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A Compact Planar Monopole Antenna for Ultra-Wideband Applications

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Abstract: - This study introduces a planar ultra-wideband (UWB) patch antenna that operates across a broad frequency spectrum within the UWB range. The wideband performance is achieved by incorporating a defected ground structure (DGS) technique. The antenna has a compact size of 32×33×1.6 mm³ and is fabricated using an economical FR-4 substrate. Experimental results demonstrate an impedance bandwidth ranging from 3.1 GHz to 12.4 GHz. This significant bandwidth enhancement is attributed to the use of a half-plane semicircular-shaped ground structure, achieving 132.4% impedance bandwidth. The antenna exhibits a peak gain varying between 2 dB and 7.5 dBi over the entire frequency range. The design parameters of the antenna are fine-tuned through systematic optimization techniques, and the measured outcomes align closely with the simulated predictions.

Keywords: Ultra-wideband (UWB), defected ground structure (DGS), microstrip antenna, X band, Ku band.

I. INTRODUCTION

The rapid advancements in wireless communication technology have sparked significant interest in compact patch antennas with wideband performance. These antennas have become critical for next-generation wireless systems, which demand high data rates, superior spectral efficiency, and extensive bandwidth. To meet these requirements, the Federal Communications Commission (FCC) allocated the frequency spectrum from 3.1 GHz to 10.6 GHz for ultra-wideband (UWB) applications in 2002 [20].

UWB patch antennas have gained prominence among researchers due to their wide range of benefits, including broad bandwidth, simple design, cost-effectiveness, ease of fabrication, stable radiation patterns, and seamless integration with other RF components [10]. Beyond the UWB band, the X and Ku bands have emerged as important frequency ranges for communication systems. According to the IEEE, the X band spans frequencies from 8 to 12 GHz, while the Ku band covers 12 to 18 GHz. The X band supports applications such as satellite communication, radar systems, weather monitoring, defense tracking, maritime navigation, and vehicle speed detection. Similarly, the Ku band is widely used for satellite communication, particularly in fixed satellite services (FSS) operating between 11.7 and 12.7 GHz and direct broadcast satellite (DBS) services in the 12.2–12.7 GHz range. Numerous designs of patch antennas with UWB capabilities have been introduced in recent years. For instance, a novel approach based on mode analysis was proposed in [4], enabling the enhancement of bandwidth by integrating multiple modes. In [6], a flower-shaped antenna supporting UWB, C, X, and Ku bands was designed, achieving an impressive 137% impedance bandwidth, covering 3.45 GHz to 18.5 GHz. Another study [7] presented a low-profile monopole antenna with a slotted circular patch and ground structure for wideband operation. Meanwhile, a compact UWB antenna featuring C-shaped slots and high gain was introduced in [8]. In this work, a meander-line slot patch antenna with a defected ground structure is proposed for UWB applications. The antenna efficiently operates across the UWB, C, X, and Ku bands, making it a versatile solution for a range of applications, including radar systems,

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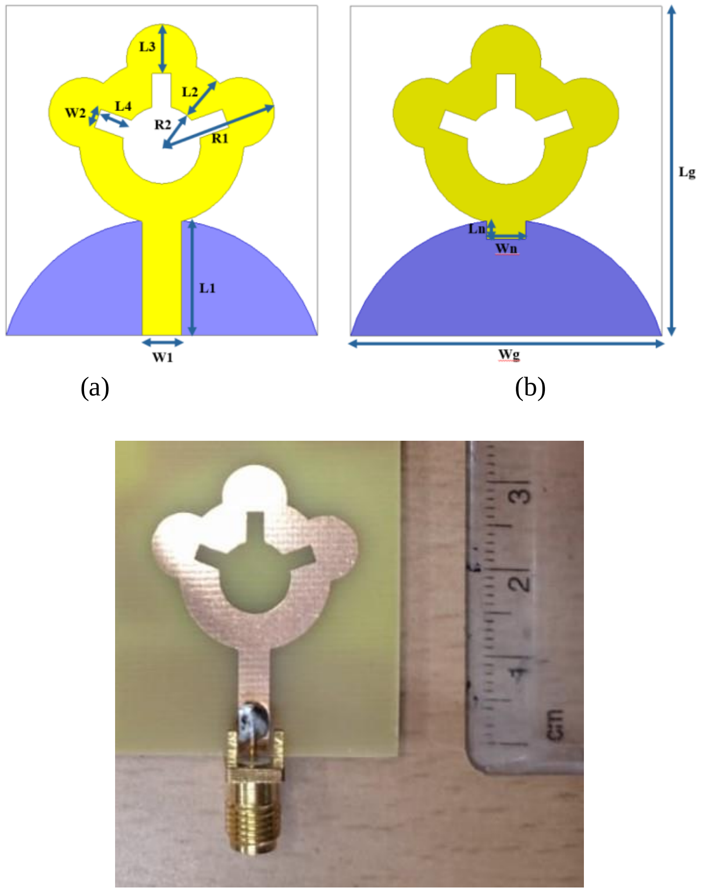
satellite communication, 5G networks, and UWB-specific technologies [12–14]. Ultra-wideband system has been widely used for the last few years due to its amazing frequency spectrum in wireless communication. According to the Federal Communications Commission (FCC), UWB system is defined as any radio system operating in the band of 3.1-10.6 GHz, has a 10 dB bandwidth larger than 25% percent of the centre frequency and a maximum equivalent isotropic radiated power spectral density of -41.3 dBm/MHz [23-27].

II. ANTENNA DESIGN AND SPECIFICATION

The presented antenna is designed using an FR4 substrate, which is 1.6 mm thick. The FR4 material is chosen for its affordability and ease of fabrication, making it an ideal candidate for use as a substrate. The antenna has a compact form factor with dimensions of 32×33×1.6 mm³. The design incorporates a patch with a meander-line slot and a ground plane featuring a half-plane semicircular structure. To achieve ultra-wideband (UWB) performance, a defected ground structure (DGS) is employed [15-18]. Additionally, a rectangular notch is introduced into the ground plane to further improve the bandwidth, as detailed in Section III. The antenna uses a microstrip line feed to maintain a planar configuration. The structural details of the proposed antenna are illustrated in Fig. 1. The Table 1 shows the details parameters of proposed antenna.



(a) (b)

(c)

Fig. 1. Configuration of the antenna (a) Top view (b) Bottom view (c) Fabricated Prototype of the proposed antenna

Table 1: Proposed MIMO Antenna Dimensions

Dimensions	**Value (in mm)**	**Dimensions**	**Value (in mm)**
Wg	32	W1	4
Lg	33	W2	2

L1	11.5	R1	12.15
L2	4.7	R2	3.6
L3	5.1	Ln	2
L4	3.46	Wn	4

III. RESULTS AND DISCUSSION

A. Reflection coefficient and bandwidth

In this section, the reflection coefficient (S11) vs frequency plot has been presented. Figure 2 shows the S11 curves at each step of the antenna development process. In the simulation, the operational frequency band of designed antenna is obtained from 3.4 GHz to 12.4 GHz. The percentage impedance bandwidth is 135.8 %. A parametric analysis has been done to achieve better results for the UWB patch antenna.

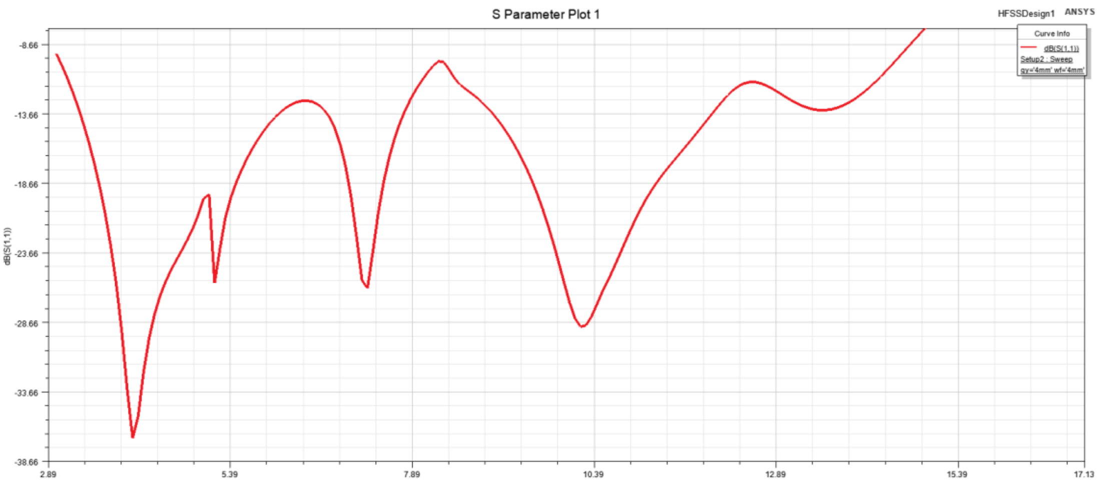


Fig. 2. Reflection coefficient vs. frequency graph

B. Gain, Radiation pattern and Current distribution

As illustrated in Fig. 4, the proposed antenna achieves a gain ranging between 2 and 6.8 dB throughout the operational frequency range. The maximum recorded gain is 7.5 dB at 10.2 GHz. The compact design and cost-effectiveness of the antenna make its gain and efficiency highly suitable for wireless communication applications [17]. Fig. 5 presents the antenna's radiation patterns at various frequencies. Fig. 3 shows the current distribution of the proposed antenna.

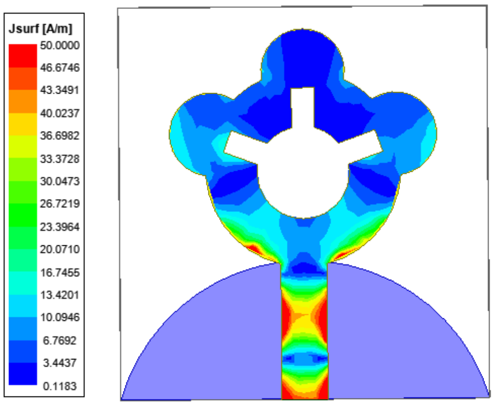


Fig. 3. Simulated Current distribution of the proposed antenna at 10.2 GHz.

The bidirectional radiation pattern is observed in lower range of operational frequency band as the antenna structure is a dipole. It has been observed that the shape of the radiation pattern. At lower frequencies within the operational range, the radiation pattern is bidirectional, characteristic of a dipole-like structure. As the frequency increases, changes in the shape of the radiation pattern and the direction of maximum radiation are observed. Figure 7 depicts the current distribution across the antenna patch at 12 GHz. The analysis reveals that the current density is highest near the feed line and gradually diminishes across the patch, with a concentration of current at the patch edges.

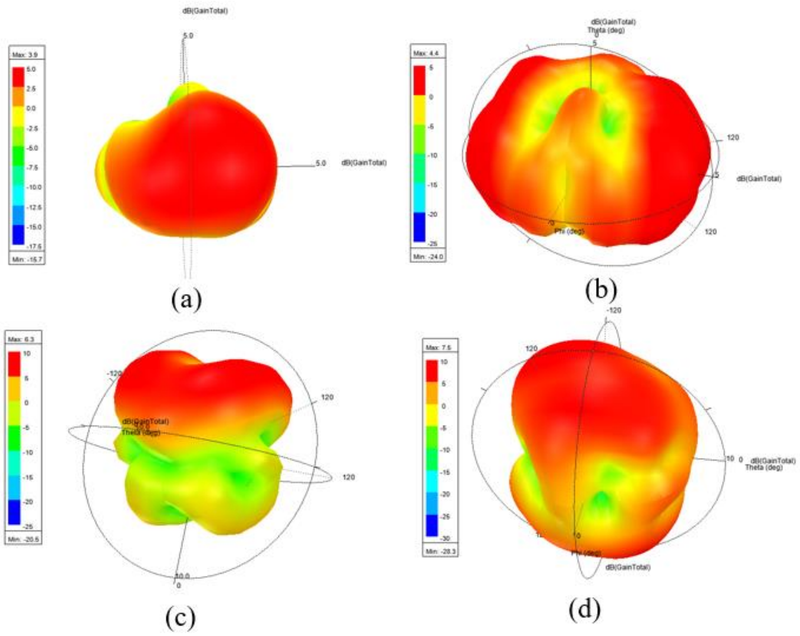


Fig. 4. Simulated 3D polar plot of the designed antenna at (a) 4.2 GHz (b) 5 GHz (c) 7 GHz (d) 10.2 GHz

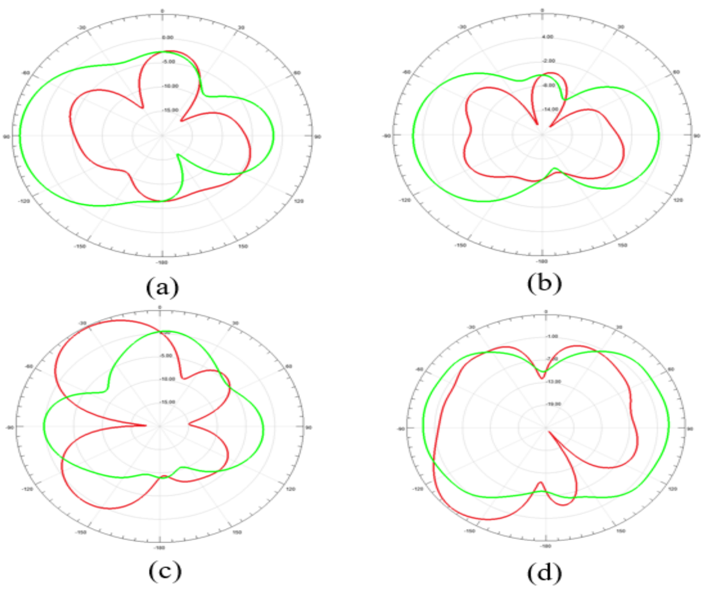


Fig. 5. Simulated radiation pattern of the designed antenna at (a) 4.2 GHz (b) 5 GHz (c) 7 GHz (d) 10.2 GHz

Ref.	**Substrate permittivity (ϵ_r)**	**Dimensions (mm^3)**	**Frequency Range (GHz)**	**Bandwidth**	**Gain (dBi)**
[1]	Polymer Substrate	39×39×0.503	2.36-2.55	0.9 GHz	2.6
[6]	RT Duroid 5880 (2.2)	47×47×1.575	2.36-2.4	320 MHz	3.67
[7]	Jeans material (1.7)	58×68×0.2	2.4-2.6	200 MHz	5.76

[9]	RT Duroid 5 780	45×30×0.787	2.2-5.2	320 MHz	2.3
[18]	FR-4 (4.4)	60×53×1	2.4-2.55	155 MHz	2.22
This Work	**FR-4 (4.4)**	**32×33×1.6 mm³**	**3.1 - 12.4**	**9.3 GHz**	**7.5**

IV. CONCLUSION

This paper presents a compact ultra-wideband (UWB) planar patch antenna with an operational frequency range spanning from 3.1 GHz to 12.4 GHz. The proposed design effectively supports UWB, X, and Ku band applications. The development and evolution of the antenna are comprehensively analyzed in this work. The measured impedance bandwidth (S11 < -10 dB) is calculated to be 135.8%, demonstrating a broad operational range. The antenna achieves a peak gain between 2 dBi and 7.5 dBi across its entire frequency range. Compactness is achieved through careful optimization of the antenna dimensions, ensuring its practicality for various applications. The obtained results confirm that this antenna is well-suited for diverse purposes, including UWB communication, satellite systems, radar operations, and wireless cellular networks.

REFERENCES

[1] Sharma, N, Bhatia, SS. Design of printed monopole antenna with band notch characteristics for ultra-wideband applications. Int J RF Microw Comput Aided Eng. 2019; 29:e21894.J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[2] Baudha, S, Yadav, MV. A novel design of a planar antenna with modified patch and defective ground plane for ultra-wideband applications. Microw Opt Technol Lett. 2019; 61: 1320– 1327.

[3] Zong, W-H, Yang, X-M, Li, S, Qu, X-Y, Wei, X-Y. A compact slot antenna configuration for ultrawideband (UWB) terminals and mobile phones. Int J RF Microw Comput Aided Eng. 2018; 28:e21400.

[4] C. Sun, "A Design of Compact Ultrawideband Circularly Polarized Microstrip Patch Antenna," in IEEE Transactions on Antennas and Propagation, vol. 67, no. 9, pp. 6170-6175, Sept. 2019.

[5] M. Tang, T. Shi and R. W. Ziolkowski, "Planar Ultrawideband Antennas With Improved Realized Gain Performance," in IEEE Transactions on Antennas and Propagation, vol. 64, no. 1, pp. 61-69, Jan. 2016.

[6] Devana, V. N. Koteswara Rao, Rao, AM. A compact flower slotted dual band notched ultrawideband antenna integrated with Ku band for ultrawideband, medical, direct broadcast service, and fixed satellite service applications. Microw Opt Technol Lett. 2021; 63: 556– 563.

[7] Saha TK, Goodbody C, Karacolak T, Sekhar PK. A compact monopole antenna for ultra-wideband applications. Microw Opt Technol Lett. 2019;61:182–186.

[8] Hammache, B, Messai, A, Messaoudene, I, Denidni, TA. A compact ultrawideband antenna with three C-shaped slots for notched band characteristics. Microw Opt Technol Lett. 2019; 61: 275– 279.

[9] M. G. N. Alsath and M. Kanagasabai, "Compact UWB Monopole Antenna for Automotive Communications," in IEEE Transactions on Antennas and Propagation, vol. 63, no. 9, pp. 4204-4208, Sept. 2015.

[10] H. Yang, X. Xi, Y. Zhao, L. Wang and X. Shi, "Design of Compact Ultrawideband Slot Antenna With Improved Band-Edge Selectivity," in IEEE Antennas and Wireless Propagation Letters, vol. 17, no. 6, pp. 946-950, June 2018.

[11] C. Chen, "A Uniplanar Ultrawideband Antenna With Unidirectional Radiation for WLAN/WiMAX Applications," in IEEE Antennas and Wireless Propagation Letters, vol. 20, no. 5, pp. 743-747, May 2021.

[12] M. N. Shakib, M. Moghavvemi and W. N. L. Mahadi, "A low-profile patch antenna for ultrawideband application," in IEEE Antennas and Wireless Propagation Letters, vol. 14, pp. 1790-1793, 2015.

[13] M. Midya, S. Bhattacharjee, and M. Mitra, "Circularly polarized planar monopole antenna for ultra wideband applications," Int. J. RF Microw. Computer-Aided Eng., vol. 29, 2019.

[14] J. Liu et al., "A Low-Profile, Directional, Ultrawideband Antenna," in IEEE Antennas and Wireless Propagation Letters, vol. 18, no. 2, pp. 255-259, Feb. 2019.

[15] De, Arnab, Bappadittya Roy, Ankan Bhattacharya, and A. K. Bhattacharjee. "Investigations on a circular UWB antenna with Archimedean spiral slot for WLAN/Wi-MAX and satellite X-band filtering feature." International Journal of Microwave and Wireless Technologies 14, no. 6, 2022, pp. 781-789.

[16] Peddakrishna, S and Khan, T "Design of UWB monopole antenna with dual notched band characteristics by using π-shaped slot and EBG resonator", AEU-International Journal of Electronics and Communications 96, 2018, pp.107–112.

[17] Anumoy Ghosh, Tapan Mandal & Santanu Das, “Design and analysis of triple notch ultrawideband antenna using single slotted electromagnetic bandgap inspired structure”, Journal of Electromagnetic Waves and Applications, 33:11, 2019, pp.1391-1405.

[18] L. Guo, M. Min, W. Che and W. Yang, "A Novel Miniaturized Planar Ultra-Wideband Antenna," in IEEE Access, vol. 7, pp. 2769-2773, 2019.

[19] Singh, R. and Pujara, D.A., A novel design of ultra-wideband quarter circular microstrip monopole antenna. Microw. Opt. Technol. Lett., 59:, pp.225-229, 2017.

[20] Fcc, F. C. C. "First report and order on ultra-wideband technology." FCC, Washington, DC, USA, 2002.

[21] Tripathi, S., Pathak, N. P., & Parida, M. “A dual feed PIN diode based switchable multiband planar meandered antenna for intelligent transportation system application”, International Journal of RF and Microwave Computer‐Aided Engineering, 29(11), 2019, e21936.

[22] Raj, S., Mishra, P. K., Tripathi, S., & Tripathi, V. “A Defected Ground Structure Based Compact Circular Patch Antenna Design for mm Wave Application”, Defence Science Journal, 72(4), 592-599, 2022.

[23] Tripathi, S., Pathak, N. P., & Parida, M. “Microwave front-end subsystems design for ITS/GPS applications. Engineering Science and Technology, an International Journal, 19(4), 1815-1825, 2016.

[24] Raj, S., Tripathi, S., Upadhyay, G., Tripathi, S. S., & Tripathi, V. S. “An electromagnetic band gap-based complementary split ring resonator loaded patch antenna for glucose level measurement”, IEEE Sensors Journal, 21(20), 22679-22687, 2021.

[25] Tripathi, S., Pathak, N. P., & Parida, M., “Concurrent Dual-Band Double-Layer High Gain Planar Antenna for WAICs/ITS Application”, In Computing, Communication and Signal Processing: Proceedings of ICCASP 2018, pp. 37-46, Springer Singapore, 2019.

[26] Tripathi, S., Pathak, N. P., & Parida, M. “Dual-band dual-beam microstrip patch antenna for intelligent transportation systems application”, In 2018 5th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON), pp. 1-5, IEEE, November, 2018.

[27] Tripathi, S., Pathak, N. P., & Parida, M. “Symmetrical double‐comb multi‐slotted large bandwidth antenna for intelligent transportation systems” International Journal of RF and Microwave Computer‐Aided Engineering, 29(1), 2019, e21471.

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