JPPIPA 11(8) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Performance Analysis of a Unidirectional Double E-Shaped Microstrip Antenna in the ISM Band

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Received: May 08, 2025
Revised: July 11, 2025
Accepted: August 25, 2025
Published: August 31, 2025

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DOI: 10.29303/jppipa.v11i8.12118

Abstract: This research explores the design and simulation of a unidirectional double E-shaped microstrip antenna (MSA) operating at 5.8 GHz. The antenna was designed using CST Studio Suite, with Rogers RT 5880 as the substrate material due to its favorable dielectric properties. The design process involved adjusting the patch geometry by introducing slots to enhance bandwidth and gain. Simulation results show a return loss of −38.05 dB and a VSWR of 1.025, both indicating excellent impedance matching. Additionally, the antenna exhibits a directional radiation pattern with a peak gain of 7.63 dBi. These findings highlight the antenna's potential for compact and high-performance wireless communication systems in the ISM frequency band.

Keywords: Bandwidth; High gain antenna; ISM band; Microstrip

Introduction

Indonesia's geographical condition as an archipelagic country influences unstable weather patterns and makes it vulnerable to extreme weather phenomena such as droughts or excessive rainfall (Anjasman, 2023). The mountainous terrain and tropical rainforests contribute to this region having one of the highest annual rainfall levels in Indonesia (Mardyansyah et al., 2024). Weather has an effect on several environmental processes such as soil erosion in mining sites (Aditya et al., 2023) and changes in weather can influence human health (Deswanti et al., 2022; Mucci et al., 2023). Weather information serves as a crucial and integral component (Danitasari et al., 2024; Rusdiansah et al., 2024). Therefore, an effective and accurate early warning system in real time is required by utilizing weather radar technology. Wireless communication is widely adopted to support human needs (Nafrianto, 2021; Ehsan et al., 2021) such as wireless sensor network in which is used to monitor environmental conditions (Indra et al., 2023; Siregar, 2023). This technology has advanced significantly due to continuous innovations in signal processing, transmission techniques, and antenna design (Kang et al., 2021; Cakula & Pratt, 2021; Supriya et al., 2015; He et al., 2022). Innovation in technology has significantly influenced multiple aspects of human life (Kuswanti et al., 2024).

Antennas have become essential elements in contemporary wireless communication systems (Balanis, 2005; Shanmugasundaram et al., 2018), which are continuously evolving and expanding into various domains, including mobile communications (Rana et al., 2024), satellite technologies (Apriono et al., 2023), radar systems (Nagy, 2023), and other related applications. A variety of antenna structures and configurations have been engineered for different applications (Wang et al., 2019; Boehmert et al., 2018). Consequently, there is a pressing need for antennas that can operate effectively while maintaining a compact and lightweight form. Microstrip antennas (MSAs) present several advantages, including the use of lightweight materials and ease of

How to Cite:
Natalia, Quzwain, K., Olivia, L. N., & Rahmawati, P. (2025). Performance Analysis of a Unidirectional Double E-Shaped Microstrip Antenna in the ISM Band. *Jurnal Penelitian Pendidikan IPA*, *11*(8), 1062–1067. https://doi.org/10.29303/jppipa.v11i8.12118

fabrication (Alam & Kurniawan, 2018). However, they are often constrained by inherent limitations such as low gain and narrow bandwidth (Bansal, 2008; Surjati, 2010).

To address these challenges, various enhancement techniques have been developed. Common approaches include modifying the patch geometry (Khanna et al., 2015; Quzwain et al., 2024). The U-slot technique can be applied to enhance the bandwidth (Kirana, 2021; Sandi et al., 2020). The concept of array can be used to improve the gain and bandwidth as well (Ruliyanta & Nugroho, 2021; Madiawati & Simanjuntak, 2020; Quzwain et al., 2023). Another concept that can be implemented to maximize the antenna performance is incorporating slots into the radiating patch or ground plane—referred to as Defected Ground Structure (DGS) (Ajay et al., 2020; Fadila et al., 2024)—and exciting higher-order modes (Khan et al., 2024). Among these, the use of slots has proven particularly effective in optimizing the spacing between fundamental modes, tuning resonance frequencies, and improving input impedance matching, all of which contribute to enhanced bandwidth (Sahu & Sharma, 2020) and overall antenna performance. However, their antennas is still low gain and their antennas are not compact.

This paper presents a double E-shaped microstrip antenna to improve its gain performance. Simulation results indicate that the designed antenna is capable of achieving a gain of 7.63 dB with S_{11} of −38.05 dB. The structure of this paper is as follows: Section 2 describes the antenna design, Section 3 discusses the simulation outcomes, and Section 4 highlights the key findings of this study.

Antenna Design

The E-shaped microstrip antenna is designed with overall dimensions of 70 × 75 mm², as illustrated in Figure 1. The antenna employs Rogers RT 5880 as the substrate material, which has a thickness of 1.575 mm, a dielectric constant (ε_r) of 2.2, a conductor thickness (t) of 0.035 mm, and a loss tangent (tan δ) of 0.0009 (Senthilkumar et al., 2022). Furthermore, he stages of the E-shaped MSA design flow chart in the Figure 2. The E-shaped patch is a modified version of a rectangular microstrip design, incorporating slits to enhance performance. The width of patch can be defined by the following equation (Balanis, 2005):

$$Wp = \frac{c}{2fr\sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

Meanwhile, the length of patch can be determined by using:

$$L = L_{reff} - 2\Delta L \tag{2}$$

With the increase in length (2ΔL) obtained from:

$$\Delta L = 0.412h \frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{3}$$

And, its effective length (L_{reff}) is:

$$L_{reff} = \frac{c}{2f\sqrt{\varepsilon_{reff}}} \tag{4}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + \frac{12h}{W}}}\right) \tag{5}$$

The width of feedline was calculated by using equation below:

$$W_f = \frac{2h}{\pi}\left\{\begin{matrix}(B-1) - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \\ \left|\ln(B-1) + 0{,}39 - \frac{0.61}{\varepsilon_r}\right|\end{matrix}\right\} \tag{6}$$

With the value of B obtained from:

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}} \tag{7}$$

On the other side, the length of 50Ω feed line impedance can be determined by using:

$$L_f = \frac{\lambda_g}{4} \tag{8}$$

With the guided length is:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \tag{9}$$

Table 1 shows the optimized parameters and Figure 1 illustrates the designed antenna.

Table 1. The dimensions of the purposed antenna

Parameter	Values (mm)
Groundplane Width (W_g)	70
Groundplane Length (L_g)	75
Patch Width (W_p)	57.5
Patch Length (L_p)	51.2
Feedline Width (W_f)	7
Feedline Length (L_f)	8.874

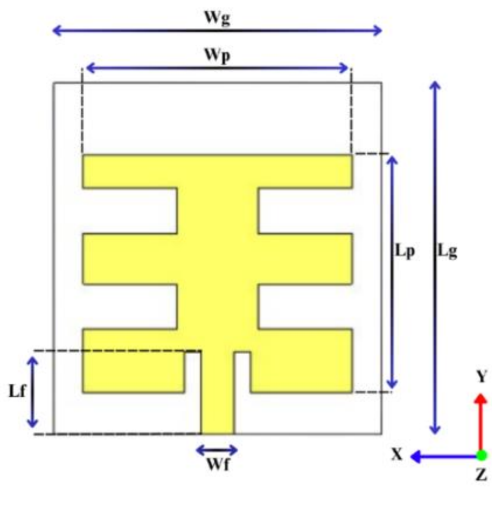

Figure 1. Design of E-shaped MSA

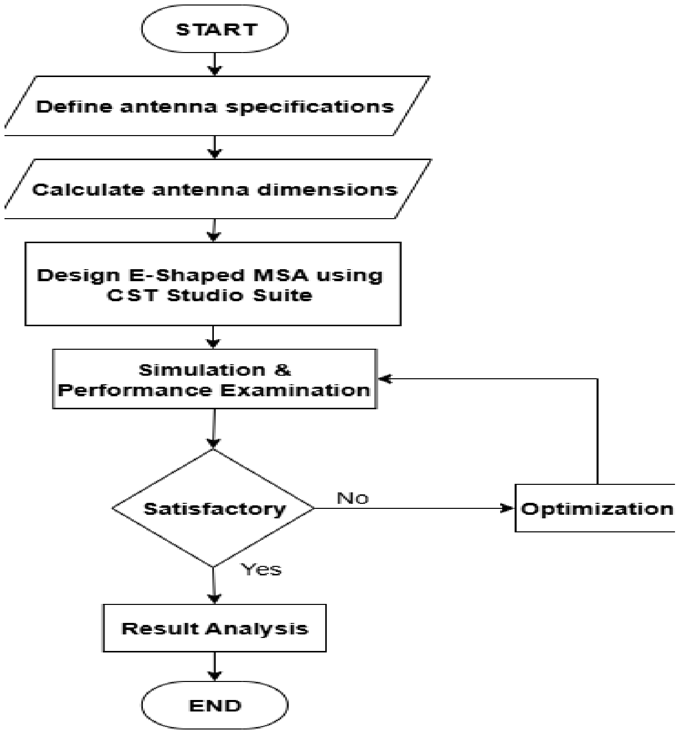

Figure 2. Flowchart of the designed antenna

Figure 2 shows flowchart of the designed antenna. The first step in designing the proposed antenna in this study is defining the design specifications. In this step, operating frequency, bandwidth, and gain must be specified. Once the antenna specifications are defined, the corresponding design dimensions can be calculated. The width, length, and feed dimensions are the crucial parameters in designing antenna. The next step is simulation using electromagnetic (EM) software in order to verify the calculated parameters. The analysis can be carried out to evaluate key parameters, once the simulation results demonstrate good performance.

Result and Discussion

The performance of the proposed double E-shaped microstrip antenna was analysed through simulation, focusing on operation at the ISM frequency of 5.8 GHz. Figure 3 shows S_{11} of the designed antenna. It shows a sharp dip at 5.8 GHz, reaching −38.05 dB, which indicates excellent impedance matching and minimal signal reflection. The antenna operates effectively within the 5.860–5.734 GHz range, providing a −10 dB bandwidth of 126 MHz, making it suitable for ISM band applications. In indicates that the simulated Voltage Standing Wave Ratio (VSWR) at 5.8 GHz is 1.025, which is very close to the ideal value of 1. This confirms efficient power transfer from the feed line to the antenna, with negligible energy loss due to reflection. On the other hand, Figure 4 provides the simulated radiation pattern of the proposed antenna. The 3D far-field plot supports these findings, showing a well-defined directional beam. The antenna achieves a maximum gain of 7.63 dBi, with total efficiency around −1.146 dB, which is quite reasonable for a microstrip design using a Rogers RT 5880 substrate.

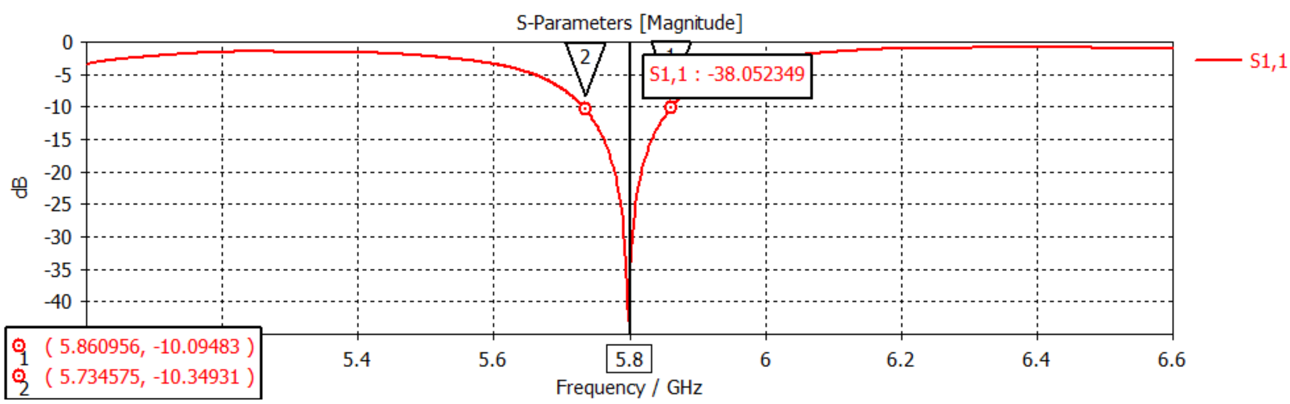

Figure 3. The simulated S11 of the proposed antenna

Radiation pattern analysis was carried out in two principal planes: Phi = 0° and Phi = 90°. In the Phi = 0° plane, the antenna exhibits a main lobe gain of 7.12 dBi, directed at 0°, with a 3 dB beamwidth of 50.8° and side lobe level of −16.7 dB. In the Phi = 90° plane, the main lobe gain increases to 7.67 dBi, pointing at 53°, and the beamwidth narrows to 40.3°, with a side lobe level of −0.5 dB. These results indicate a directional radiation pattern with minimal unwanted radiation.

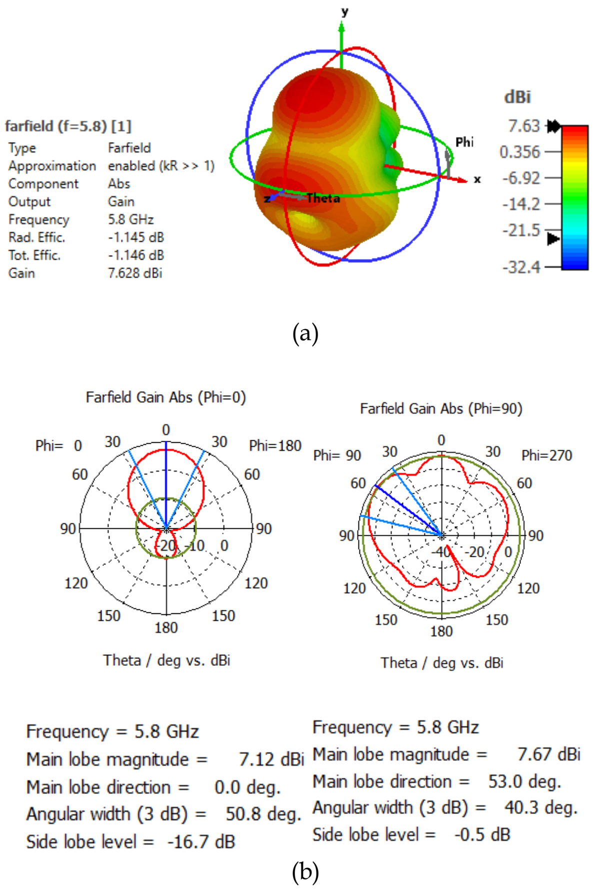

Figure 4. The simulated radiation pattern of the proposed antenna in (a) 3-D and (b) 2-D

Conclusion

The design and simulation of the double E-shaped microstrip antenna successfully demonstrate its effectiveness for ISM band applications at 5.8 GHz. With S_{11} of −38.05 dB and a VSWR of 1.025, the antenna offers strong impedance matching and low signal reflection. The directional radiation pattern and gain of 7.63 dBi further confirm its suitability for wireless systems that require both compact size and efficient performance. The use of Rogers RT 5880 and slot modifications plays a significant role in enhancing bandwidth and gain. Overall, this antenna design offers a reliable and practical solution for modern wireless communication needs.

Acknowledgments
The authors would like to express their heartfelt gratitude to Telkom University for supports this research

Author Contributions
Conceptualization, N., K. Q., L.N.O., P. R.; methodology, N., K. Q.; validation, N., K. Q.; formal analysis, N., K. Q.; investigation, N., K. Q..; resources, P. M. Z. and T. R.; data curation, R. A. E.: writing—original draft preparation, N.; writing—review and editing, N., K. Q..: visualization, and N. All authors have read and agreed to the published version of the manuscript.

Funding
This research received no external funding.

Conflicts of Interest
The authors declare no conflict of interest.

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