The Spirit of Society Journal
International Journal of Society Development and Engagement
LPPM - Universitas Narotama
ISSN : 2594 - 4777 (Online)
2597 - 4742 (Print)
https://jurnal.narotama.ac.id/index.php/scj/index

Design and Analysis of Microstrip Patch Antennas to Support the Implementation of Smart Ports

M B Rahmat[1*], Y Widiarti[1], E Setijadi[2], A Idris[3], A Julia[3], S A Hamzah[4], Nurhayati[5], K S H Putri[1]

[1] Department of Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, East Java, Indonesia

[2] Department of Electrical Engineering, Sepuluh November Institute of Technology, Surabaya, East Java, Indonesia

[3] Wireless Technology Group, School of Electrical Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia

[4] Department of Electronic Engineering, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussien Onn Malaysia, Parit Raja, Johor Malaysia.

[5] Department of Electrical Engineering, State University of Surabaya, East Java, Indonesia

Correspondent author: mbasuki.rahmat@ppns.ac.id

Abstract: Smart port is a port concept which is designed and managed efficiently and effectively, which includes various technologies such as the use of automation systems, robotics, the Internet of Things (IoT), and data analysis. the main service to convert a port into a smart port or Port 4.0. categorized into three main areas: Smart infrastructure is focused on “fixed assets” in ports, such as buildings (e.g. warehouses or stacking areas), cranes, trains, and roads. Smart traffic is focused on “moving assets” such as ships, trucks, trains and containers. Smart trading is focused on the flow of cargo. Digitalization with information and communication technology and automation are fundamental factors in pushing a port towards a smart port. One of the important components in communication technology is the antenna. several devices exchange data for remote monitoring using wireless communication. Antennas are very important in wireless communications. This article explains antenna design and analysis to support Dedicated Short-Range Communications (DSRC) in smart ports. This paper designs, simulates, and analyzes a microstrip patch antenna (MPA) for wireless applications. FR-4 (lossy) and Roggers RT/duroid with a dielectric permittivity of 4.3 and 2.2 has been used as a substrate material. The simulation was carried out using computer simulation technology (CST) suite studio 2019 software. Simulation with FR-4 material showed a return loss of -21.23 dB, gain of 2.718 dBi, directivity of 7.525 dBi, voltage standing wave ratio (VSWR) of 1.1864, bandwidth (BW) is 0.0635 GHz, and Simulation using Rogers RT5880/duroid material showed a return loss of -10.813 dB, gain of 8.084 dBi, directivity of 8.528 dBi, voltage standing wave ratio (VSWR) of 1.8095, bandwidth (BW) is 0.0441 GHz

Keywords: Smart Ports, DSRC, MPA, wireless, communication

INTRODUCTION

1. Introduction

One of the key components facilitating 5G technology is the microstrip patch antenna (MPA). MPAs offer a range of benefits including wider bandwidth (BW), higher efficiency, lower power consumption, and a higher gain, making them a fitting choice for 5G applications.

The microstrip antenna, or patch antenna, dates back to its patented inception in 1955. It comprises a sandwich-like structure with a layer of conductive material on either side of an insulating substrate. The layer at the bottom is known as the "ground plane," while the top layer is referred to as the "patch." Both layers are conductive, adhering to the principles of printed circuit boards, hence the name "printed antennas." Key parameters like the length, width, thickness of the substrate, dielectric constant of the substrate material, and the placement of the feed line significantly influence the antenna’s performance. Essentially, an MPA connects to both a source and a load terminal, acting as an impedance-matching device to ensure efficient signal transmission. It converts electrical signals into electromagnetic waves for transmission, and upon reception, transforms these electromagnetic waves back into electrical signals(Islam et al., 2008). This dual capability is an essential aspect of transduction, the core principle of antenna function. The surge in demand for wireless communication and the trend towards miniaturization have presented new challenges in antenna design(Nawaz et al., 2013). Despite advances, MPAs face limitations, notably in their narrow BW and low gain.

These limitations are critical for a variety of applications, including some governmental security uses, demanding continuous innovation and optimization. Traditional rectangular MPAs can be modified into various geometric shapes such as square, circular, triangle, donut, and dipole, each with unique performance characteristics (Abdulrab & Habaebi, 2015). The construction of an MPA involves three layers: the ground structure layer, typically made of copper; the substrate layer, which can be composed of dielectric materials like air, FR4, or Rogers; and the top conductive patch(Rana & Rahman, 2022; Tiwari et al., 2020)(Tiwari et al., 2020).

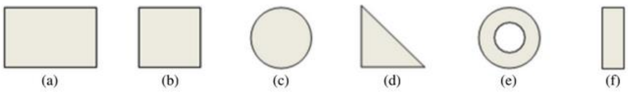

Figure 1. Representative shapes of microstrip patch elements (a) rectangle, (b) square, (c) circle, (d) triangle, (e) donut, (f) dipole

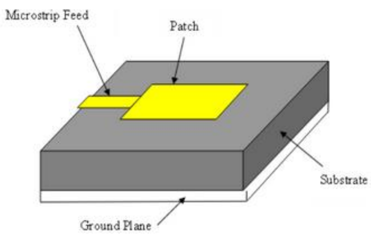

Figure 2. Patch antenna geometry

METHODOLOGY

Patch antennas play a crucial role in modern wireless communication networks due to their efficient design and versatility. These antennas, primarily fabricated using microstrip technology, are often realized in rectangular and circular shapes, which are prevalent in daily applications due to their simplicity and effectiveness (Aneesh et al., 2013).

The use of microstrip patch antennas (MPAs) is increasing rapidly across various fields such as wireless communication, vehicle-to-vehicle communication, biomedical applications, networked machine learning, and artificial neural networks, among others. Numerous studies have been published, focusing on optimizing the performance and capabilities of MPAs, particularly within the S-band frequency range.

Different MPA configurations, including rectangular, circular, and triangular patches, suitable for 5G networks has discovered by (Rana & Rahman, 2022) and confirmed that the proposed antenna parameters aligned with earlier studies' results. MATLAB's Simulink and Antenna Toolboxes is used to build and simulate a 2.45 GHz square patch MPA, addressing the trade-offs in antenna size, cost, performance, and return loss (Abdulhussein et al., 2021).

An inset-fed rectangular MPA using CST design studio was developed and tested with different grounding methods, achieving varied return loss values, demonstrating the antenna's flexibility in meeting specific design criteria (Duman et al., 2022) (Demirbas et al., 2022)and an antenna with 2.4 GHz working frequency meeting IEEE 802.11 standards, with copper grounding and patching, suitable for Wi-Fi research has been used (Devi et al., 2022).

The effectiveness of an MPA designed for the 2.45 GHz ISM band in wireless sensor networks has been confirmed to improve return loss and radiation patterns (Mahbub et al., 2021) (Abdulhussein et al., 2021)

Conclusively, the continual research and development of MPAs highlight their pivotal role in advancing wireless communication technologies. With a focus on optimizing various parameters like gain, bandwidth, and return loss, MPAs are poised to meet the increasing demands of modern wireless applications.

RESULTS AND DISCUSSION

A Microstrip Patch Antenna most important parts are ground, substrate/dielectric, patch and feedline (Kang et al., 2012). Microstrip antennas, with their low profile and lightweight features, have become an integral component in the realm of wireless communication. Their versatility in design and functionality aids in their widespread application across various sectors. The continual advancements in simulation software, like CST, have furthered the development and optimization of these antennas.

The CST software allows for detailed simulation of microstrip antenna (MPA) designs, providing critical insights into their performance characteristics. By simulating different parameters, CST can present a comprehensive overview, including return loss, bandwidth, radiation pattern, and gain. This enables engineers to refine the design for optimal performance in specific applications.

Figure 3, as referenced, presumably displays key metrics derived from CST simulations. These metrics are essential in evaluating the proposed antenna design's efficiency. For instance, a low return loss indicates better impedance matching, implying lesser signal reflection and higher transmission efficiency. The bandwidth showcases the range of frequencies over which the antenna can effectively operate, which is crucial for various wireless communication standards.

Radiation patterns are another vital aspect, illustrating how the antenna directs the energy. They help in understanding the coverage area and potential interference issues. High gain values, ideally in the desired direction, suggest that the antenna can transmit signals more effectively in that orientation.

Analysing these characteristics allows engineers to assess the antenna's suitability for particular wireless communication needs. By iterating through the design and simulation process, they can make informed adjustments, improving performance metrics to meet specific criteria. Thus, the use of CST software in simulating MPA designs is invaluable, ensuring that the proposed solutions are both innovative and practical for modern wireless communication challenges.

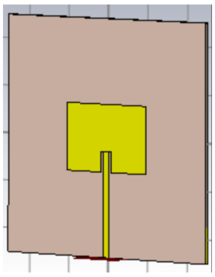

Figure 1. The antenna structure developed in CST

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

$$Wp = \frac{C_0}{2fr\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (1)$$

The dielectric constant of effective potential:

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

Extended length:

$$L_{ext} = \frac{C_0}{2fr\sqrt{\varepsilon_{reff}}} \quad (3)$$

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

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

Antenna Parameters

Table 1 indicates parameters used in the design of 2.45 GHz, where we use length, and width of patch, substrate and ground, also the height of substrate used in the design process.

Table 1. Antenna parameters in millimeters (mm)

	FR4	**Rogers RT5800**
W	45	67
L	28	38.5
Wg	95	
Lg	95	
h	1.5	

Return Loss

Consider a patch antenna constructed using FR-4 and Rogers RT Duroid 5880 substrate materials. This antenna may exhibit a return loss of -21.32 dB, a bandwidth ranges from 2.4149 GHz to 2.4784 GHz, and an operating frequency range between 2.4081 GHz and 2.4522 GHz, with a return loss of -10.813 dB at its resonance frequency of 2.45 GHz. Such parameters indicate a high-performance antenna well-suited for precise communication tasks, highlighting the importance of return loss and S-parameters in antenna design and functionality.

The return loss versus frequency graph in Figure 5 indicates the performance characteristics of the recommended patch antenna at the solution frequency of 2.45 GHz. For the FR-4 substrate, the return loss is -21.32 dB, while for the Rogers RT droid substrate, it is -10.813 dB. Both values signify the antenna's effectiveness in minimizing signal reflection, although a higher negative value is desired for optimal performance.

Figure 5 also illustrates the bandwidth (BW) of the antenna, which is 0.0635 GHz for the FR-4 substrate and 0.0441 GHz for the Rogers RT droid substrate. These bandwidth values are crucial indicators of the operating frequency range over which the antenna performs efficiently.

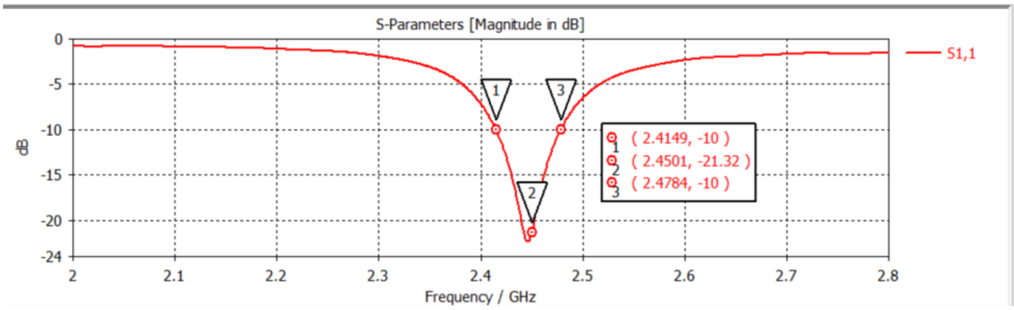

Figure 2. Return loss vs frequency of the antenna FR-4

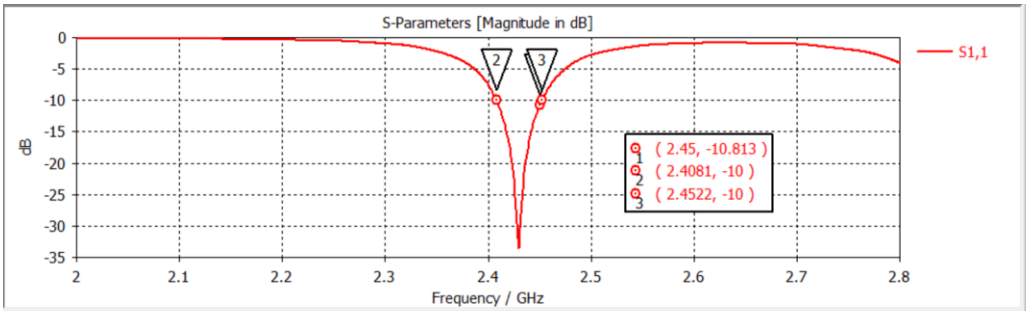

Figure 3. Return loss vs frequency of the antenna Roger RT5800

Furthermore, a similar return loss plot for the proposed antenna at varying frequencies is available in Figure 4, accessible via a provided link. Together, these figures highlight the importance of substrate choice on the antenna's performance metrics, such as return loss and bandwidth, which are vital for efficient signal transmission and reception.

Voltage Standing Wave Ratio and Bandwidth

At a frequency of 2.45 GHz, the VSWR for different materials can vary, impacting performance. For instance, using FR-4 material, the VSWR is recorded at 1.1864 with a frequency span from 2.4149 GHz to 2.4784 GHz. This represents a high level of efficiency in RF power transmission. Conversely, for Rogers RT/duroid material, the VSWR is slightly higher at 1.8095, with a frequency span ranging from 2.4081 GHz and 2.4522 GHz. While still within an acceptable range, the higher VSWR indicates a slightly less efficient transfer of power compared to FR-4 material.

The Voltage Standing Wave Ratio (VSWR) is an important metric used to evaluate how effectively radio frequency (RF) power is transferred from a power source to a load through a transmission line. Ideally, the VSWR value should be between 1 and 2 for optimal communication. When the impedance matching value is closer to one, it represents a more efficient transfer of power.

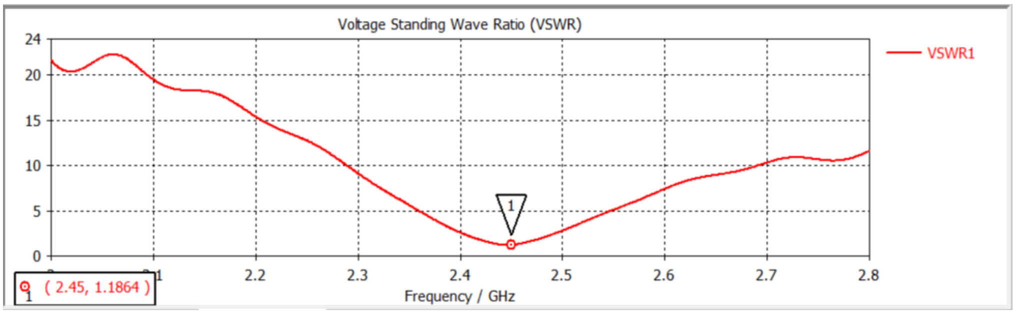

Figure 4. Voltage Standing Wave Ratio for FR-4 Material

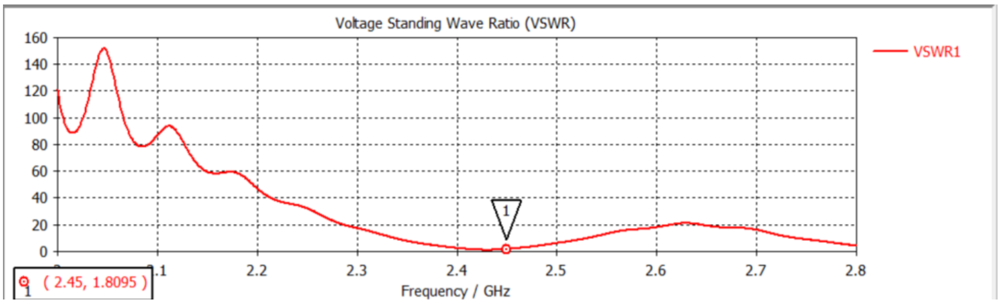

Figure 5. Voltage Standing Wave Ratio for Roger RT5800 Material

Gain and Radiation Pattern

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 2.718 dB and 8.084 dB by using FR-4 and Roggers RT/duroid substrate materials, respectively. The gain of the proposed design is 8.084 dB at 2.45 GHz. 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 (Mahbub et al., 2021). 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 (Tiwari et al., 2020) (Nurhayati et al., 2021).

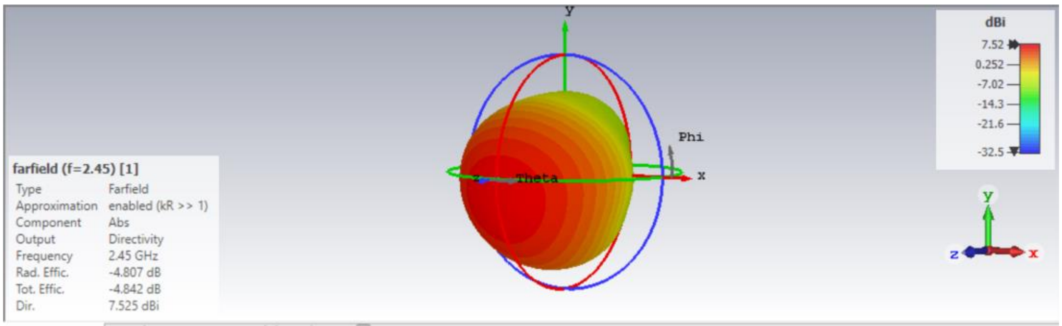

Figure 6. Radiation Pattern FR-4

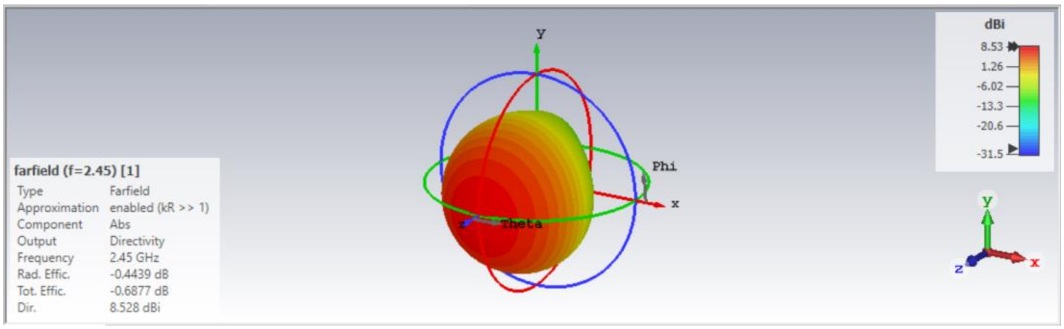

Figure 7. Radiation Pattern Roger RT5800

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 (Mahbub et al., 2021). Figure 8 shows 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 7.525 dBi and 8.528 dBi, with the proposed design achieving a directivity of 8.528 dBi.

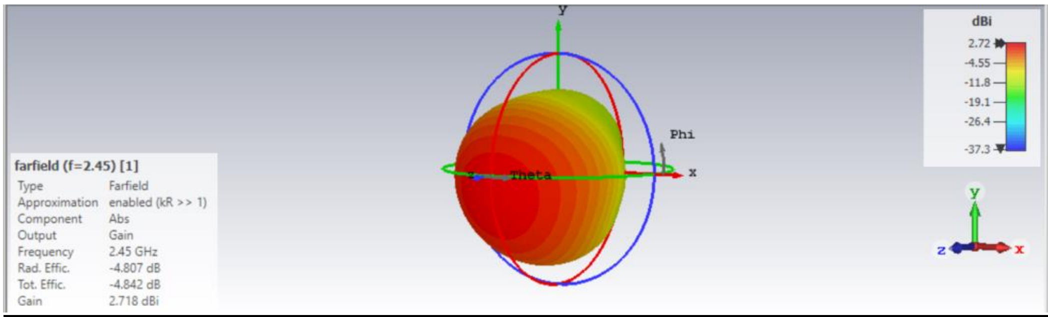

Figure 8. Gain pattern for FR-4

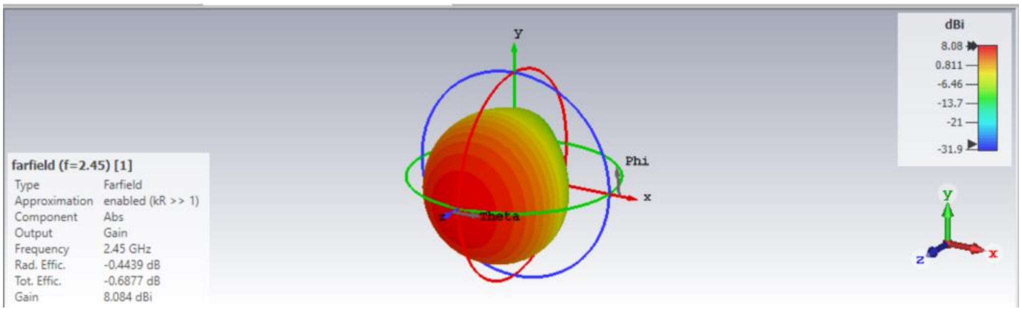

Figure 9. Gain pattern for Roger RT5800

Figure 9 provides a visual illustration of the polar radiation pattern. The primary lobe of the FR-4 substrate material has an intensity of 7.52 dBi, and its angle of incidence is 10.0 degrees. The angle that corresponds to a value of 3 dB is 76.4 degrees. This antenna has a sidelobe level of -12.2 dB on the sidelobe scale. To reiterate, the magnitude of the primary lobe is 8.54 dBi for the Rogers RT duroid material, and the angle is 3.0 degrees. A figure of 73.4 degrees represents the 3 dB angular value. Also, their side lobe level is -22.9 dB.

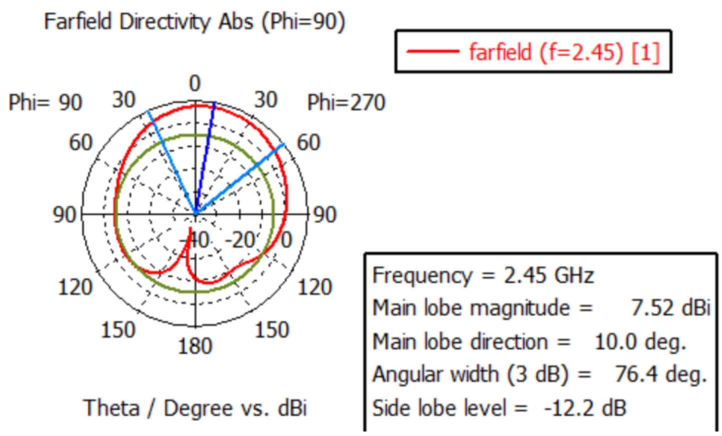

Figure 10. Farfield directivity FR 4

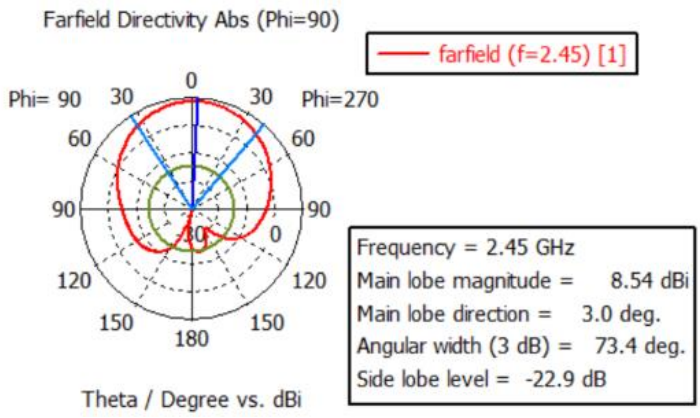

Figure 11. Farfield directivity Roger RT5800

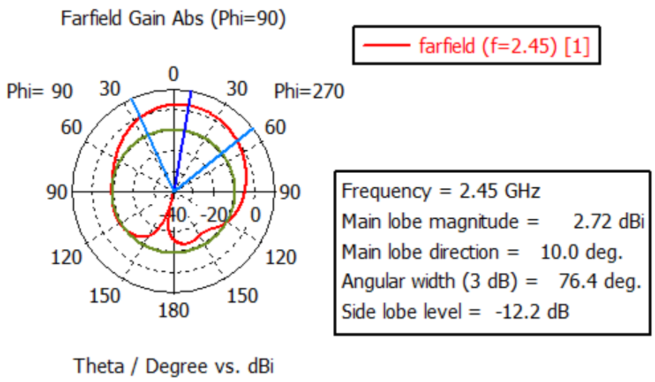

Figure 12. Farfield gain FR 4

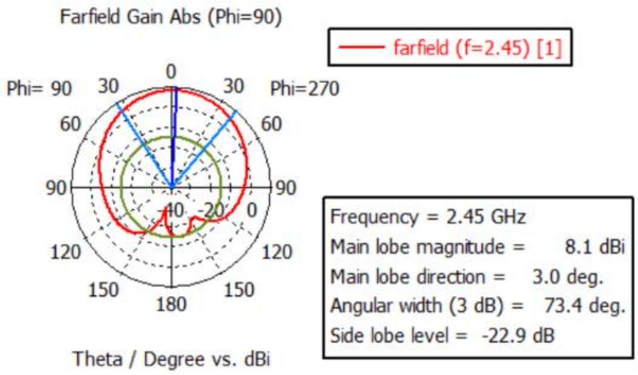

Figure 13. Farfield gain Roger RT5800

Result Analysis

In this investigation, the FR-4 and the Roggers RT duroid 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 2.718 dB, the directivity is 7.525 dBi, the return loss is -21.32dB, the BW is 0.0635GHz, the VSWR is 1.1864. On the other hand, the return loss, gain, directivity, BW, VSWR for the material that was utilized in the Rogers RT Duroid are, respectively, -10.813 dB, 8.084 dB, 8.528dBi, 0.0441GHz, 1.8095. The antenna uses Roggers substrate material to meet its operational goals of increased gain, strong directivity. Table 2 displays the findings of the simulation, which are summarized in the following sentence.

Table 2. Parameter analysis results

Parameters	FR-4	Roggers RT5880
Return loss (dB)	-21.32	-10.813
BW (GHz)	0.0635	0.0441
Gain (dB)	2.718	8.084
Directivity (dBi)	7.525	8.528
VSWR	1.1864	1.8095

CONCLUSIONS

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 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 of -10.813 dB, 8.0842 dB, 8.528 dBi, 1.8095 respectively. Furthermore, the FR-4 results include return loss, gain, directivity gain, VSWR of -21.32dB, 2.718 dB, 7.47 dBi, 1.1864, 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.

.

Acknowledgments (Optional): We would like to express our deepest gratitude to the Shipbuilding Institute of Polytechnic Surabaya for providing research funding through the PPNS DIPA Fund with Contract Number: 1366/PL19.ppk/TI 00.01/2024. We would also like to express our thanks to Professor Ts Dr Azlina Idris C.Eng from Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia who has taken the time to provide input in the development and refinement of the antenna simulation process. The author would also like to thank sister Aidatul Julia, from Universiti Teknologi MARA for her valuable input so that this research could run smoothly. Then to Mr. Eko Setijadi, S.T., M.T., Ph.D, we would like to express our gratitude for his input and support so that this research can run better.

REFERENCES

Abdulhussein, A. M., Khidhi, A. H., & Naser, A. A. (2021). Omnidirectional Microstrip Patch Antenna for 2.4 GHz Wireless Communications. *Journal of Physics: Conference Series*, *2114*(1), 012051. https://doi.org/10.1088/1742-6596/2114/1/012051

Abdulrab, W. S., & Habaebi, M. H. (2015). *DESIGN OF RECTANGULAR MICROSTRIP PATCH ANTENNA USING STEPPED CUT AT FOUR CORNERS FOR BROADBAND/ MULTIBAND APPLICATION*. *10*. www.arpnjournals.com

Aneesh, M., Ansari, J., Singh, A., & Sayeed, S. (2013). Analysis of S-shape Microstrip Patch Antenna for Bluetooth application. *International Journal of Scientific and Research Publications*, *3*(11). www.ijsrp.org

Demirbas, G., Gocen, C., & Akdag, I. (2022). Micro-strip Patch 2.4 GHz Wi-Fi Antenna Design For WLAN 4G- 5G Application. *ICONTECH INTERNATIONAL JOURNAL*, *6*(1), 68–72. https://doi.org/10.46291/ICONTECHvol6iss1pp68-72

Devi, G. S. K. G., Veni, S. K., Vidyavathi, T., & Ahmad, S. J. (2022). Design of a Compact ISM-band Microstrip Slot Antenna for Wireless Sensor Nodes. *Indian Journal Of Science And Technology*, *15*(38), 1958–1964. https://doi.org/10.17485/IJST/v15i38.1678

Duman, M., Koç, S. A., Yılmaz, Y., Ramazan, F., Mert, O., & Özkan, R. (2022). Effect of FR4 Ground Layer on Rectangular Microstrip Patch Antenna in terms of Length and Width. *Academic Perspective Procedia*, *5*(3), 456–461. https://doi.org/10.33793/acperpro.05.03.8356

Islam, M. T., Misran, N., Shakib, M. N., & Yatim, B. (2008). Stacked multiple slot microstrip patch antenna for wireless communication system. *2008 International Conference on Electrical and Computer Engineering*, 783–786. https://doi.org/10.1109/ICECE.2008.4769316

Kang, J.-S., Kim, J.-H., Kang, N.-W., & Kim, D.-C. (2012). Antenna measurement using S-parameters. *2012 Conference on Precision Electromagnetic Measurements*, 658–659. https://doi.org/10.1109/CPEM.2012.6251101

Mahbub, F., Islam, R., Kadir Al-Nahiun, S. A., Akash, S. B., Hasan, R. R., & Rahman, Md. A. (2021). A Single-Band 28.5GHz Rectangular Microstrip Patch Antenna for 5G Communications Technology. *2021 IEEE 11th Annual Computing and Communication Workshop and Conference (CCWC)*, 1151–1156. https://doi.org/10.1109/CCWC51732.2021.9376047

Nawaz, M. I., Huiling, Z., Sultan Nawaz, M. S., Zakim, K., Zamin, S., & Khan, A. (2013). A review on wideband microstrip patch antenna design techniques. *2013 International Conference on Aerospace Science & Engineering (ICASE)*, 1–8. https://doi.org/10.1109/ICASE.2013.6785554

Nurhayati, N., De-Oliveira, A. M., Chaihongsa, W., Sukoco, B. E., & Saleh, A. K. (2021). A Comparative Study of Some Novel Wideband Tulip Flower Monopole Antennas with Modified Patch and Ground Plane. In *Progress In Electromagnetics Research C* (Vol. 112).

Rana, Md. S., & Rahman, Md. M. (2022). Study of Microstrip Patch Antenna for Wireless Communication System. *2022 International Conference for Advancement in Technology (ICONAT)*, 1–4. https://doi.org/10.1109/ICONAT53423.2022.9726110

Tiwari, R., Sharma, R., & Dubey, R. (2020). Microstrip Patch Antenna Array Design Anaylsis for 5G Communication Applications. *SMART MOVES JOURNAL IJOSCIENCE*, *6*(5), 1–5. https://doi.org/10.24113/ijoscience.v6i5.287