works	3.5	2.2	-50.423	7.43	1.0061	0.1221 GHz

5. CONCLUSION

This study presents the simulation, analysis, and operation of a 3.5 GHz MPA. The antenna exhibited remarkable performance through simulation, with a return loss of -50.423 dB, a VSWR of 1.0061, a bandwidth of 0.1221 GHz, and a directional gain of 7.43 dBi. The applicability of this concept extends to the S-band, which encompasses radars, mobile phones, and WLAN. The research paper holds potential for future wireless applications. The simulations highlight the antenna's excellence as a choice for wireless communication systems. The antenna fabrication is imminent, enabling prompt measurements, and a quick comparison to the simulated models.

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