Brilliance
Research of Artificial Intelligence

E-ISSN : 2807-9035
Volume 6, **Number** 4, November 2026
https://doi.org/10.47709/brilliance.v6i4.9651

Design of a Compact Meander-Line Antenna for LoRa Applications at 920–923 MHz

Deri Latika Herda[1*], Popy Maria[2], Everlyn Rahmadina[3], Gardinia Naz Surya[4]
[1,2,3,4]Politeknik Negeri Padang, Indonesia
[1*]deri@pnp.ac.id, [2]popy.pnp@gmail.com, [3]pelinrahmadina@gmail.com, [4]gardinianazsurya0506@gmail.com

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***Corresponding Author**

Article History:
Submitted: 15-09-2026
Accepted: 24-09-2026
Published: 01-11-2026

Keywords:
920-923 MHz; CST Simulation; LoRa; Meander-Line Antenna

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ABSTRACT

The rapid development of Internet of Things (IoT) technology requires compact, energy-efficient, and long-range wireless communication devices, making antenna design an important aspect of system development. LoRa technology provides a solution for long-range wireless communication in the sub-GHz frequency range. However, conventional antennas often have relatively large dimensions, limiting their suitability for compact and portable IoT devices. This study presents the design of a compact meander-line microstrip antenna for LoRa applications at 920–923 MHz. The meander-line structure is employed to reduce the physical dimensions of the antenna while maintaining suitable electromagnetic performance. The antenna is designed using an FR-4 substrate with a relative permittivity of 4.3 and a thickness of 1.6 mm. The design and electromagnetic simulation are performed using CST Studio Suite 2019. The proposed antenna has a substrate dimension of 42 mm × 42.5 mm. The simulation results show a return loss (S_{11}) of −23.47 dB at 920 MHz, a bandwidth of 32 MHz, a VSWR of 1.143, and a simulated gain of approximately 0.75 dBi over the 920–923 MHz frequency range, with a bidirectional radiation pattern. The results demonstrate that the proposed meander-line structure provides a compact antenna design with satisfactory impedance matching and radiation characteristics for LoRa applications.

INTRODUCTION

The increasing integration of wireless connectivity into compact electronic devices has created a growing demand for antennas with reduced physical dimensions. In many Internet of Things (IoT) applications, the available space for an antenna is limited by the size and form factor of the device. This requirement becomes more challenging at lower operating frequencies, where the relatively long wavelength generally leads to larger antenna dimensions. Consequently, reducing the physical size of an antenna while preserving its desired electromagnetic characteristics remains an important consideration in compact wireless devices.

LoRa technology is widely adopted for IoT applications that require long-range wireless connectivity and low power consumption. Its operation in the sub-GHz frequency region provides favorable propagation characteristics for such applications. In the 920–923 MHz frequency range, however, an antenna designed for a compact device must satisfy both the required operating frequency and the available physical space. A conventional antenna structure can require dimensions that are relatively large compared with the size of the intended IoT device. This condition motivates the investigation of alternative antenna geometries capable of providing a longer electrical path within a smaller physical area.

Meander-line structures offer an effective approach to antenna miniaturization by folding the conductive path into a compact geometry. The folded configuration increases the electrical length of the radiating element without requiring the same increase in its physical length. The resonant characteristics of the antenna can consequently be adjusted through the geometry of the meander structure. Nevertheless, miniaturization also introduces design challenges because variations in the meander dimensions, ground plane, and feeding structure can significantly affect impedance matching and resonant frequency. Careful optimization of these parameters is therefore required to obtain the desired operating characteristics.

In this work, a compact meander-line microstrip antenna is designed for LoRa applications in the 920–923 MHz frequency range. The antenna is developed using an FR-4 substrate with a relative permittivity of 4.3 and a thickness of 1.6 mm. The antenna geometry is systematically optimized through electromagnetic simulation using CST Studio Suite 2019. The optimization considers several geometric parameters, including the substrate, ground plane, feedline, and additional patch elements, to obtain the desired resonant characteristics within the target frequency range. The resulting antenna is evaluated in terms of return loss, VSWR, bandwidth, gain, and radiation pattern. The objective of this study is to obtain a compact antenna configuration suitable for LoRa-based IoT devices while maintaining acceptable simulated electromagnetic performance.

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LITERATURE REVIEW

Research on LoRa and other sub-GHz antennas has generally focused on achieving adequate radiation performance while addressing the dimensional constraints of compact wireless devices. At lower operating frequencies, antenna miniaturization is particularly challenging because the relatively long wavelength tends to result in physically larger radiating structures. Consequently, various approaches have been investigated, including the use of large radiating structures or arrays to improve radiation performance and the use of compact geometries, particularly meander-based configurations, to reduce the physical dimensions of the antenna.

One approach is to employ relatively large antenna structures to obtain improved gain and bandwidth. A triangle-shaped microstrip patch antenna was reported for LoRaWAN applications at 868 MHz, with dimensions of 160 × 170 × 1.6 mm³ (Krishna & Raju, 2021). A 12-element Yagi antenna developed for a LoRa RFM95W module operating at 915 MHz achieved a return loss of −17.8 dB, a VSWR of 1.29, and an average gain of 5.6 dB (Alviandi et al., 2021). A similar approach was demonstrated using a 1 × 2 antipodal Vivaldi array, which achieved a gain of 5.16 dBi and a bandwidth of 344 MHz over the 900–923 MHz frequency range (Herda et al., 2025). Although these structures provide favorable radiation characteristics, their relatively large dimensions or multiple radiating elements can limit their integration into compact IoT devices.

An alternative approach is to reduce antenna dimensions through compact radiating structures. A meander dipole antenna with dimensions of 55 × 55 × 1.6 mm³ achieved a gain of more than 0.5 dBi and a radiation efficiency of more than 75% over its operating band (Bhardwaj et al., 2023). A meander-line microstrip antenna was also developed for a 915 MHz LoRa smart-home application using CST Studio Suite 2019, demonstrating the applicability of a meander configuration to LoRa systems (Abdurrazaq et al., 2022). Similarly, a meander planar inverted-F antenna was investigated for the 915–925 MHz range, which is compatible with LoRa and Sigfox applications. The design achieved an S_{11} of −21 dB, a bandwidth of 13.5 MHz, and a resonant frequency of 924.9 MHz (Sabila et al., 2022). These studies demonstrate the potential of meander configurations for reducing antenna dimensions while maintaining operation in the sub-GHz region.

Further studies have investigated compact meander structures for broader sub-GHz IoT applications. Hussain et al. (2022) proposed a compact meandered loop slot-line antenna with frequency reconfigurability using a varactor diode. The antenna covered 758–1034 MHz, with reported gain values ranging from 0.86 to 1.8 dBi. A low-profile compact meander-line telemetry antenna operating at 402.5 MHz was also developed using an open-loop configuration, demonstrating that meandering can increase the effective electrical length while reducing the physical dimensions of the antenna (Sulaiman et al., 2022). In addition, Zalfani et al. (2022) developed a miniaturized planar meander-line antenna for UHF CubeSat communication, demonstrating the applicability of meander structures to compact sub-GHz satellite communication systems.

Meander structures have also been combined with frequency-reconfiguration and additional loading techniques. Bouyedda et al. (2021) developed a frequency-reconfigurable meander-line antenna incorporating lumped components and a PIN diode for hybrid connectivity between LPWAN and LEO satellite networks. The antenna operates at 401, 466, and 868 MHz depending on the PIN diode configuration. A frequency-selective-surface-loaded meander-line antenna was developed for an integrated LoRa and GNSS system, with dimensions of 90 × 90 × 1.635 mm³ (Gunasekaran et al., 2025). An interconnected coil and patch-meander-line dipole developed for passive HF and UHF RFID applications achieved dimensions of 67.84 × 26.92 × 1.6 mm³ and a realized gain of −4.26 dBi at 922.5 MHz (Kawdungta et al., 2024). These studies indicate that additional loading and reconfiguration techniques can provide further control over the resonant characteristics of compact antennas.

Other investigations have explored meander-based miniaturization for different wireless applications. An eighth-mode substrate integrated waveguide with a meandered slot was proposed for a dual-band wearable antenna operating at 867 and 915 MHz, with gains of −0.9 and −0.7 dBi, respectively (Casula et al., 2023). A compact dual-band implantable antenna employing a meander-line structure was also developed for biotelemetry applications at 1.4 and 2.4 GHz (Kangeyan & Karthikeyan, 2024). A compact wearable printed monopole incorporating meandered monopoles was also investigated for LoRa localization at 915 and 923 MHz, demonstrating the applicability of meander-based structures to LoRa systems operating close to the target frequency range (Yahya et al., 2024). These studies further demonstrate the flexibility of meander-based structures for achieving compact antenna configurations across different wireless applications.

Overall, the reviewed studies indicate that antenna miniaturization can be achieved through meander-line structures, compact ground-plane configurations, resonant loading, and frequency-reconfiguration techniques. However, maintaining good impedance matching, sufficient bandwidth, and positive gain while reducing antenna size remains challenging, particularly in the sub-GHz range. This challenge is relevant to the 920–923 MHz LoRa band, where previous studies have mainly focused on frequencies near 915 MHz or 922.5 MHz using different structures and dimensions. Therefore, this study investigates a compact meander-line microstrip antenna specifically designed for 920–923 MHz LoRa applications while maintaining acceptable impedance matching and positive gain.

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METHOD

Antenna Design Specification

The proposed antenna was designed for LoRa applications operating in the 920–923 MHz frequency range. The main design specifications are summarized in Table 1. An FR-4 substrate was selected because of its low cost, availability, and suitability for prototype fabrication. The substrate has a relative permittivity of 4.3 and a thickness of 1.6 mm. The target operating frequency was selected within the 920–923 MHz LoRa frequency band.

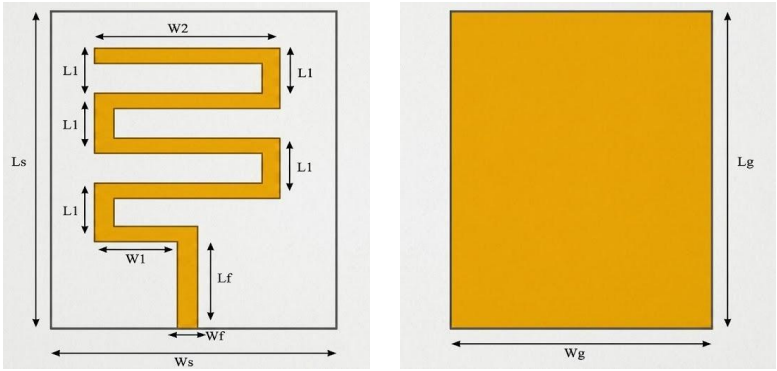
Table 1. Antenna design specification

Parameter	Specification
Operating Frequency	920–923 MHz
S_{11}	≤ −10 dB
VSWR	≥ 2
Gain	≥ 0.5 dBi
Radiation Pattern	Bi-directional

Initial Design

The initial antenna geometry was developed based on a previously reported meander-line antenna structure presented by Bhardwaj et al. (2023). The reported antenna has a physical dimension of 55 × 55 mm² and demonstrates the potential of a meander-line configuration for antenna miniaturization in the sub-GHz frequency range. The reference antenna has a physical dimension of 55 × 55 mm² and demonstrates the potential of a meander-line configuration for antenna miniaturization in the sub-GHz frequency range. The geometry and dimensions of the reference antenna are shown in Figure 1, while the corresponding geometrical parameters are summarized in Table 2.

In this study, the reported antenna geometry was used as the initial reference rather than directly adopting its final design. The geometry was reconstructed and subsequently modified to satisfy the requirements of the 920–923 MHz LoRa operating frequency range. The initial dimensions and geometrical configuration were used as a starting point for the subsequent optimization process, enabling the effects of the proposed modifications on the antenna's electromagnetic performance to be systematically investigated.



(a) (b)

Figure 1. Geometry of initial design: (a) front view and (b) back view (Bhardwaj et al., 2023)

Table 2. Dimensions of the initial design

W_s	L_s	W_1	W_2	W_f	L_1	L_f
55	55	18	30	2.8	4	10

Optimization of the Proposed Meander-Line Antenna

The optimization of the proposed meander-line antenna was performed sequentially to shift the resonant frequency toward the target LoRa operating range of 920–923 MHz while maintaining suitable impedance matching and radiation performance. The optimization process consisted of six stages: initial design, substrate reduction, ground-plane reduction, feedline reduction, first patch addition, and final design. The S_{11} and gain responses obtained from each optimization stage are presented in Figure 2 and Figure 3, respectively.

The initial design exhibited a minimum S_{11} of approximately −0.93 dB at 932 MHz within the 915–932 MHz evaluation range, indicating poor impedance matching in the target frequency region. Therefore, further geometrical modification was required. After substrate reduction, the minimum S_{11} was approximately −0.97 dB at 932 MHz. This result shows that reducing the substrate dimensions alone did not provide a significant improvement in impedance matching, and the resonance remained outside the desired 920–923 MHz range.

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The optimization was subsequently continued by reducing the ground-plane dimensions. This modification significantly improved the S_{11} response, with a minimum value of approximately −6.00 dB at 928 MHz. Although the −10 dB criterion had not yet been achieved, the resonance had shifted closer to the target frequency range. At this stage, the gain was approximately 0.52 dBi at 928 MHz.

The feedline was then optimized to improve the impedance matching with the 50Ω excitation port. The optimized configuration produced a minimum S_{11} of approximately −5.98 dB at 932 MHz, with a corresponding gain of approximately 0.49 dBi. Since the S_{11} response was still above the −10 dB criterion, further modification of the radiating structure was required.

The next stage involved the addition of the first conductive patch, which resulted in a substantial improvement in impedance matching. The minimum S_{11} reached approximately −15.37 dB at 928 MHz, satisfying the −10 dB criterion. However, the corresponding gain was approximately 0.44 dBi, indicating that the improvement in impedance matching did not directly result in an increase in gain at this stage.

Finally, the radiating structure was further modified to obtain the final design. The minimum S_{11} improved to −23.47 dB at 920 MHz, while the gain increased to approximately 0.76 dBi. The resonant frequency was therefore successfully shifted to the lower boundary of the target 920–923 MHz LoRa frequency range. Overall, the optimization demonstrates that the combination of ground-plane modification, feedline optimization, and radiating-structure modification was essential to achieve the desired impedance matching and radiation performance while maintaining a compact antenna configuration.

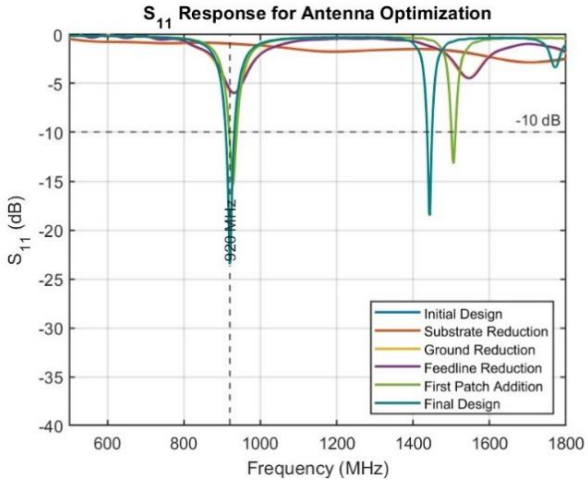


Figure 2. S_{11} response for antenna optimization

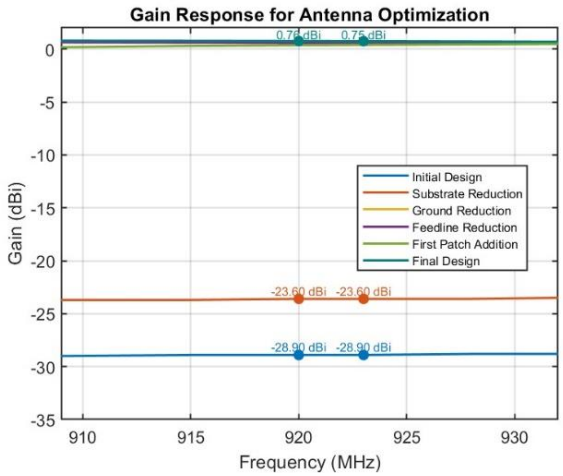


Figure 3. Gain response for antenna optimization

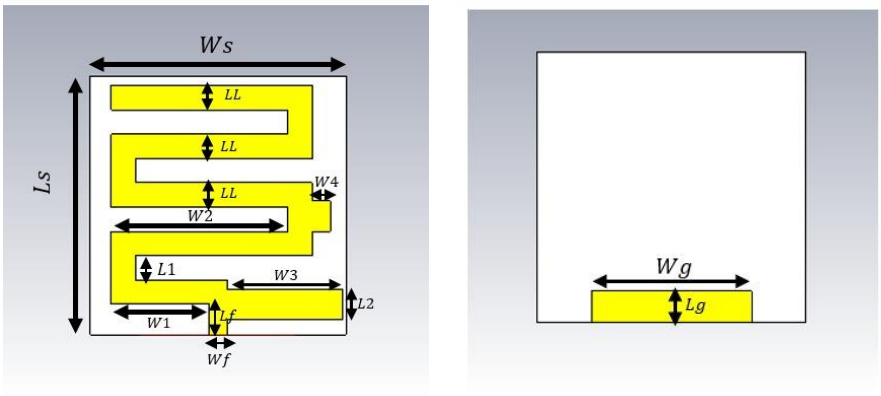
RESULT

Following the optimization process, the resulting meander-line antenna configuration is illustrated in Figure 4. The main geometrical parameters of the optimized structure are provided in Table 3. Its simulated performance is presented through the S_{11} response, VSWR, impedance bandwidth, gain, and radiation pattern.

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(a) (b)

Figure 4. Geometry of the proposed meander line antenna: (a) font view and (b) back view

Table 3. Dimensions of the proposed meander line antenna

W_s	L_s	W_1	W_2	W_3	W_4	L_L	L_1	L_2	W_g	L_g	W_f	L_f
42	42.5	15	29	19	3	4	4	5	25	5	2.9	5

Figure 5 compares the simulated S_{11} responses of the initial and final meander-line antenna designs. The initial design exhibits poor impedance matching in the target frequency range, with an S_{11} value of approximately −0.93 dB at 932 MHz. In contrast, the final design achieves a minimum S_{11} of −23.47 dB at 920 MHz. The final design also provides a −10 dB impedance bandwidth from approximately 909.69 to 932.13 MHz, covering the target LoRa frequency range of 920–923 MHz..

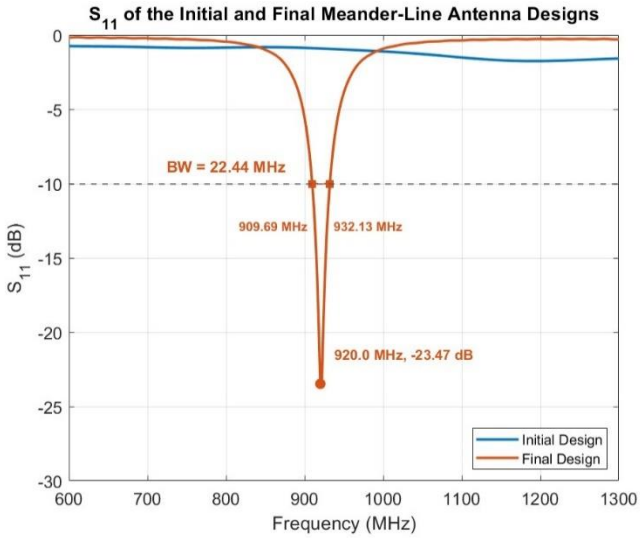


Figure 5. S_{11} of the initial and final meander-line antenna designs

Figure 6 presents a comparison of the simulated VSWR responses of the initial and final antenna designs. The initial design shows a high VSWR in the target frequency region, corresponding to its poor impedance matching. Following the optimization process, the final design exhibits a VSWR of approximately 1.14 at 920 MHz and remains below 2 throughout the 920–923 MHz operating range.

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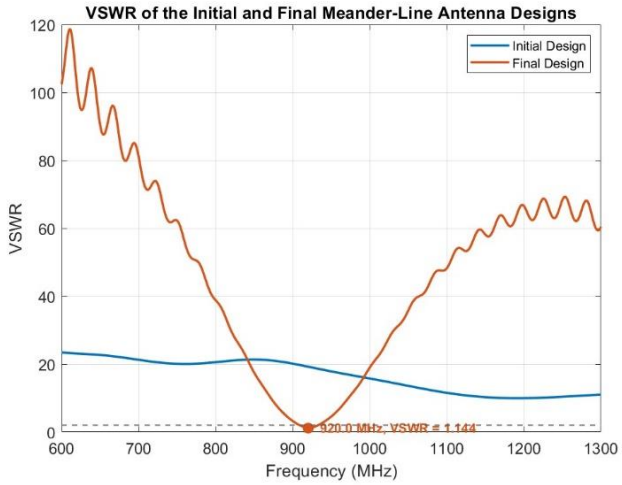


Figure 6. VSWR of the initial and final meander-line antenna designs

Figure 7 compares the simulated gain responses of the initial and final antenna designs. The gain of the initial design is approximately −28.9 dBi within the 920–923 MHz frequency range based on the exported CST data, whereas the final design exhibits a gain of approximately 0.75–0.76 dBi over the same frequency range. At 920 MHz, the final design achieves a gain of 0.756 dBi.

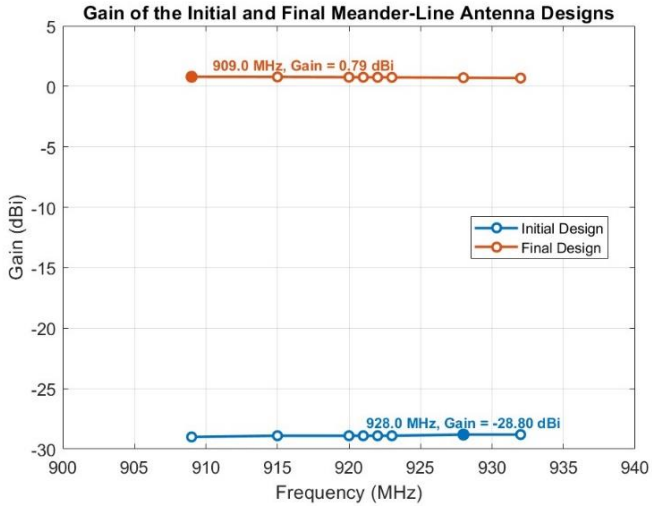


Figure 7. Gain of the initial and final meander-line antenna designs

Figure 8 presents the simulated radiation patterns of the initial and final antenna designs at 920 MHz. Both designs exhibit bidirectional radiation characteristics, with two dominant radiation directions oriented along opposite axes. The final design maintains a bidirectional radiation pattern after the geometrical optimization.

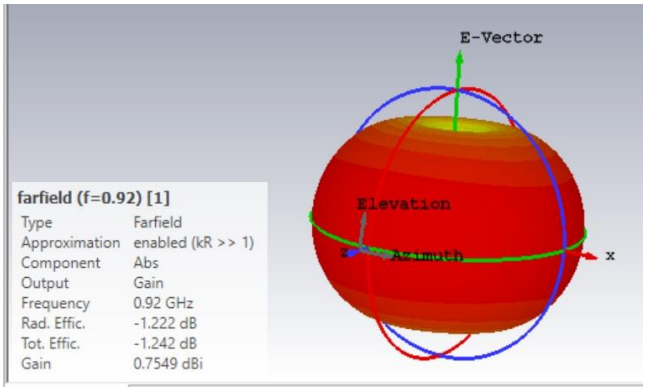


Figure 8. Radiation pattern of the proposed meander-line antenna at 920 MHz

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DISCUSSION

The optimization results demonstrate that the geometrical modifications effectively transformed the initial meander-line configuration into a compact antenna suitable for LoRa operation. The reduction of the substrate and ground-plane dimensions initially produced only limited improvement in impedance matching, whereas the subsequent feedline adjustment and modification of the radiating structure resulted in a more pronounced shift of the resonance toward the target frequency. In particular, the addition of the conductive patch significantly improved the impedance response, indicating that the radiating geometry played an important role in determining the resonant behavior of the antenna. The final configuration therefore represents a compromise between physical miniaturization and electromagnetic performance.

The final antenna achieves a minimum S_{11} of −23.47 dB at 920 MHz, with a −10 dB impedance bandwidth of approximately 22.44 MHz. This bandwidth covers the entire 920–923 MHz operating range targeted for the LoRa application. The corresponding VSWR of approximately 1.14 at 920 MHz further indicates good impedance matching between the antenna and the 50 Ω excitation port. The antenna also provides a simulated gain of approximately 0.75 dBi at 920 MHz. The radiation pattern exhibits bidirectional characteristics, with the main radiation directed along opposite axes. These results indicate that the compact geometry maintains acceptable radiation performance despite the substantial reduction in physical dimensions.

A comparison with previous meander-based antenna designs is presented in Table 3. The proposed antenna has a planar dimension of 42 × 42.5 mm², which is smaller than the 55 × 55 mm² meander dipole reported by Bhardwaj et al. (2023) and the 90 × 90 mm² meander-line antenna incorporating an FSS reported by Gunasekaran et al. (2025). It also provides a higher gain than the −4.26 dBi reported for the interconnected coil and patch-meander-line dipole of Kawdungta et al. (2024), although the latter was developed for RFID applications at different operating frequencies. Compared with the meandered-slot SIW antenna reported by Casula et al. (2023), the proposed antenna has substantially smaller dimensions while providing a positive gain at 920 MHz. These comparisons show that the proposed antenna offers a favorable combination of compact size, impedance matching, and positive gain for LoRa operation in the 920–923 MHz frequency range.

Table 4.Comparison of the proposed antenna with previous meander-based antenna designs

Reference	Antenna Structure	Frequency (MHz)	Dimension (mm^3)	Gain
Bhardwaj et al. (2023)	Meander dipole	868	55 × 55 × 1.6	0.5
Gunasekaran et al. (2025)	Meander-line with FSS		90 × 90 × 1.635	−0.12
Kawdungta et al. (2024)	Interconnected coil and patch meander-line dipole	13.56 and 922.5	67.84 × 26.92 × 1,6	−4.26
Casula et al. (2023)	Meander-slot eight mode SIW	915	114.75 × 118.03 × 3.61	−0.9 and −0.7
This work	**Compact meander-line antenna**	**909-932**	**42 × 42.5 × 1.6**	**0.75**

CONCLUSION

This study presented a compact meander-line antenna for LoRa applications in the 920–923 MHz frequency range. Through successive optimization of the substrate, ground plane, feedline, and radiating structure, the antenna dimensions were reduced to 42 × 42.5 × 1.6 mm³. The final design achieved a minimum S_{11} of −23.47 dB at 920 MHz, a −10 dB impedance bandwidth of 22.44 MHz, and a VSWR of 1.14, with the bandwidth fully covering the 920–923 MHz operating range. The antenna also achieved a simulated gain of 0.75 dBi and exhibited a bidirectional radiation pattern. These results demonstrate that the proposed meander-line configuration can provide suitable impedance and radiation performance while maintaining a compact physical size for LoRa applications.

ACKNOWLEDGMENT

The authors would like to express their gratitude to Politeknik Negeri Padang for the support provided in conducting this research under Contract Number 298/DST/PL9.10/AL.04/2026. The authors also acknowledge all parties who contributed to the completion of this research.

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Volume 6, **Number** 4, November 2026
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