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REGULAR ARTICLE

Design of Efficient Miniaturized Printed Monopole Antenna for Short-Range Wireless Applications

MD. Ataur Safi Rahaman Laskar[1,*], SK. Moinul Haque[2]

[1] *Department of Electronics and Communication Engineering, Swami Vivekananda Institute of Science and Technology, Kolkata, WB, India*
[2] *Antenna Research Laboratory, Aliah University, Kolkata, WB, India*

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The article provides a comprehensive discussion on the design details of the proposed antenna topology, thoroughly outlining the results from both simulations and experiments. Additionally, a comparison with past studies is included to offer a broader perspective on the performance characteristics of the antenna. The communication explores return loss, radiation characteristics and input impedance to ensure a deeper understanding of the antenna performance. The proposed design achieves a significant frequency reduction of 65.28 % compared to a reference antenna, highlighting its potential for short-range wireless communication at 434 MHz. In simulations, the measured efficiency is 65.36 %, while the antenna exhibits a corresponding 10 dB bandwidth of 1.25 %. The antenna topology consists of a compact printed monopole ($0.086\lambda_0 \times 0.052\lambda_0 \times 0.002\lambda_0$) resonating at 434 MHz. Designed for reduced resonant frequencies, the antenna is suitable for short-range wireless applications at 434 MHz. Fabricated on an FR-4 glass epoxy microwave substrate, the lightweight and low-profile printed antenna utilizes a 50 Ω microstrip feed for excitation. To enhance the understanding of the antenna measurement configuration, the measurement setup for the antenna topology is provided. This article explored into the analysis of this antenna design, emphasizing its practical applications and advantages.

Keywords: Monopole antenna, Compact antenna, Efficient antenna, Printed antenna, Miniaturization, Short-Range Wireless communications.

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1. INTRODUCTION

Designing a compact antenna that meets specific frequency band requirements while maintaining optimal performance and adhering to spatial constraints presents a significant challenge for the research community. This difficulty is particularly relevant in the context of various applications, such as vehicular communication systems, industrial automation, low-power IoT devices, consumer electronics, RFID technology, utility metering solutions, alarm systems, wireless sensor networks, and remote control systems. The increasing focus on short-range communication within the Ultra High Frequency spectrum, particularly at 434 MHz, has drawn substantial research interest due to its broad range of use cases. The prominence of compact antennas in modern electronic devices is primarily driven by spatial limitations inherent in contemporary electronic designs. The widespread adoption of this approach across multiple disciplines enhances system performance while enabling seamless antenna integration into portable devices. Emphasizing compactness remains a crucial aspect of adapting antenna characteristics to evolving application requirements.

The increasing demand for compact antennas, driven by the continuous miniaturization of modern communication devices, has led to the development of various microstrip antenna designs. Several studies have explored innovative approaches to antenna miniaturization to enhance their applicability in constrained environments. For instance, research in [1] and [2] investigates the use of meandered antennas, both printed and sleeved, specifically designed for tire pressure monitoring systems operating at reduced resonant frequencies. Additionally, the study in [1] highlights the development of compact, asymmetric co-planar waveguide antennas tailored for tire pressure monitoring at a specific frequency. Further advancements include the work in [2], which proposes dual-band low-profile antennas to enhance the accuracy of tire pressure measurements, and [3], which demonstrates a low-profile meandered slot antenna operating at 412 MHz on an FR-4 glass epoxy substrate for tire pressure monitoring applications. Various compact antenna designs for wireless communication are presented, including a miniaturized dual-band slot antenna with a 48.25 % resonant frequency reduction [4], three-dimensional coupled non-planar monopole antennas [5], and miniature non-planar dipole antennas for short-range communication [6]. Additionally, a complementary slot resonator antenna with *L*-probe feed for 434 MHz [7] and an ultra-wideband antenna with *T* and

* Correspondence e-mail: mdataurlaskar@gmail.com

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inverted T slots featuring a defected ground system for 5G communication [8] are detailed.

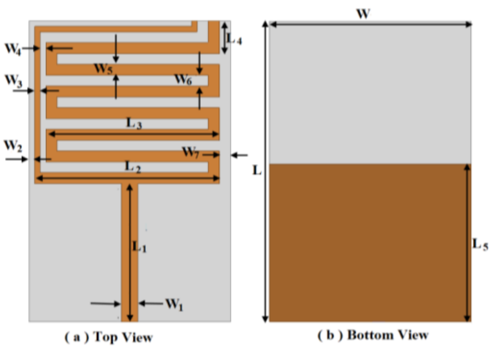
A thorough review of the existing literature indicates that the relatively large size of conventional antennas presents challenges in their seamless integration into communication systems, highlighting a significant research gap across various applications. While printed antennas are widely utilized, this study aims to address this gap by focusing on the adaptation of efficient printed antennas for short-range wireless communication through a deliberate reduction of their resonant frequency.

Overall, the proposed antenna exhibits promise for various modern wireless communication systems, especially in short range wireless communication applications, owing to its compact size, affordability, narrow bandwidth and superior performance characteristics within the 434 MHz frequency range. The subsequent sections provide a detailed examination of the design process for the printed monopole antenna, which resonates at 434 MHz, as presented in Section 2.

The proposed antenna demonstrates appropriate radiation and impedance characteristics for its intended applications, while also exhibiting significantly reduced dimensions compared to designs reported in existing literature. Section 3 presents the results and discussion, offering a comprehensive analysis of the antenna's performance. Finally, Section 4 provides conclusive remarks based on the findings of this study.

2. DESIGN AND ANALYSIS OF COMPACT MONOPOLE ANTENNA FOR WIRELESS COMMUNICATIONS

This section introduces a low profile, compact, simple monopole antenna design for application in short ranges wireless communications. It has become important to develop antenna with attributes like increased compactness, lightness, affordability, ease of installation on planar surfaces and the capacity to function in a variety of complicated and dynamic situations.



(a) (b)

Fig. 1 – Geometry of the compact monopole antenna (a) Top view (b) Bottom view

According to the aforementioned parameters, the monopole antenna geometry is shown in Figure 1(a, b) and fabricated prototype is illustrated in Figure 6 offers a clear depiction of the design from both the top and bottom layers along with 50 Ω microstrip feed line. The radiating meandered strip is placed on top surface and the partial ground plane is situated the bottom surface of that dielectric substrate. The antenna is designed using FR-4 dielectric substrate with a standard height of 1.60 mm. The value of an antenna design parameters are, L = 60, L_1 = 30, L_2 = 33, L_3 = 31, L_4 = 6, L_5 = 35, W = 35.96, W_1 = 3, W_2 = 1, W_3 = 1, W_4 = 1, W_5 = 2, W_6 = 2, W_7 = 1.96, h = 1.60. All dimensions are in millimeter unit. The resonant frequency of this antenna depends on factors like the length, the width of each parts.

3. RESULT AND DISCUSSION

This monopole antenna is customized to resonate within the radio frequency band employed for short-range wireless communication. The dimensions of the antenna measure 0.086λ_0 in length, 0.052λ_0 in width and 0.002λ_0 in height, where λ_0 represents the free space wavelength of the antenna to make the topology unique. The meandered slots cause the antenna to resonate in the desired frequency range. The bandwidth (10 dB) is 1.25 % indicating a relatively narrow bandwidth and efficiency is 65.36 %. Also, it has been focused to reduce the resonant frequency of an antenna to make it compact in-spite of performance of the antenna does not significantly alter. In short range communication, antenna should be preferable small in size and process omnidirectional radiation characteristics. Additionally, this topology gives designers more freedom in selecting design elements and makes the antenna easier to produce.

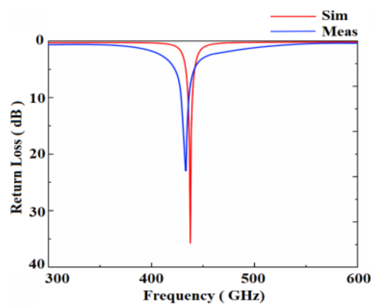
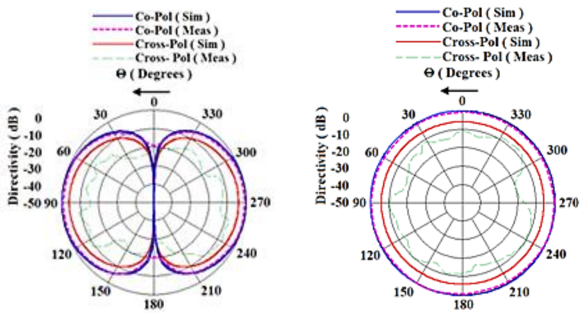


Fig. 2 – Measured and simulated return loss characteristics of compact monopole antenna



(a) (b)

Fig. 3 – Radiation characteristics (a) *E*-plane (b) *H*-plane

The return loss is shown in Figure 2 and radiation characteristic of the monopole antenna is presented in Figure 3 (a) *E*-plane (b) *H*-plane. The simulation and measured results exhibit a strong agreement between the two sets of response, particularly for specific radio frequency bands used in short-range wireless communication applications at 434 MHz. The discrepancy between simulated and measured properties of the antenna can be primarily attributed to erroneous fabrication dimensions, as well as unavoidable errors in the fabrication and measurement processes. In comparison to the simulated resonant frequency 0.27 % fabrication errors occurred during measurement process. Despite being low-profile and lightweight, the proposed antenna is suited for short ranges wireless communication at 434 MHz.

Table 1. Comparison of antennas with past works in respect to resonant frequency, efficiency and design complexity.

Ref.	Antenna Topology	Resonant Frequency (± 10)	Dimension (mm^3)	Efficiency (%)	Design complexity
[1]	Printed Monopole antenna	315 MHz	161.90 × 16.19 × 1.99	Low	Complex
[2]	Sleeve Meander Monopole antenna	434 MHz	165 × 42 × 1.60	–	Moderate
[1]	Loop antenna	315 MHz	20(*L*) × 10(*H*) × 1(*D*)	Low	Moderate
[1]	Whip antenna	315 MHz	20(*L*) × 10(*H*) × 1(*D*)	High	Moderate
[9]	Monopole antenna	868 MHz	400 × 400 × 78	–	Moderate
[9]	Low profile dual-band loop (LPDL)	868 MHz	400 × 400 × 1.5	–	Moderate
[2]	Inverted-F antenna (IFA)	433.92MHz	75.5 × 26.5 × 15	–	Moderate
[3]	Ultra small Helical with tap feed	315 MHz	12(*D*) × 9.5(*H*) × 10(*N*)	9.42	Complex
[3]	Ultra-small helical using parasitic	315 MHz	12(*D*) × 11.6(*H*) × 13.5(*N*)	10.79	Complex
[10]	Meandered Slot Antenna	413 MHz	170 × 20 × 1.58	Low	Moderate
[13]	Compact Slot Antenna	434 MHz	170 × 20 × 1.58	78.56	Moderate
This work	**Printed Monopole**	**434 MHz**	**60 × 35.96 × 1.6**	**65.36**	**Simple**

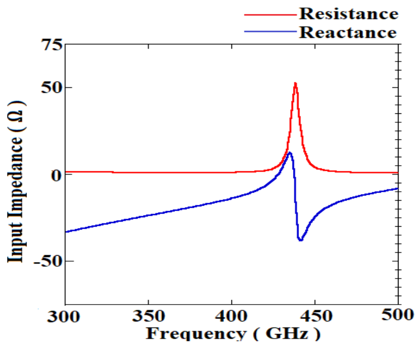


Fig. 4 – Input impedance characteristics (a) Resistance (b) Reactance

Within the domain of short-range wireless communication applications, the frequencies typically span from 300 MHz to 960 MHz and there is a distance of 3 to 100 meters between the transmitter and receiver. In the context of short-range wireless communication, the most commonly used resonant frequency in Europe within the 413/434/868 MHz range (±10). Among these options, the 434 MHz (±10) frequency band is the preferred choice for transmitting and receiving information. The proposed antenna is much smaller than the printed monopole (operating frequency 315 MHz, 161.90 × 6.19 × 1.99 mm^3 in size) noted in [1], sleeve meander printed monopole antenna (operating frequency 434 MHz, 165 × 42 × 1.60 mm^3 in size) presented in [2], monopole antenna (operating frequency 868 MHz, 400 × 400 × 78 mm^3 in size) illustrated in [11], meandered slot antenna (170 × 20 × 1.58 mm^3 in size, operating frequency 412 MHz) presented in [12], and compact slot antenna (operating frequency 434 MHz, 170 × 20 × 1.58 mm^3 in size) presented in [15].

Figure 3 (a, b) shows the normalized radiation pattern. The *E*-plane is defined when the phi (φ) value is 0 degrees, and the *H*-plane is defined when the phi (φ) value is 90 degrees. The measurement characteristics also included to verify the simulated result. As depicted in Figure 4, the value of input resistance and reactance at operating frequency are 50 Ω and 0 Ω respectively.

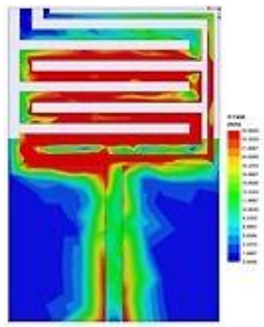
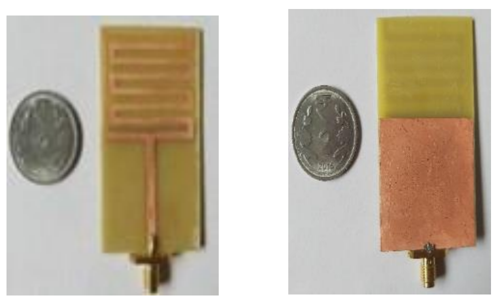


Fig. 5 – *H*-field plot



(a) (b)

Fig. 6 – Fabricated prototype of the patch antenna (a) Top view (b) Bottom view

Figure 5 shows the *H*-field plot of monopole antenna. It can be noted that proposed antenna has very good input impedance characteristics. The graphical representation that illustrates the relationship between input impedance and frequency displays a significant level of concordance or alignment. This means that the observed input impedance values closely correspond to the expected behavior as the frequency changes. It can be stated that the compact monopole antenna is better comparison with existing research work. Comparison table with recent works in respect of reduced resonant frequency presented in Table 2. After the analyzed of return loss, radiation pattern and input impedance characteristics, it can be stated that the proposed antenna is a good choice due to its 434 MHz frequency band which is very much applicable for short ranges wireless communication application. The measurement configuration for the monopole antenna is shown in Figure 7. Comparison of antennas with past works in respect to resonant frequency, efficiency and design complexity for short ranges wireless application tabulated in Table 1.

Table 2. Comparison table with recent works in respect to antenna size, resonant frequency, reduced resonant frequency.

Ref., Year	Antenna Topology	Antenna Size (λ_0= wave length)	Resonant Frequency	Bandwidth (– 10 dB)	Frequency Reduction
[17], 2021	Metasurface Antenna	$0.48\lambda_0 \times 0.48\lambda_0 \times 0.06\lambda_0$	6.67 GHz	–	42 %
[13], 2020	Slits and Strip loading slot	$0.212\lambda_0 \times 0.212\lambda_0 \times 0.010\lambda_0$	1.27 GHz	11.56 %	61.39 %
[16], 2020	Patch Antenna	$0.433\lambda_0 \times 0.433\lambda_0 \times 0.026\lambda_0$	2.6 GHz	–	63 %
[14], 2019	Slits and Strip loading slot	$0.21\lambda_0 \times 0.21\lambda_0 \times 0.010\lambda_0$	1.20 GHz	2.23 %	63.52 %
This Work	**Printed Monopole**	$\mathbf{0.086\lambda_0 \times 0.052\lambda_0 \times 0.002\lambda_0}$	**434 MHz**	**1.25 %**	**65.28 %**

Fig. 7 – The measurement configuration for the patch antenna

4. CONCLUSION

This study presents the development, optimization, fabrication and performance evaluation of a compact, low-profile, and lightweight printed monopole antenna designed for short-range wireless communication applications. The effectiveness of the proposed compact antenna has been assessed through experimental measurements of a fabricated prototype. The antenna has been optimized to achieve a reduced resonant frequency, making it particularly suitable for short-range wireless communication at 434 MHz within the European Union frequency allocation. The proposed antenna topology consists of a compact printed monopole with dimensions of $0.086\lambda_0 \times 0.052\lambda_0 \times 0.002\lambda_0$, resonating at 434 MHz. The antenna exhibits a corresponding 10 dB bandwidth of 1.25 %, with a simulated efficiency of 65.36 %. When compared to a reference antenna, the design demonstrates a significant resonant frequency reduction of 65.28 %. These findings provide valuable insights into the potential application of low-frequency resonance antennas in short-range wireless communication systems.

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Розробка ефективної мініатюрної друкованої монопольної антени для бездротових застосувань малого радіусу дії

MD. Ataur Safi Rahaman Laskar[1], SK. Moinul Haque[2]

[1] *Department of Electronics and Communication Engineering, Swami Vivekananda Institute of Science and Technology, Kolkata, WB, India*
[2] *Antenna Research Laboratory, Aliah University, Kolkata, WB, India*

У роботі представлено дані стосовно конструкції топології антени, результати як моделювання, так і експериментів. Досліджуються втрати на відбиття, характеристики випромінювання та вхідний імпеданс, щоб забезпечити глибше розуміння характеристик антени. Запропонована конструкція досягає значного зниження частоти на 65,28 % порівняно з еталонною антеною, що підкреслює її потенціал для бездротового зв'язку на короткій відстані на частоті 434 МГц. У моделюванні виміряна ефективність становить 65,36 %, тоді як антена демонструє відповідну смугу пропускання 10 дБ на рівні 1,25 %. Топологія антени складається з компактного друкованого монополя ($0,086\lambda_0 \times 0,052\lambda_0 \times 0,002\lambda_0$), що резонує на частоті 434 МГц. Розроблена для знижених резонансних частот, антена підходить для бездротових застосувань на короткій відстані на частоті 434 МГц. Виготовлена на мікрохвильовій підкладці зі скляної епоксидної смоли FR-4, легка та низькопрофільна друкована антена використовує мікросмужкове живлення 50 Ом для збудження. Для кращого розуміння конфігурації вимірювань антени наведено схему вимірювання для топології антени.

Ключові слова: Монопольна антена, Компактна антена, Ефективна антена, Друкована антена, Мініатюризація, Бездротовий зв'язок малого радіусу дії.