

Design and Realization of an Ultra-Wideband Patch Monopole Antenna for Medical IoT and Wearable Healthcare Applications

M.H. Diallo Yaccoub¹, Aye Mint Mohamed Mostapha² Aichetou Mohameden³, Noura Aknin⁴

^{1, 2, 3} Department of Physics, University of Nouakchott, Faculty of Science and Technology

^{1, 4} Abdelmalek Essaâdi University, Faculty of Science, Tétouan, Morocco

^{1, 4} Laboratory of Information Systems and Telecommunications

Yadiallo82@gmail.com

Abstract

Printed antennas are particularly attractive for medical IoT applications due to their low cost, compact design, and ease of integration into wearable or implantable devices. This paper presents a novel approach to enhance radiation efficiency and overall performance of ultra-wideband (UWB) antennas by combining size miniaturization with the integration of slots on the ground plane. The study focuses on a rectangular patch UWB antenna operating over a frequency range from 2 GHz to 4.8 GHz, achieving a relative bandwidth (BR %) of 82%. Specifically, the antenna covers the 2.0–2.4 GHz band suitable for wearable health monitoring and body area networks (BANs), the 3.1–4.0 GHz band for real-time patient monitoring and wireless ECG/EEG sensors, and the 4.0–4.8 GHz band for microwave-based medical imaging and short-range diagnostics. The antenna geometry, design, and performance were analyzed using CST Microwave Studio simulation software. Detailed design procedures, simulation results, and discussions on its suitability for various medical IoT applications are presented in this paper.

Keywords- Ultra-Wideband (UWB), Antenna design, Medical Internet of Things (IoT),

1. Introduction

Ultra-wideband (UWB) technology has recently become an attractive choice for applications requiring high-speed, short-range wireless communication. In the context of medical Internet of Things (IoT), UWB is particularly promising for wearable health devices, real-time patient monitoring, remote diagnostics, and hospital automation systems [1-3]. The main advantage of UWB lies in its very large radio spectrum, allowing high data rates while maintaining low power consumption, which is critical for battery-operated medical devices [4-5]. UWB is defined as any radio technique with a bandwidth of 500 MHz or more, or more than 25% of its center frequency. It relies on the generation of very short-duration pulses, resulting in spectral components over a wide frequency range. Regulatory agencies, such as the Federal Communications Commission (FCC), authorize UWB operation in the 3.1–10.6 GHz band, with strict emission limits (e.g., -41 dBm/MHz) to avoid interference with other systems [6]. For medical IoT applications, the 2–4 GHz sub-band is often preferred for wearable and implantable devices due to lower absorption in human tissues, adequate penetration, and sufficient bandwidth for data transmission and localization [7-8]. Designing antennas for UWB medical IoT devices presents several challenges. These include miniaturization to fit small or implantable devices, maintaining efficiency and omnidirectional radiation patterns, and mitigating detuning effects

caused by proximity to the human body [9-12]. Various antenna structures have been developed to meet these requirements, including printed monopole and patch antennas, often incorporating techniques such as slots, metasurfaces, or high-permittivity substrates for bandwidth enhancement and size reduction [13-16]. In this work, we propose a rectangular patch UWB antenna designed for medical IoT applications. The antenna uses an FR4 substrate ($\epsilon_r = 4.4$, loss tangent = 0.025, $h = 1.5$ mm) and is fed via a microstrip line, with slots integrated on the lower face of a partial ground plane to enhance bandwidth. The antenna design was carried out using CST Microwave Studio, and its configuration, design, and implementation are detailed in the following sections [17-23].

2. Antenna Description

The proposed antenna is a low-profile rectangular patch printed on an FR4 substrate, characterized by a relative permittivity $\epsilon_r = 4.4$, a loss tangent of $\tan\delta = 0.025$, and a thickness of $h = 1.5$ mm. The radiating patch, with dimensions $W_p \times L_p$, is fed by a 50 Ω microstrip line of length $L_f = 20$ mm and width $W_f = 2.9$ mm. A partial ground plane of dimensions 20×12 mm² is placed on the backside of the substrate, as shown in Figure 1. This configuration forms the basic radiating element of the antenna and ensures proper impedance matching with the feed line [1-4-16]. However; conventional patch antennas typically

exhibit limited bandwidth, which restricts their use in modern wireless communication systems. To address this issue and improve the antenna's radiation characteristics, slots of increasing lengths were etched along the y-axis of the ground plane. These slots generate additional current paths, resulting in the excitation of multiple resonant modes. The combination of these modes significantly expands the operational bandwidth of the antenna [2-5-6-20]. A parametric study was conducted to analyze the effect of the slot geometry and placement on the antenna's reflection coefficient (S_{11}), impedance bandwidth, directivity, and radiation efficiency. The optimized structure, illustrated in Figure 2, achieves a wide operating band ranging from 2.1 GHz to 3.1 GHz, centered at 2.4GHz. This bandwidth of approximately 1 GHz corresponds to a relative bandwidth of about 40%, which makes the antenna suitable for several wireless standards, including Bluetooth and ISM (2.4 GHz), UMTS (2.17 GHz), and WiBro (2.3–2.39 GHz) [9-12-15-16]. Such a wideband response ensures reliable coverage for Internet of Things (IoT) applications, where multi-standard compatibility, compact size, and low cost are essential design requirements.

Parameter	L	W	LP	Wp	Lf	Wf	Lm
Value	40mm	25mm	15mm	10mm	20mm	2.9mm	12mm

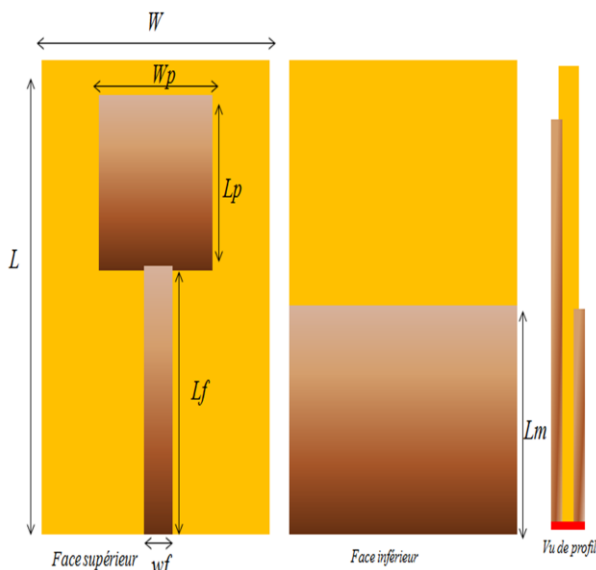


Fig.1: Base antenna

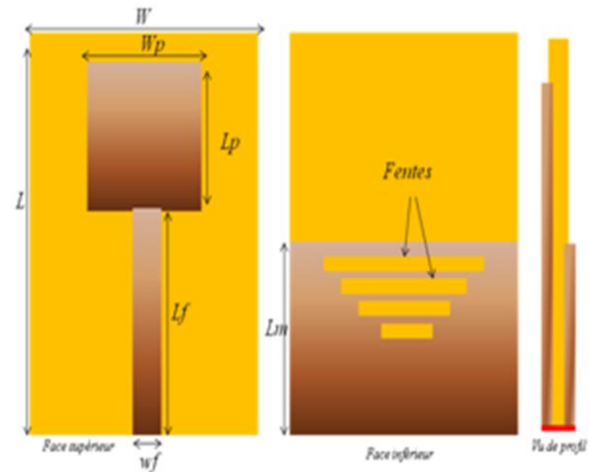


Fig.2: Geometry of the proposed antenna

Figure 3 illustrates the return loss of the base antenna, demonstrating an operational bandwidth from 2.1GHz to 3.1GHz, centered at 2.4GHz. With an absolute bandwidth of 1GHz and a relative bandwidth (BR%) of 40%, the antenna effectively covers multiple communication bands, including Bluetooth/ISM, UMTS (2.17GHz), WiBro (2.3–2.39GHz), WLAN (2.4–2.48GHz), and Mobile WiMAX (2.5–2.69GHz). The wideband performance is achieved using a single-resonance mode, making the antenna highly suitable for IoT devices that require compact, low-power, and multi-standard connectivity for applications such as smart healthcare, wearable sensors, and wireless monitoring systems [1-5-11-16]. Recent research confirms the effectiveness of ultra-wideband (UWB) antennas in small IoT devices, wearable systems, and biomedical telemetry, emphasizing wideband performance, compact form factor, and multi-band coverage [2-6-10-12-15-17]. These designs illustrate the potential of UWB antennas to support future IoT ecosystems that demand low-power, multi-standard, and reliable wireless communication solutions.

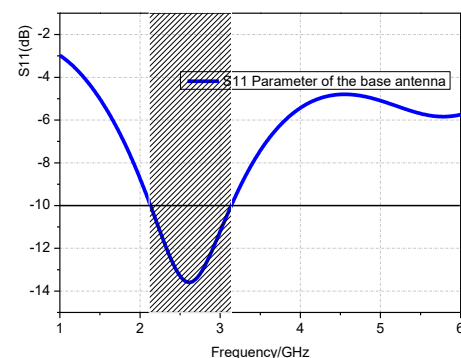


Fig.3: return loss of the base antenna

3. Parametric Study

The return loss of the antenna was analyzed for various slot configurations. The results indicate that incorporating slots not only broadens the antenna's operational bandwidth but also introduces a secondary resonance at higher frequencies. As the number of slots increases from one to four, the bandwidth gradually expands, and the secondary resonance becomes more distinct. Figure 4. Return loss of the antenna for different slot configurations. Adding slots broadens the bandwidth and introduces a secondary resonance. The four-slot configuration achieves the widest bandwidth and is selected for the final design. This parametric study highlights that the number of slots is a key factor in maximizing bandwidth and enabling multi-band performance. Implementing four slots ensures effective coverage of the target frequency range and stabilizes the secondary resonance, resulting in an antenna well-suited for IoT and wireless communication applications [1-7].

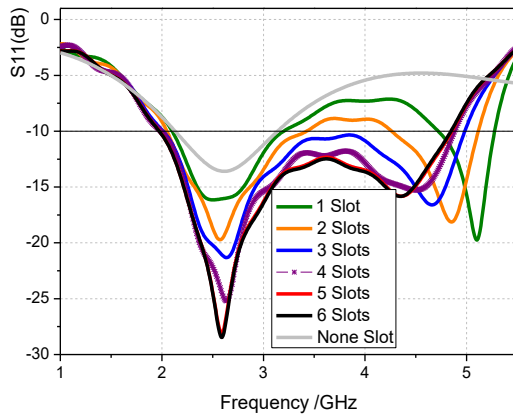


Fig.4: return loss based on the number of slots

After optimizing the number of slots for maximum bandwidth, the effects of slot width and length were investigated. Figure 5 shows the return loss as a function of frequency for different slot widths, indicating that the widest bandwidth is achieved with a slot width of 0.4 mm. Subsequently, the impact of slot length was analyzed, allowing the identification of optimal dimensions for efficient operation over the targeted frequency band.

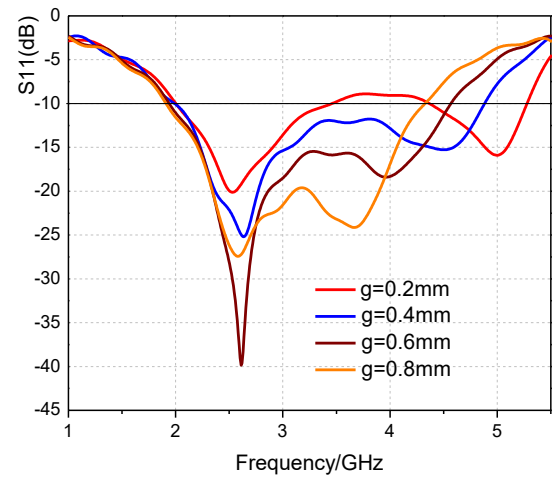


Fig.5: return loss as a function of the width of slots

The figure 6 presents S11 parameter versus frequency for various values of Lf (Length of slots). The best band width is obtained for Lf = 10mm.

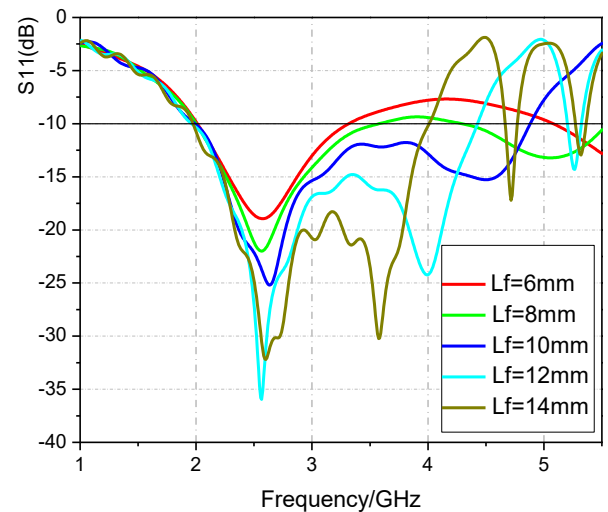


Figure 7 shows the S11 return loss for two slot configurations: slots of equal length (given antenna) and slots of decreasing length. Both configurations broaden the antenna's bandwidth, but the given antenna achieves a wider band and a second resonance, due to the distribution of electromagnetic fields among the slots.

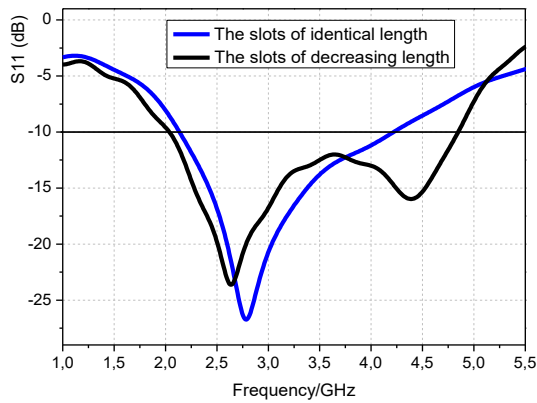


Fig.7: return loss from the slots of the same length and slots of decreasing length

Figure 8 presents a comparison of the S_{11} parameter between the base antenna and the proposed slot antenna. The introduction of slots significantly broadens the antenna's bandwidth, achieving an ultra-wideband response with a reflection coefficient below -10 dB over the frequency range of 2 GHz to 4.8 GHz, corresponding to a relative bandwidth (BR%) of 82%. Two resonance modes are observed, centered at 2.6 GHz and 4.5 GHz, corresponding respectively to the bands used for Bluetooth/ISM (2.4–2.48 GHz) and WiMAX (2.5–2.69 GHz and 3.4–3.69 GHz). This wide frequency coverage enables the antenna to support multiple wireless communication applications, particularly in the field of medical IoT, including patient monitoring, biomedical data transmission, and connected wearable health devices. The slot design also enhances selectivity and performance stability, ensuring reliable and efficient transmission in demanding medical environments.

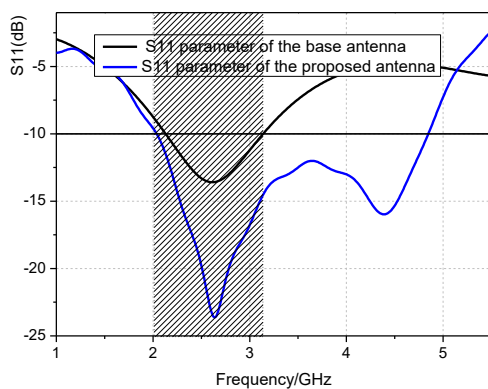


Fig.8: Comparison of S_{11} parameter of the proposed antenna and the base antenna

The prototype of the proposed antenna, shown in Figure 1, was fabricated according to its optimized design parameters and subsequently tested, as illustrated in Figure 9. The return loss was measured using a Hewlett Packard Network Analyzer (ZVL 13.6 GHz, Rohde & Schwarz) and plotted accordingly. The schematic of the measurement setup is presented in Figure 10.

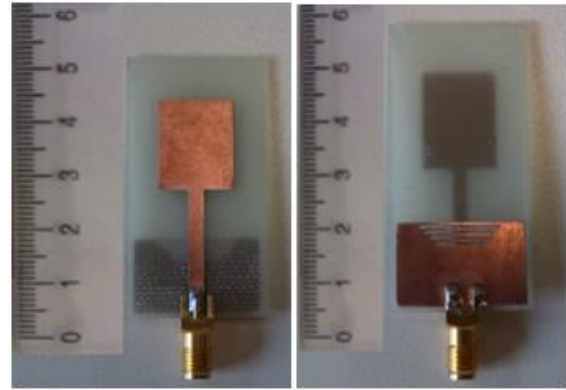


Fig.9: Photograph of the proposed antenna

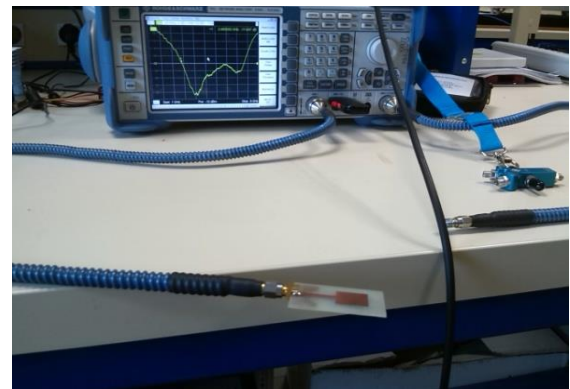


Fig.10: Measured return loss

The simulated and measured S_{11} results of the proposed antenna are compared in Figure 11, showing good agreement between them. The measured results indicate that the antenna effectively supports the operating bands of Bluetooth/ISM (2.4–2.48 GHz), WiMAX (2.5–2.69 GHz and 3.4–3.69 GHz), and WLAN, making it suitable for IoT medical applications, such as wearable health monitors and wireless patient monitoring systems.

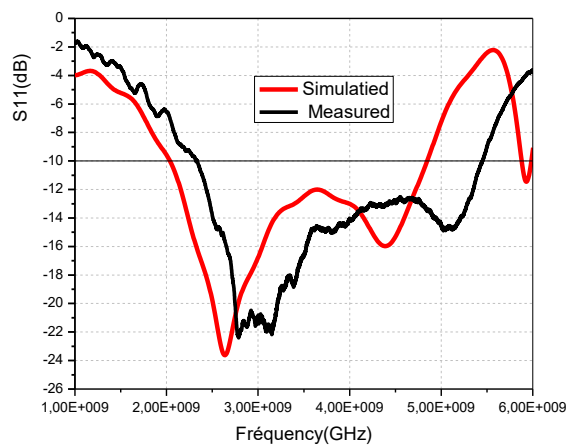


Fig.11: Simulated and measured S11 results of the proposed antenna

Figure 12 shows the group delay, an important metric for evaluating the proposed UWB antenna for medical IoT applications. A low and stable group delay ensures minimal distortion of transmitted electrical impulses, which is critical for reliable medical communication. The antenna exhibits a group delay between -0.5ns and 0.5ns over the $2.07\text{--}4.8\text{GHz}$ band, confirming its suitability for mobile UWB operation in medical IoT systems.

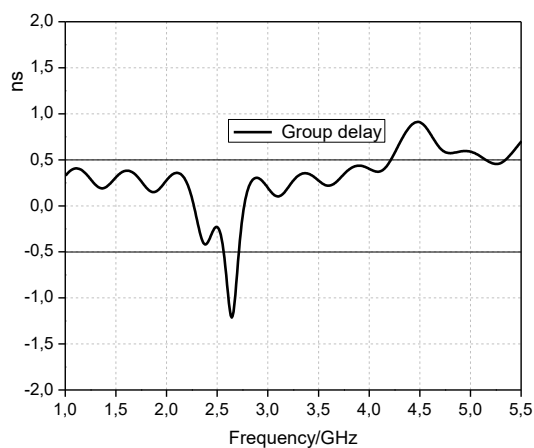
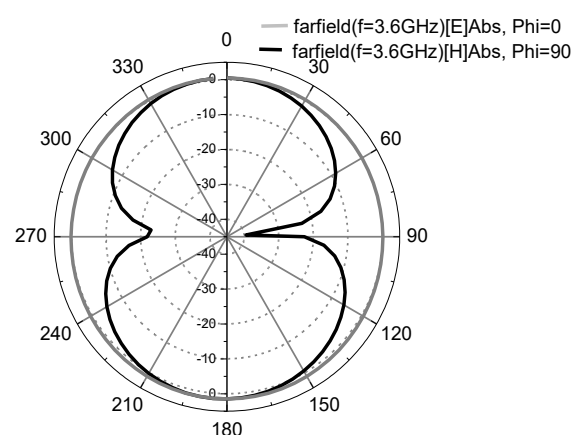
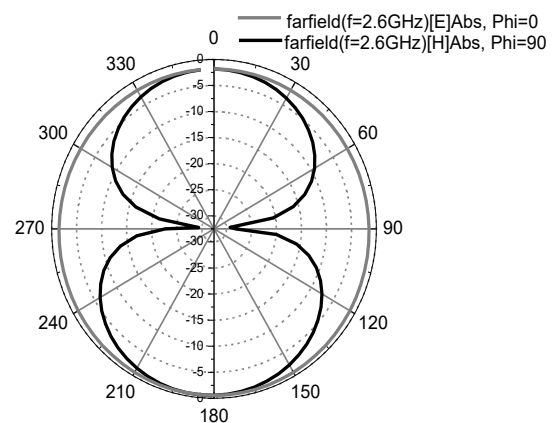
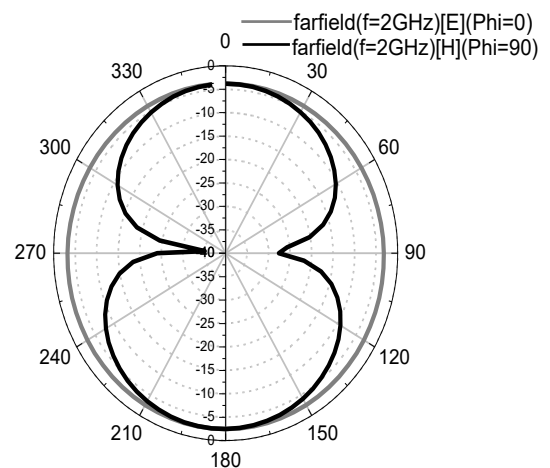


Fig.12: Group delay

Figure 13 shows the simulated radiation patterns of the antenna at 2GHz, 2.6GHz, 3.6GHz, 4.6GHz, and 4.8GHz. The antenna exhibits a nearly omnidirectional radiation pattern in the H-plane (XZ-plane) and a bidirectional pattern in the E-plane (YZ-plane), making it well-suited for mobile medical IoT devices that require reliable wireless connectivity in varying orientations.



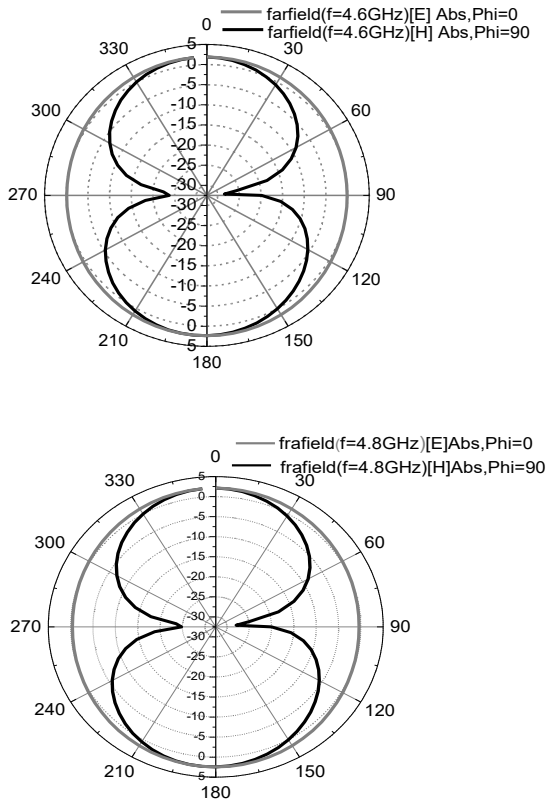


Fig.13: Radiation pattern of the proposed antenna E-Plane (yz-plane) and H-Plane (xz-plane)

Figure 14 presents a comparison of the gain between the base antenna and the proposed antenna. It can be observed that the introduction of slots has little impact on the overall antenna gain. The maximum gain values of both antennas are nearly identical up to 4.8GHz. Across the frequency range of 2GHz to 4.8GHz, covering medical IoT bands such as 2.4GHz (Bluetooth/ISM), 2.5–2.7GHz and 3.4–3.7GHz (WiMAX), the gain steadily increases from –0.5dB to 4.8dB, after which it begins to decrease.

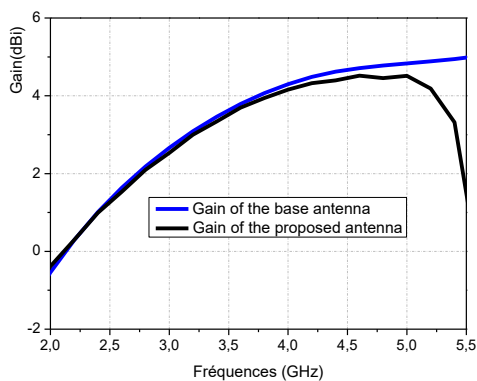


Fig 14: Comparing the gain of the base antenna and the proposed antenna

4. Conclusion

In this paper, a monopole printed patch antenna was designed to operate over the frequency range of 2GHz to 4.8GHz, covering Bluetooth/ISM, 2.5/3.5GHz, WiMAX (2.5–2.69GHz / 3.4–3.69GHz), and medical IoT applications. The proposed design enhances the compactness and energy efficiency of wireless systems while remaining robust and easily integrable with microstrip technology. Simulation results show that the antenna provides nearly omnidirectional radiation patterns in the H-plane and bidirectional patterns in the E-plane, ensuring stable coverage for mobile and portable devices. The ultra-wideband operation achieves a reflection coefficient below –10dB across the targeted frequencies, with a peak gain of 4.8dBi, offering an optimal balance between performance and compact size. Consequently, this antenna represents an effective solution for medical IoT applications requiring reliable transmission, minimal distortion, and easy integration into portable or implantable devices.

References

- [1] M. Mokayef and M. H. Amen Summakieh, "An Ultra-Wideband Antenna for IoT Connectivity," *International Journal of Internet of Things and Web Services*, vol. 2, 2017.
- [2] E. M. Ali, W. Awan, M. S. Alizaidi, A. Alzahrani, D. H. Elkamchouchi, F. Falcone, and S. S. M. Ghoneim, "A Shorted Stub Loaded UWB Flexible Antenna for Small IoT Devices," *Sensors*, vol. 23, no. 748, 2023.
- [3] F. Afrizal, Y. Yulindon, D. Meidelfi, and M. Silvanac, "The Small UWB Monopole Antenna with Stable Omnidirectional Radiation Pattern," *International Journal on Informatics Visualization*, Dec. 2022.
- [4] M. F. Ahmed, M. H. Kabir, and A. Z. M. Touhidul Islam, "An Ultra-Wideband Patch Antenna for Future Internet of Things Applications," *Journal of Science and Arts*, vol. 23, no. 4, pp. 1067–1080, 2023.
- [5] H. A. Ragheb, M. Housam, M. Salah, and A. El-Damak, "Efficient Super-Ultra-Wideband Monopole Antenna Design for Multi-Band Wireless Applications," *Electrical Engineering*, no. 133, 2024.

- [6] L. Sarika, J. Pavani, B. Gowthami, K. Deepanjali, and A. Bhargavi, "Optimized Design of a UWB Monopole Antenna with Triple Band Notches on Rogers RT for Wireless Applications," *International Journal of Creative Research Thoughts (IJCRT)*, vol. 13, no. 4, Apr. 2025.
- [7] U. R. Dave, S. S. Modasiya, A. J. Dave, and R. M. Patel, "Progressions in Ultra-Wideband Antenna Design: A Comprehensive Overview of Innovative Strategies and Real-world Implementations," *SSRG International Journal of Electronics and Communication Engineering*, vol. 11, no. 5, pp. 139–154, May 2024.
- [8] D. Kundu, A. W. Reza, A. H. M. I. Ferdous, A. A. Mamun, and M. J. Hossen, "Sawtooth Bow-Tie Antenna: A Compact Solution for Super High-Frequency Ku Band, K Band, and Ultra-Wideband (UWB) Wireless Communication Systems," *International Journal of Engineering Trends and Technology*, vol. 73, no. 4, pp. 210–224, Apr. 2025.
- [9] S. Choudhary, "Advances in IoT-Enabled Smart Systems: Integrating Antenna Design, Organic Electronics, and Nanomaterials," *International Journal of Research Publication and Reviews*, vol. 6, no. 5, pp. 2963–2968, May 2025.
- [10] D. T. T. Tu, N. V. Hoa, and N. T. T. Nga, "A High Directional Antenna at All Three Operating Bands for Wide-Band IoT Applications Based on IEEE 802.11ax/be Standard," *Journal of Communications*, vol. 20, no. 4, pp. 483–490, 2025. doi:10.12720/jcm.20.4.483-490
- [11] R. P. Singh, U. Anupama, G. Rishitha, D. N. Varun, N. Lokesh, and B. Sowmya, "An UWB Wearable MIMO Antenna for Biomedical and IoT Applications," *Journal of Emerging Technologies and Innovative Research (JETIR)*, vol. 11, no. 5, May 2024. [Online]. Available: www.jetir.org
- [12] B. B. Qas Elias and P. J. Soh, "Design of a Wideband Spring Textile Antenna for Wearable 5G and IoT Applications Using Characteristic Mode Analysis," *Progress In Electromagnetics Research M*, vol. 112, pp. 177–189, 2022.
- [13] S. N. Mahmood, A. J. Ishak, A. Ismail, A. C. Soh, Z. Zakaria, and S. Alani, "On-Off Body Ultra-Wideband (UWB) Antenna for Wireless Body Area Networks (WBAN)," *IEEE Access*, Aug. 10, 2020.
- [14] W. Fathallah, C. Abdelhamid, C. Baccouch, M. Alsharef, K. Jouili, and H. Sakli, "UWB Printed MIMO Antennas for Satellite Sensing System (SRSS) Applications," *International Journal of Advanced Computer Science and Applications (IJACSA)*, vol. 15, no. 8, 2024.
- [15] R. O. Prakash, C. S. Yadav, R. L. Yadava, and R. K. Yadav, "Low Profile and Wideband Antennas for IoT Applications," in *2nd International Conference on Advancement in Electronics & Communication Engineering (AECE)*, 2022.
- [16] S. Uddin, M. Mohibullah, and M. Hasan, "Design of Ultra-Wideband (UWB) Microstrip Patch Antenna for Biomedical Telemetry Applications," *ICCK Transactions on Mobile and Wireless Intelligence*, vol. 1, no. 1, 2025. doi:10.62762/TMWI.2025.250467
- [17] M. H. Tsoi, K. M. Wu, J. S. M. Yuen, Y. S. Choy, and S. W. Y. Mung, "Wideband Planar Coupled-Feed Antenna for Internet of Things Applications," in *2020 IEEE Asia-Pacific Microwave Conference (APMC)*, Hong Kong, 2020, pp. 460–462.
- [18] A. J. A. Al-Gburi, Z. Zakaria, M. Palandoken, I. M. Ibrahim, A. A. Althuwayb, S. Ahmad, and S. S. Al-Bawri, "Super Compact UWB Monopole Antenna for Small IoT Devices," *Computers, Materials & Continua (CMC)*, vol. 73, no. 2, 2022.
- [19] F. Tubbal, L. Matekovits, and R. Raad, "Antenna Designs for 5G/IoT and Space Applications," *Electronics*, vol. 11, no. 16, p. 2484, 2022. doi:10.3390/electronics11162484
- [20] H. A. and N. N. Uddin, "A Compact Slotted Microstrip Patch Antenna Operating at 28 GHz for 5G-IoT Applications," *IJIST*, vol. 7, May 2025, pp. 13–24.
- [21] G. B. W. Mohamed, A. K. M. Z. Hossain, and N. B. Hassim, "A Tri-Elliptic Shaped Microstrip Patch UWB Antenna for Chipless RFID Tags," *International Journal of Intelligent Engineering and Systems*, vol. 18, no. 2, 2025. doi:10.22266/ijies2025.0331.43
- [22] M. F. Ahmed, M. H. Kabir, and A. Z. M. Touhidul Islam, "An Ultra-Wideband Patch Antenna for Future Internet of Things Applications," *Journal of Science and Arts*, vol. 23, no. 4, pp. 1067–1080, 2023.
- [23] D. K. D. S, A. M., B. D., H. S. M., and L. B. H., "Performance Analysis on 1*2 L Shaped Microstrip Patch Antenna for 2.4GHz," *International Advanced Research Journal in Science, Engineering and Technology*, vol. 12, no. 5, May 2025.