Transparent Ultra-Wideband Antenna with Trapedoidal Defected Ground

Suleiman Babale Aliyu, Tan Kim Geok,
Mohamed Abdelfattah Morsi Abdelkarim Marei and
Sharul Kamal Abdul Rahim

October 10, 2023

Transparent Ultra-Wideband Antenna with Trapezoidal Defected Ground

Suleiman Aliyu Babale

Faculty of Engineering and Technology, Multimedia University, Melaka 75450, Malaysia

Department of Electrical Engineering, Bayero University, Kano - Nigeria
sababale.ele@buk.edu.ng

Tan Kim Geok

Faculty of Engineering and Technology, Multimedia University, Melaka 75450, Malaysia.

kgtan@mmu.edu.my

Mohamed Abdelfattah Morsi Abdelkarim Marei

Faculty of Engineering and Technology, Multimedia University, Melaka 75450, Malaysia.

1151303381@student.mmu.edu.my

Sharul Kamal Abdul Rahim

Wireless Communication Centre, Universiti Teknologi Malaysia, Skudai 81310, Johor, Malaysia

sharulkamal@fke.utm.my

***Abstract*— This paper presents the design, simulation, and performance evaluation of a transparent Ultra-Wideband (UWB) monopole antenna using the commercially available CST Studio software. The antenna is designed on a transparent quartz substrate, augmented with a silver mesh structure to enhance conductivity while maintaining optical clarity. The integration of transparency and high conductivity enables seamless deployment on various transparent surfaces, such as windows, vehicle windshields, and other see-through mediums. The proposed transparent UWB monopole antenna demonstrates an impressive impedance bandwidth of 157%, spanning the frequency range from 1.52 GHz to 12.58 GHz. This exceptional bandwidth coverage is vital for accommodating a wide array of wireless communication applications, including high-data-rate transmission, radar systems, and IoT devices. The antenna's performance characteristics, including its radiation pattern, gain, and efficiency, were systematically evaluated through comprehensive simulations.**

***Keywords*—** *Ultra-Wideband, transparent quartz substrate, monopole antenna, impedance bandwidth.*

I. INTRODUCTION

Ultra-wideband (UWB) antennas are characterized by their wide bandwidth, high gain, and low profile. A wide bandwidth is necessary to support the high data rates that are possible with UWB. The high gain is required to ensure that the UWB signal can be received over a long distance. The low profile is desirable for applications where space is limited, such as in mobile devices. There are many different types of UWB antennas, each with its advantages and disadvantages. Some of the most common types of UWB antennas include planar antennas, dipole antennas, monopole antennas, and slot antennas. They are used in a wide variety of applications, including Indoor positioning, medical imaging, radar, and wireless communications [1]–[3].

In recent years, there has been a growing exploration of microstrip patch antenna designs with Ultra-wideband (UWB) capabilities, as proposed in the literature references [4]–[10]. Nevertheless, only a limited number of studies on UWB have taken into consideration the challenge of achieving a broad impedance bandwidth while simultaneously upholding a heightened radiation efficiency. Furthermore, the physical and electrical dimensions of the UWB antennas have often been quite substantial, thus restricting their application in compact scenarios.

In several papers [11], [12], monopole antennas for ultra-wideband applications were suggested. A rhomboidal DGS ring is used to increase the proposed antenna's bandwidth in [11], where the authors propose new loaded planar antennas for ultra-wideband applications using defected ground structures that have very compact structures and simple configurations. Antennas have an impedance bandwidth greater than 10 GHz. Additionally, the antennas have a stable radiation pattern and an acceptable gain. [13] describes a straightforward coplanar waveguide (CPW) slot antenna that combines dual circular polarization with an ultra-wideband impedance bandwidth and a broad axial ratio bandwidth. An impedance bandwidth of 153.1 %, axial ratio bandwidth of 102.6 %, and dual circular polarization are all achieved by the suggested antenna.

For ultra-wideband applications, a high gain modified antipodal Vivaldi antenna (HG-MAVA) is presented in [14], where a wideband was achieved from 2.15 GHz to more than 11 GHz operating frequency band. Reference [15] designed a CPW-fed Dodecagon Monopole antenna with a bandwidth range of 2.97 to 15.58 GHz, covering a fractional bandwidth of 135.96 % [16] proposed a circular-shaped monopole antenna with impedance bandwidths covering the WiMAX frequency bands (2.08-4.59 GHz). [17] presented an enhanced 5G millimeter-wave wideband monopole antenna covering frequencies from 20 to more than 40 GHz. [18] proposed a printed monopole antenna with multiple stubs and a metasurface ground plane, achieving wideband coverage from 4.43 to 16.64 GHz. [19] engineered a compact circular ring microstrip patch antenna with an impedance bandwidth ranging from 2.75 to 32.035 GHz.

Sometimes, the use of metamaterials can improve the performance of wide-band patch antennas, such as increasing the radiation efficiency and enhancing the bandwidth. For instance, [20] proposed a stacked patch antenna with a modified feeding structure that achieved a bandwidth of 63.2% with a gain of 7.1 dBi. In all these literatures reviewed, a conventional board was used, and the highest impedance bandwidth achieved was in [11].

In this article, a transparent UWB monopole antenna was proposed. Apart from being transparent, which gives it the benefit of being mounted on any transparent surface such as windows, vehicle wind screen and so on. The antenna exhibited a very wide impedance bandwidth of 157 % that covered from 1.52 to 12.58 GHz.

II. ANTENNA STRUCTURE

Figure 1(a) depicts the proposed UWB antenna's top view geometry, while Figure 1(b) depicts the ground view geometry. The antenna is L x W in total size. The antenna is built on a quartz glass substrate that is 0.7 millimeters thick, 3.75 relative permittivity, and 0.004 tangent loss. The radiator's shape was created with rounded top edges, which helped to reduce its size. The gap capacitance between the lower portion of the UWB antenna and the upper portion of the DSG was used to increase the bandwidth and provide a good impedance matching. The antenna is fed by a 50-ohm microstrip feeding line. The defective ground plane with length L2 was optimized on the substrate's ground side to increase bandwidth even more. The software CST Microwave Studio 2023® was used to design and optimize the antenna. The simulation results were explained and then there was a discussion of the findings in the subsequent sections that followed.

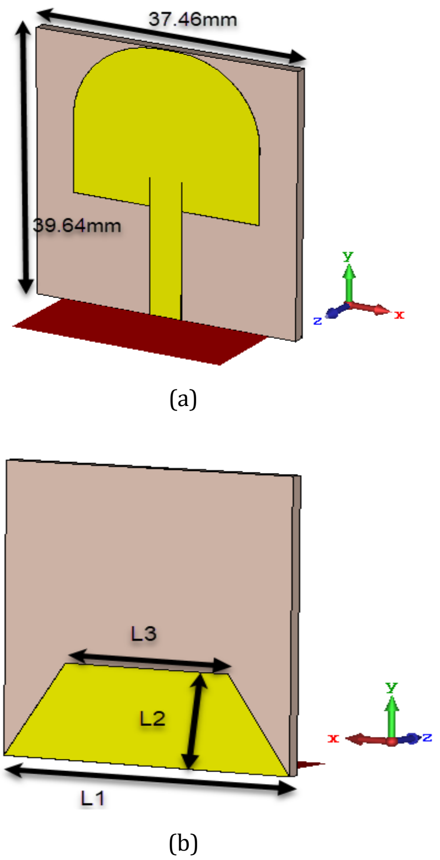


Figure 1: The geometry of the proposed UWB antenna. (a) the top view; (b) the back view

The strip feeding line at the top side of the UWB antenna was designed for 50-ohms and its length was optimized to give the best matching. From Figure 1(b), the full width of the ground plan is the same as that of the substrate at the lower side and is denoted by L1. Its vertical height L2, was defected to give the wideband operation. To further improve the bandwidth, the upper length of the defected ground denoted as L3 was varied gradually until an optimum bandwidth was achieved.

III. RESULT AND DISCUSSIONS

Conventional monopole antennas have a single resonant frequency, which limits their bandwidth. However, patch antennas with ultra-wide bandwidth can be designed by creating multiple overlapping resonant frequencies. This is the approach used to develop the proposed compact monopole antenna, which has resonance frequencies of 3.2, 5.8, and 10.0 GHz. Based on the -10 dB requirement, the optimized simulated reflection coefficient S11 (dB) against frequency (GHz) plot for the antenna given in **Figure 2** reveals a very high bandwidth of 11.06 GHz ranging from 1.52 to 12.58 GHz.

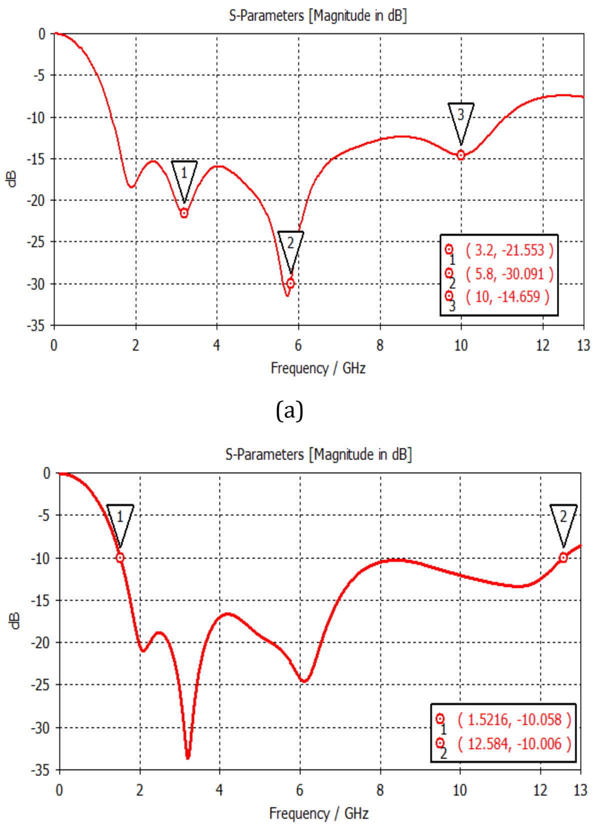


Figure 2: Simulated reflection coefficient S11 (dB) against the frequency (GHz) plot (a) Initial design, (b) Optimized design.

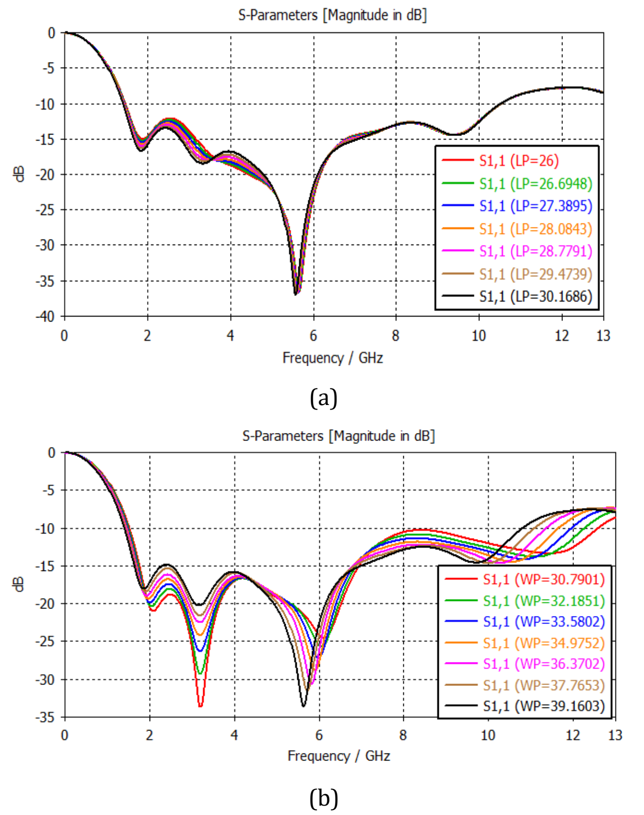


Figure 3: Effect of variation of the UWB antenna parameters on the S11. (a) Variation in length; (b) variation in width

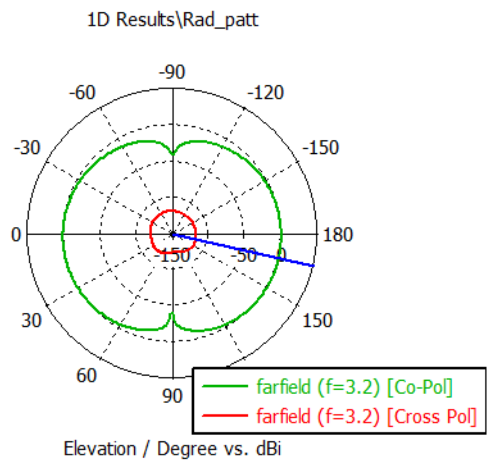
A. *Effect of Varying the Patch Size*

Both the length and the width of the UWB antenna determined the resonant frequency of the antenna as well as the amount of bandwidth to be achieved. When the length of the antenna was varied from 26mm to 30.16mm, there are no much effect on the S11 result with the exception of little change on the depth of the S11 at the lower frequencies. This can be seen from **Figure 3** (a). On the other hand, when the width of the antenna was varied from 30.79 mm to 39.16 mm, an improvement on the bandwidth was observed around the higher frequency as shown in **Figure 3** (b). apart from the change in bandwidth, the reflection coefficient fluctuates between -20 dB to -33 dB at 3.2 GHz and 5.8 GHz.

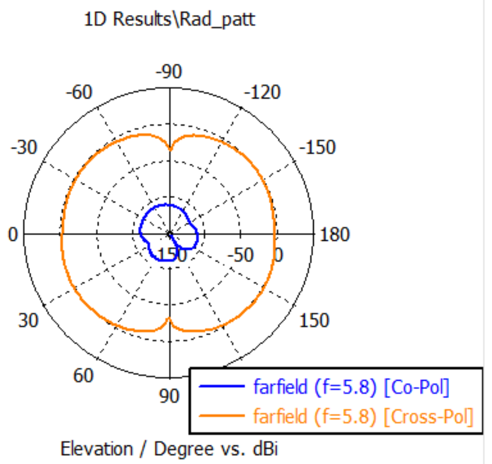
B. *Radiation Pattern*

The proposed antenna has a near-omnidirectional radiation pattern in the H-plane and an E-plane (x-z plane) radiation pattern resembling a monopole (y-z plane). **Figure 4** displays the radiation patterns at the 3.2 GHz, 5.8 GHz, and 10.0 GHz resonant frequencies. The elevation plane (E) and azimuth plane (Z) are the two primary orthogonal planes for which the findings are obtained (H).

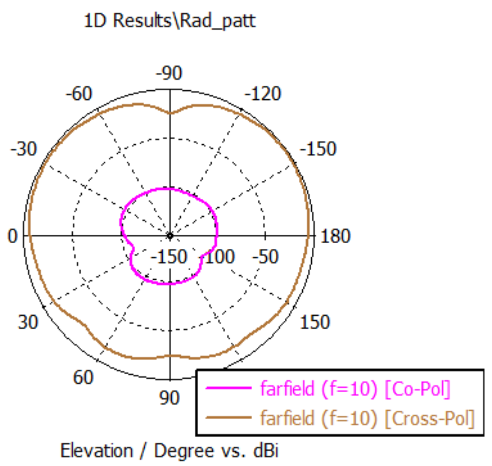
Over the full frequency range of operation, the azimuth plane exhibits a constant omnidirectional radiation pattern. The radiation pattern in the E plane is bidirectional and exhibits a little amount of distortion at high frequencies. The ultra-wideband monopole antenna's overall radiation pattern is omnidirectional, which is the best pattern that can be achieved. This means that the antenna does not depend on its placement position over the entire bandwidth. **Figure 4** shows the plot of the design power gain vs the operating frequency. It can also be noted that there is a very high co-polarization and low cross-polarization which is desirable in reducing interference in a system.



(a)



(b)



(c)

Figure 4: Radiation pattern of the proposed UWB antenna at: (a) 3.2 GHz; (b) 5.8 GHz; (c) 10 GHz;

IV. CONCLUSION

This paper designed and simulated a transparent UWB monopole antenna using a commercially available CST studio. The antenna was simulated with a transparent quartz substrate and a silver mesh which gives it high conductivity and clear visibility. This transparency will enable the antenna to be used on any transparent surface such as windows, vehicle wind screen and so on. The antenna exhibited a very wide impedance bandwidth of 157 % that covered from 1.52 to 12.58 GHz. The transparent antenna design holds significant promise for revolutionizing wireless communication deployments in modern infrastructure. Its ability to seamlessly integrate with transparent surfaces while delivering exceptional UWB performance opens avenues for novel applications in smart buildings, vehicular communication systems, and beyond. This research contributes to the expanding field of transparent electronics and ushers in a new era of inconspicuous yet high-performing wireless connectivity solutions.

V. REFERENCES

[1] A. A. Kalteh, G. R. DadashZadeh, M. Naser-Moghadasi, and B. S. Virdee, "Ultra-wideband circular slot antenna with reconfigurable notch band function," *IET Microwaves, Antennas and Propagation*, vol. 6, no. 1, pp. 108–112, 2012, doi: 10.1049/iet-map.2011.0125.

[2] A. Toktas and H. A. Turkmen, "Ultra-Wideband Monopole Antenna with Defected Ground for Millimeter-Wave Applications," *J Infrared Millim Terahertz Waves*, vol. 44, no. 1–2, pp. 37–51, Feb. 2023, doi: 10.1007/s10762-023-00904-7.

[3] Y. Luo *et al.*, "A wideband mmWave microstrip antenna based on zero-mode and TM-mode resonances," *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 32, no. 8, Aug. 2022, doi: 10.1002/mmce.23219.

[4] Y. Zhu, K. Chen, S. Y. Tang, C. Yu, and W. Hong, "Ultra-Wideband Strip-Loaded Slotted Circular Patch Antenna Array for Millimeter-Wave Applications," *IEEE Antennas Wirel Propag Lett*, pp. 1–5, 2023, doi: 10.1109/LAWP.2023.3281785.

[5] S. Yen, L. B. Boskovic, M. A. Elmansouri, and D. S. Filipovic, "Ultra-wideband directional electrically small antenna for UHF through C-band 5G and beyond 5G applications," *Microw Opt Technol Lett*, May 2023, doi: 10.1002/mop.33751.

[6] R. P. Dwivedi, U. Kiran Kommuri, S. Das, S. Lakrit, and V. Goyal, "Design of low profile high gain antenna using loop-based wideband artificial magnetic conductor for UWB applications," *Int J Microw Wirel Technol*, vol. 15, no. 3, pp. 502–512, Apr. 2023, doi: 10.1017/S175907872200037X.

[7] H. Zhang, J. Ye, S. Liao, and B. J. Hu, "An ultra-wideband high gain antenna with embedded sleeves and hexagonal cavity," *Microw Opt Technol Lett*, vol. 65, no. 8, pp. 2299–2306, Aug. 2023, doi: 10.1002/mop.33679.

[8] H. Kaur, H. S. Singh, and R. Upadhyay, "Design and Analysis of Compact Quad-Element MIMO Antenna with Asymmetrical Ground Structures for Ultra-Wideband Communication," *Wirel Pers Commun*, vol. 124, no. 4, pp. 3105–3127, Jun. 2022, doi: 10.1007/s11277-022-09504-5.

[9] M. Kamran Ishfaq *et al.*, "Compact Wide-Angle Scanning Multibeam Antenna Array for V2X Communications," *IEEE Antennas Wirel Propag Lett*, vol. 20, no. 11, pp. 2141–2145, Nov. 2021, doi: 10.1109/LAWP.2021.3100349.

[10] U. Musa, S. Babani, S. A. Babale, A. S. Ali, Z. Yunusa, and S. H. Lawan, "Bandwidth enhancement of millimeter-wave microstrip patch antenna array for 5G mobile communication networks," *Bulletin of Electrical Engineering and Informatics*, vol. 12, no. 4, pp. 2203–2211, Aug. 2023, doi: 10.11591/eei.v12i4.4680.

[11] S. A. Hosseini, Z. Atlasbaf, and K. Forooraghi, "Two new loaded compact planar ultra-wideband antennas using Defected Ground Structures," *Progress In Electromagnetics Research B*, vol. 2, pp. 165–176, 2008, doi: 10.2528/PIERB07111802.

[12] S. I. Orakwue, R. Ngah, O. Elija, and S. A. Babale, "Bandwidth Enhancement of Circular Polarized Microstrip Antenna at 2.4 GHz for WLAN Applications," *Adv Sci Lett*, vol. 24, no. 6, pp. 3933–3936, Jun. 2018, doi: 10.1166/asl.2018.11514.

[13] Z. Li, X. Zhu, and C. Yin, "CPW-fed ultra-wideband slot antenna with broadband dual circular polarization," *AEU - International Journal of Electronics and Communications*, vol. 98, pp. 191–198, Jan. 2019, doi: 10.1016/j.aeue.2018.11.018.

[14] S. A. Adamu, T. Masri, W. A. W. Z. Abidin, K. H. Ping, and S. A. Babale, "High-gain modified antipodal Vivaldi antenna for ultra-wideband applications," *Journal of Telecommunication, Electronic and Computer Engineering*, vol. 10, no. 1–12, pp. 55–59, 2018.

[15] C. Muthu Ramya and R. Boopathi Rani, "Design of CPW-Fed Dodecagon Monopole Antenna for Ultra-Wideband Applications with Hilbert Curve Fractal," 2022, pp. 731–736. doi: 10.1007/978-981-16-4625-6_73.

[16] S. Singhal and A. K. Singh, "CPW-Fed 8-Shaped Monopole Antenna for Ultra Wideband Applications," *Frequenz*, vol. 70, no. 11–12, pp. 479–489, Jan. 2016, doi: 10.1515/freq-2016-0025.

[17] R. Eid, A. Elboushi, and M. Hindy, "Wideband Monopole Antenna with Multiple Stub Resonators for 5G Applications," in *2021 38th National Radio Science Conference (NRSC)*, IEEE, Jul. 2021, pp. 80–87. doi: 10.1109/NRSC52299.2021.9509812.

[18] S. Abdul Khadar, N. Kumar Panda, S. Mohapatra, and S. Sahu, "Design of Metasurface based Printed Monopole Antenna for Wideband Applications," in *2021 2nd International Conference on Intelligent Engineering and Management (ICIEM)*, IEEE, Apr. 2021, pp. 177–181. doi: 10.1109/ICIEM51511.2021.9445315.

[19] S. Z. Ali, I. E. Khuda, K. Raza, and M. Ebrahim, "Measurement Engineering to Design a Truncated Ground Plane Compact Circular Ring Monopole Patch Antenna for Ultra Wideband Applications," *Wirel Pers Commun*, vol. 124, no. 2, pp. 1317–1336, May 2022, doi: 10.1007/s11277-021-09408-w.

[20] M. N. Shakib, M. T. Islam, and N. Misran, "Stacked patch antenna with folded patch feed for ultra-wideband application," *IET Microwaves, Antennas & Propagation*, vol. 4, no. 10, p. 1456, 2010, doi: 10.1049/iet-map.2009.0257.