Progress In Electromagnetics Research C, Vol. 138, 79–90, 2023

A Multi-Slot UWB Monopole Antenna with Dual Band Notch Characteristics

Pasumarthi Srinivasa Rao[1, *], Bondili Siva Hari Prasad[2], Jagabathuni Kavitha[1], and Uppala Jayaram[1]

Abstract—The dual band notched features of an ultra-wideband (UWB) antenna are presented. The radiator element is a rectangular one with several slots. The planned antenna's operational frequency ranges from 2.8 to 10.6 GHz. By embedding a rectangular slot on the radiator and a folding stepped resonator in the ground plane, it is possible to create dual notched bands that are 3.76–5.9 GHz with a central frequency of 5.2 GHz (WLAN) and 2.85–3.32 GHz with a centre frequency of 3.2 GHz (WiMAX). The antenna measures $32 \times 32\,\mathrm{mm}^2$ across the board. In terms of VSWR, group delay, efficiency, and radiation pattern, the antenna's performance is confirmed. Results from simulation and testing of the stated antenna are closely matched.

1. INTRODUCTION

Higher data speeds, wider bandwidth, and higher data resolution wireless communication methods have recently gained popularity. The Federal Communications Commission allotted unlicensed ultra-wideband (UWB) frequency spectrum for commercial wireless communication applications in the range of 3.1 to 10.6 GHz in 2002 in order to attain these features. Wideband wireless communication applications are well suited for UWB technology because of its low profile, low cost, lower power spectral density, consistent radiation patterns, flatter realized gain, and greater data speeds. It is difficult to strike a balance among simplicity, price, and size when designing UWB antennas.

The UWB antenna systems, however, are severely interfered by electromagnetic fields (EMI) as a result of the narrow band channels now in use in the UWB frequency range. The UWB antennas are made with characteristics that eliminate band interference in order to eliminate EMI. A number of UWB antennas with notched band characteristics are suggested in order to reduce interference with IEEE 802.16 (3.3–3.6 GHz) WiMAX, IEEE 802.11a/n (5.15–5.35/5.725–5.825 GHz) WLAN, and the downlink band of an X-band communication link (7.25–7.75 GHz).

To prevent interferences with currently deployed narrowband communication systems, UWB antennas with dual band notch features are currently the subject of in-depth study. Often, a single parasitic element or slot can only produce one notched band and falls short of the requirements for minimizing numerous interferences. Slotted geometries [1–4], parasitic elements [5–8] and other methods [9–14] are frequently employed to build a dual band-notched UWB antenna [15–17]. Planar monopoles completed by notches, defected ground, and resonating structures are quite common.

2. ANTENNA CONFIGURATION AND DESIGN APPROACH

The proposed antenna is developed on an FR-4 substrate with dielectric constant of 4.3 and thickness of 1.6 mm as shown in Figures 1(a) and (b). The radiator element consists of a microstrip fed rectangular

Received 14 July 2023, Accepted 10 August 2023, Scheduled 3 October 2023
* Corresponding author: Pasumarthi Srinivasa Rao (psraoece@gmail.com).
[1] Department of ECE, St. Ann's College of Engineering and Technology, Chirala, A.P., India. [2] Department of ECE, Lakireddy Bali Reddy College of Engineering, Mylavaram, A.P., India.

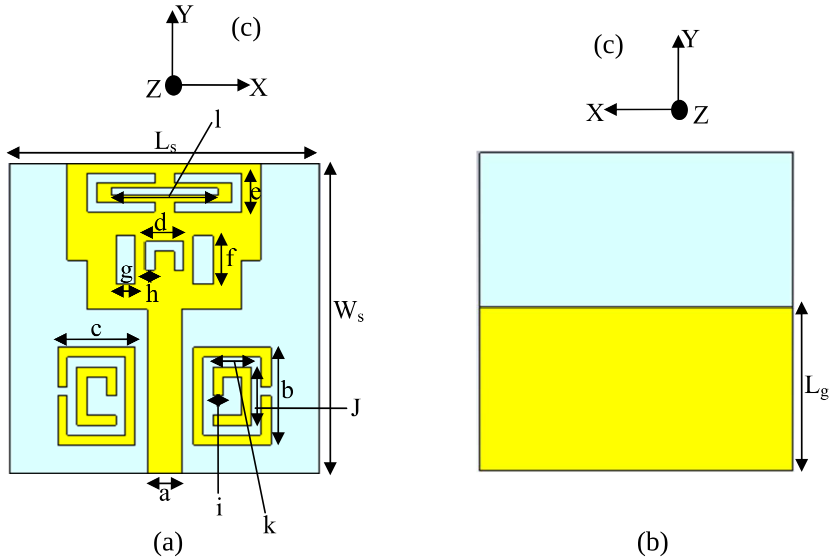


Figure 1. Dimensions of proposed antenna structure. (a) Radiating patch. (b) Defected ground plane. (c) Axes.

antenna with several slots and a split ring resonator (SRR) with two parasitic elements. Initially, a rectangular patch and several slots were introduced as shown Figure 2. A two parasitic elements SRR is also added.

The optimal parameters of the proposed antenna are shown in Table 1. The evolution of the antenna is shown in Figure 2. The S_{11} for each step of the evolution is shown in Figure 3. The bandwidth of the basic UWB antenna is 2.8–10.6 GHz. The proposed antenna is simulated by the commercial electromagnetic software CST ver. 2017, and the results are calibrated by a network analyzer Anritsu MS2037C/2.

Table 1. Optimized parameters of the proposed antenna.

Parameter	**Value (mm)**	**Parameter**	**Value (mm)**
Ws	32	f	5
Ls	32	g	2
a	3.6	h	1
b	10	i	1
c	8	J	6
d	4	k	4
e	4	l	11
Lg	16.5		

3. UWB ANTENNA WITH WLAN BAND NOTCH

By putting a rectangular slot on the radiator, as shown in Figure 4, a WLAN band notch is incorporated into a basic UWB antenna. The provided equation allows one to determine the length of the slot (1). The rectangular slot's whole physical length is indicated by l.

$$f_{Xband\_n} = \frac{c}{2 \times L_T \times \sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

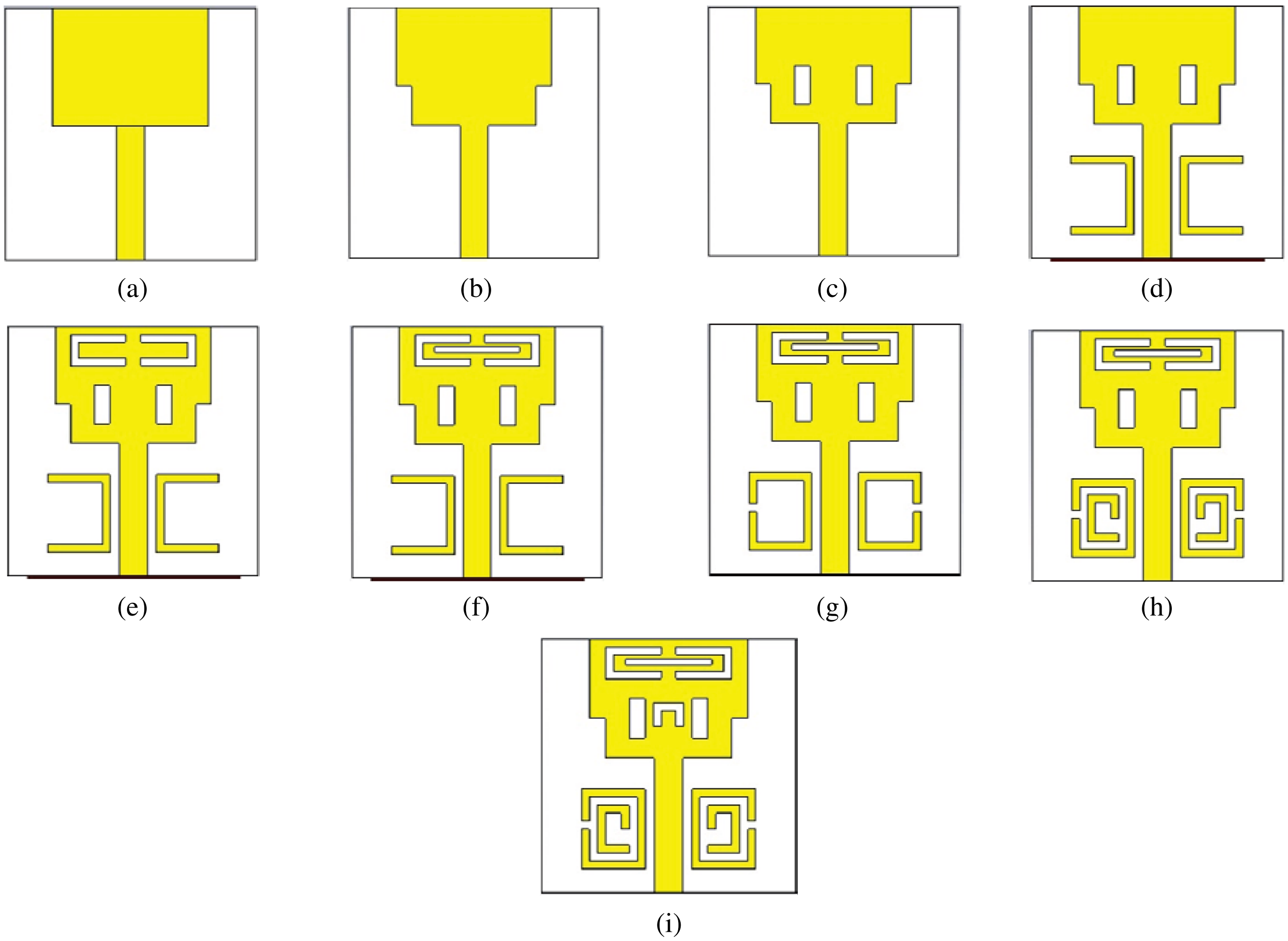


Figure 2. The step-by-step design processes; (a) Ant-A; (b) Ant-B; (c) Ant-C; (d) Ant-D; (e) Ant-E; (f) Ant-F; (g) Ant-G; (h) Ant-H; (i) Proposed.

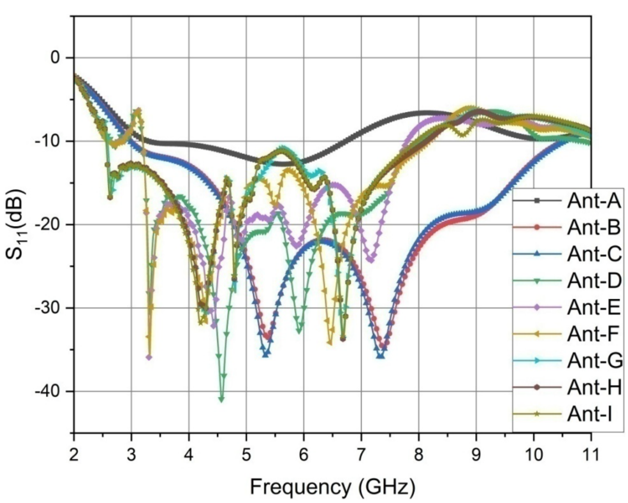


Figure 3. S_{11} comparison of antenna evolution steps.

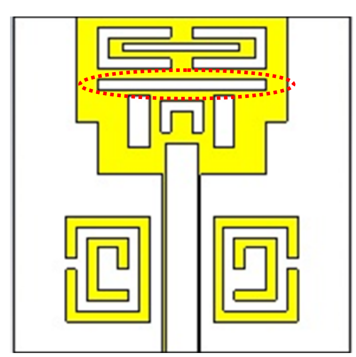


Figure 4. Antenna with WLAN notch.

Table 2. The % of magnitude error of physical length.

Notch Element	Slot length (mm)		Magnitude of length error %	Notch center frequency (GHz)
	Full wave Simulation	Design equation		
Slot	17	16.4	3.5	5.6
	17.3	16.76	3.12	5.5
	17.5	16.82	3.88	5.48
	17.6	17	3.4	5.42
	17.8	17.32	2.69	5.32
	17.9	17.72	1	5.24
	18	17.86	0.7	5.2

The predicted and optimized slot lengths are 17.86 mm and 18 mm, respectively. The proportion of length inaccuracy is 0.7 in magnitude. Table 2 displays the percentage of physical length magnitude error between the design equation and simulation. The inaccuracy is at a minimum at 5.2 GHz.

3.1. Parametric Study of the WLAN Notch

For a better knowledge of the antenna characteristics, the parametric study is important. Here, parametric analyses of the suggested antenna have been done in relation to the slot's length and width. Figure 5 illustrates the parametric analysis of the WLAN notch by changing the slot's length. The slot's length should be optimized at 16 mm.

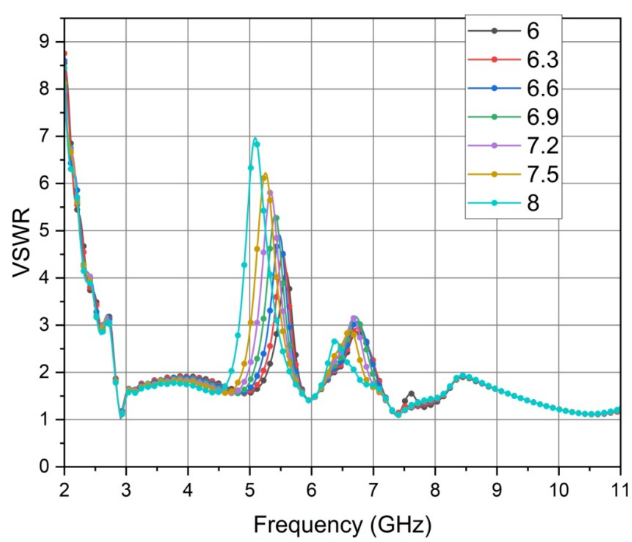


Figure 5. WLAN band notch parametric analysis length.

Figure 6 illustrates a parametric analysis of the WLAN notch by altering the slot width. It has been noted that the greatest value for voltage standing wave ratio (VSWR) is seen when the slot width is 1 mm.

Figure 7 displays the surface current distribution at the first notch at 5.2 GHz. Around the rectangular slot, the current flows are predominant. The antenna system becomes unresponsive at the notch band due to interference from the current concentration along the surface of the rectangular slot, which interferes with the antenna's ability to radiate.

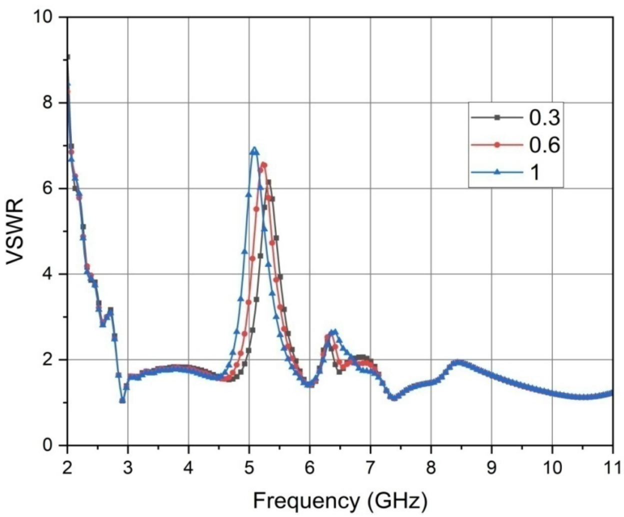


Figure 6. WLAN band notch parametric analysis width.

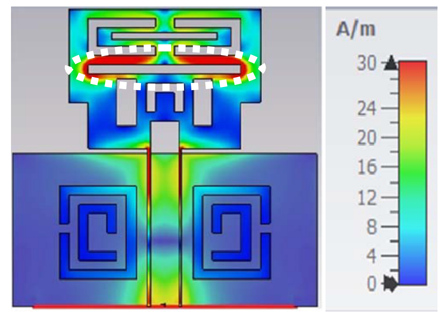


Figure 7. Surface current distribution at 5.2 GHz.

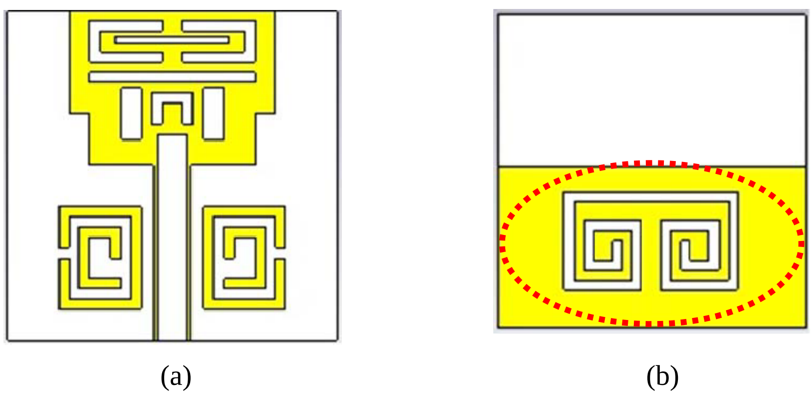


Figure 8. Antenna with dual notches. (a) Front view. (b) Back view.

4. UWB ANTENNA WITH WIMAX BAND NOTCH

By placing a folded stepped resonator in ground plane as indicated in Figure 8, a second notch band is obtained.

Figures 9 and 10 display the simulated and measured S_{11} and VSWR charts, respectively. It is clear from S_{11} that the antenna's bandwidth has not changed. WLAN's notch band is 4.76–5.9 GHz with a centre frequency of 5.2 GHz, while WiMAX's notch band is 2.85–3.32 GHz with a centre frequency of 3.2 GHz.

Figure 11 displays the surface current distribution near the WiMAX band notch. The antenna system becomes unresponsive at the notch band due to interference from the current concentration along the surface of the rectangular slot, which interferes with the antenna's ability to radiate.

Figure 12 displays the proposed antenna's radiation efficiencies with and without notches. After adding notches, it is seen that the efficiency is 37% at 3.2 GHz and 22% at 5.2 GHz, respectively. The efficiency in the remaining operating bandwidth ranges from 89% to 95%.

Figure 13 displays the gain of the dual band notched antenna both with and without notches. It is noted that the antenna's gain ranges from 3 to 4 dBi without notches. At 3.2 and 5.2 GHz, respectively, the gains are -3 dBi and -3.9 dBi when notches are applied.

Figure 14 displays the antenna's observed and simulated radiation patterns in both the XZ-plane

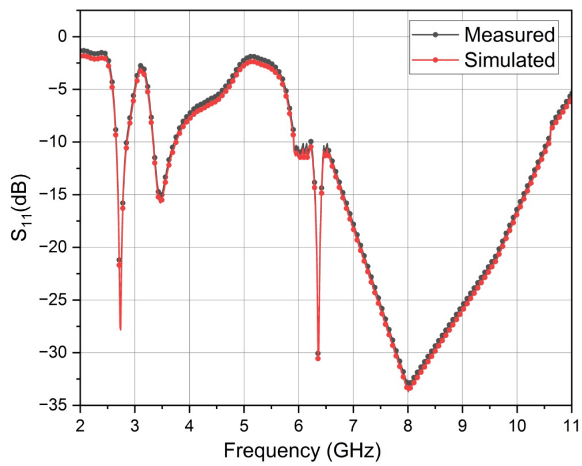


Figure 9. Simulated and measured S_{11} curves for the dual band notched antenna.

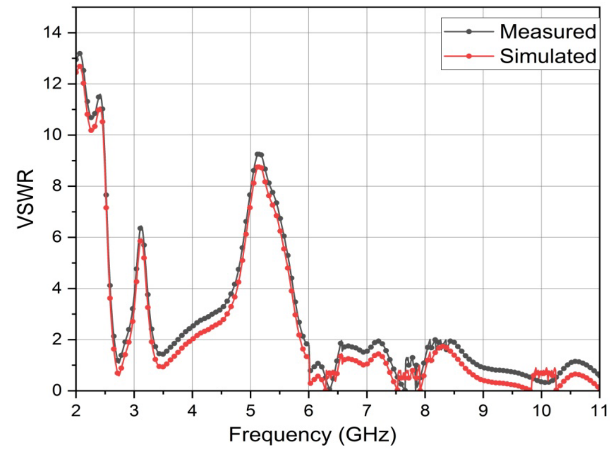


Figure 10. Measured and simulated VSWR curves for the dual band notched antenna.

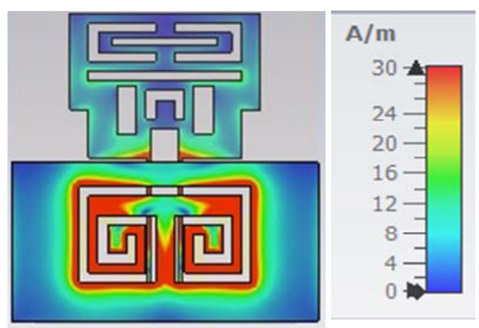


Figure 11. Surface distribution at 3.2 GHz.

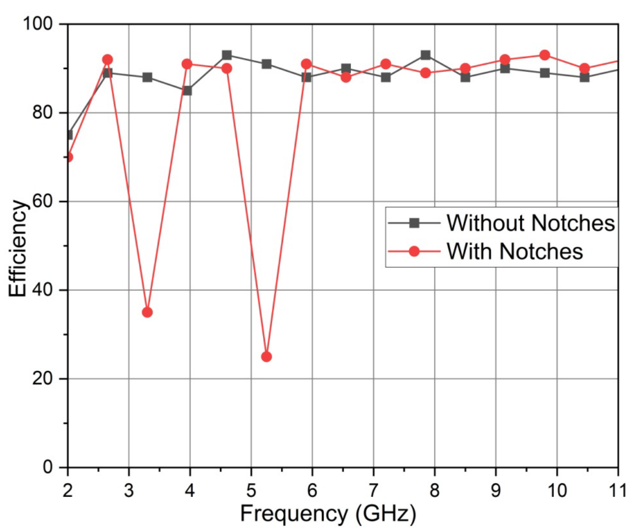


Figure 12. Efficiency.

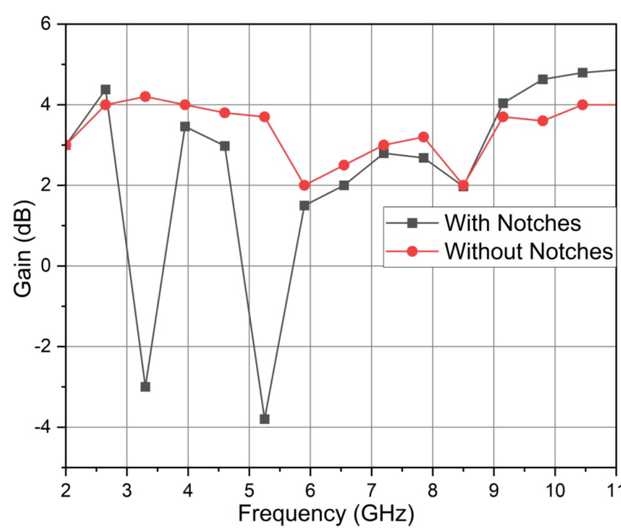
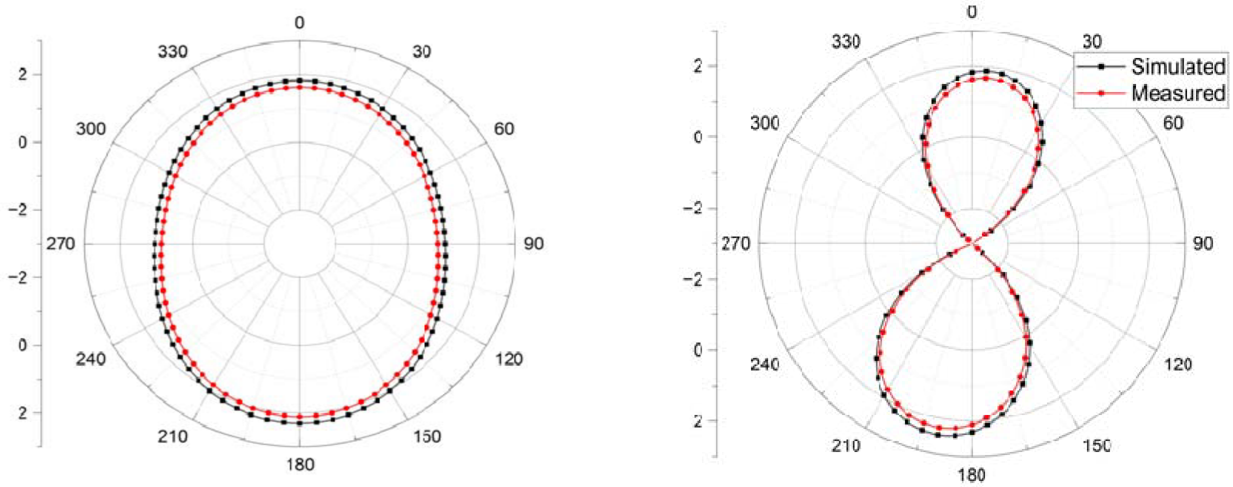
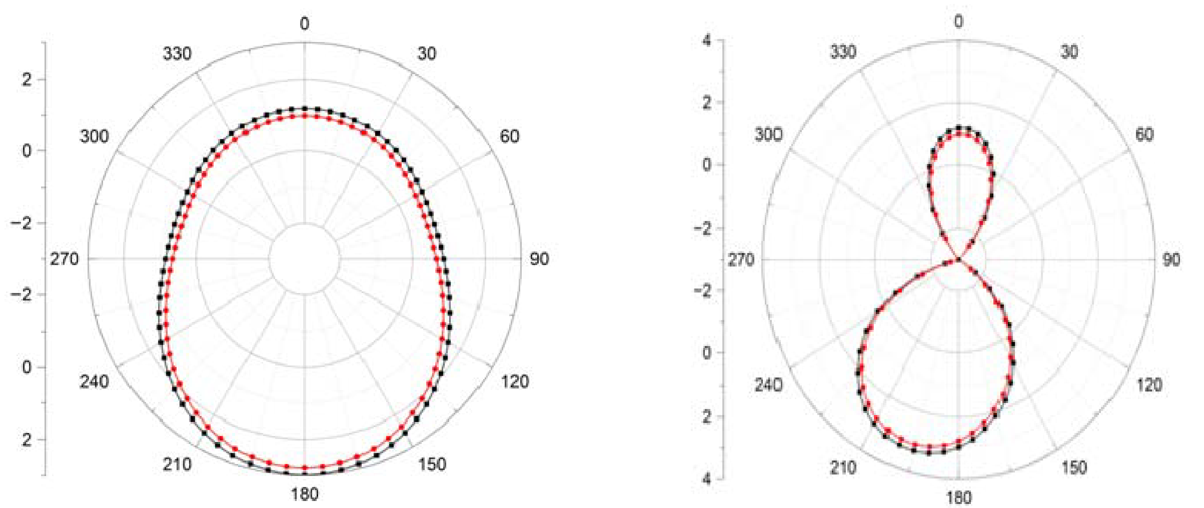


Figure 13. Gain.

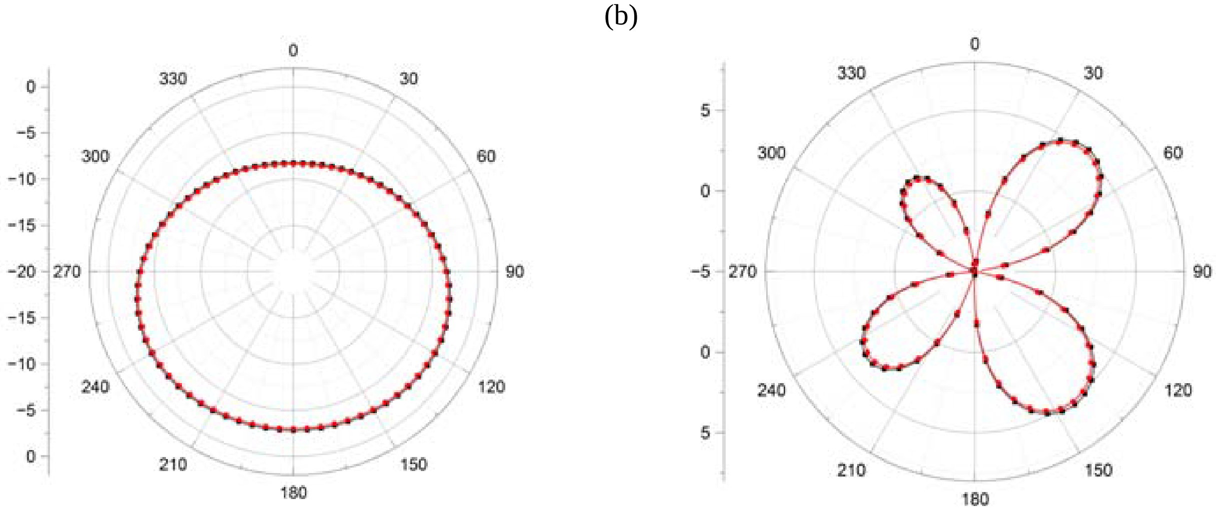
and YZ-plane. On the YZ plane, the radiation patterns are bidirectional. The fabricated prototype is shown in Figure 15.



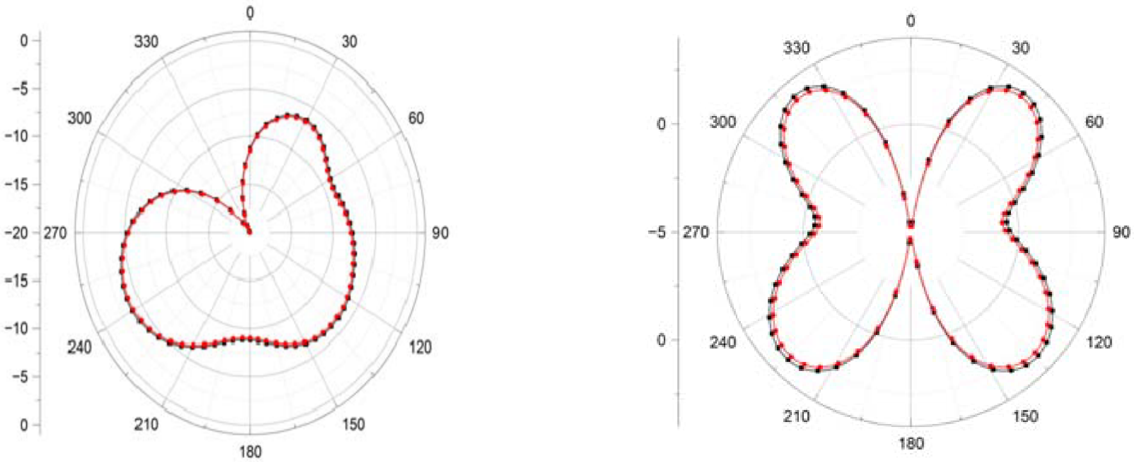
(a)



(b)

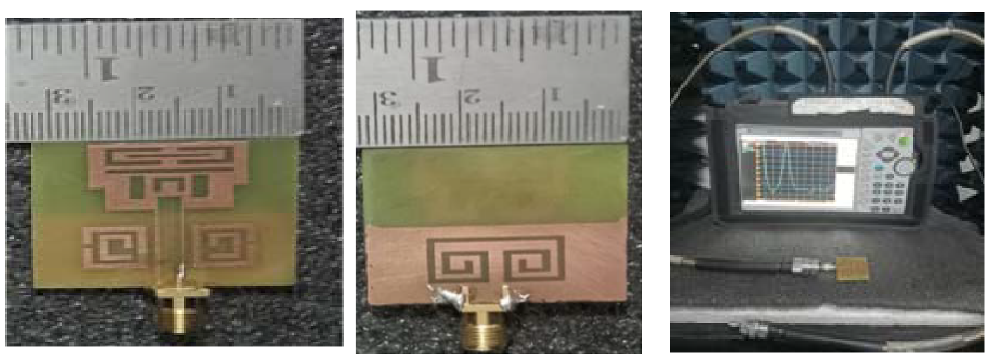


(c)



XZ-plane (d) *YZ*-plane

Figure 14. Measured and simulated radiation pattern in XZ-plane and YZ-plane (a) 2.74 GHz, (b) 3.48 GHz, (c) 6.35 GHz, (d) 7.77 GHz.



(a) (b) (c)

Figure 15. Fabricated prototype. (a) Front view. (b) Rear view. (c) Measurements using VNA.

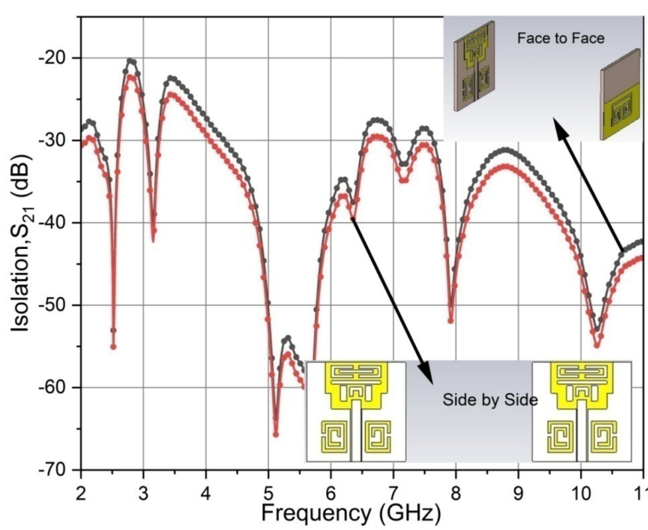


Figure 16. Isolation (S_{21}) side by side and face to face.

5. TIME DOMAIN CHARACTERISTICS

Two identical suggested antennas are maintained fixed at a distance of 40 mm in side-by-side and face-to arrangements as shown in Figure 16 to observe the time domain features. As shown in Figure 16, the measured transmission loss (S_{21}) between two antennas is reported to be between < -40 dB and < -60 dB in both side-by-side and face-to-face configurations.

5.1. Group Delay

Figures 17 and 18 display the proposed antenna's group delay plot. In UWB aerial design, group delay is a crucial parameter that reflects the level of pulse signal distortion. Equation can be used to compute it (2). When the pair of antennas is set up face-to-face and side-by-side, they are 40 mm apart. For both side-by-side and face-to-face systems, the group delay response is flat at 0 ns spanning the frequency range of 2.8 to 10.6 GHz, with the exception of the higher WLAN and WiMAX band notch frequencies. For both side-by-side and face-to-face arrangements, the group delay variances are just 0.20 ns or less over the antenna's operating frequencies, indicating that the antenna has more consistent response. For side-by-side and face-to-face configurations, the group delay varies from 1.50 to 2.09 ns and from 1.46 to 2.09 ns, respectively. The group delay shows that the suggested antenna rejects WLAN and WiMAX spectrum applications, respectively, as it abruptly ranges from 0.31 to 12 ns for 5.2 GHz and from -0.21 to -5.5 ns for 3.2 GHz. The aforementioned outcomes show that the antenna has good linear transmission properties. The performance comparison of the proposed antenna is shown in Table 3.

$$\tau_g = -\frac{d\theta(\omega)}{d\omega} \tag{2}$$

Table 3. Comparison with literature.

Ref	Size (mm^2)	Bandwidth (GHz)	Notch Bands	Notch technique	VSWR	Gain (dB)
[18]	29 × 35	2.66–14.86	WiMAX WLAN	Stubs	7 16	2.65–3.6
[19]	24 × 28	3.42–11.79	WLAN X	Stubs	18 16	2–4.08
[20]	40 × 40	2.6–10.6	WiMAX WLAN	CSRR Slots	NR	NR
[21]	36 × 45	3.1–11.6	4.8 7.7	Slots	9.5 10	4–8.48
[22]	16 × 22	3.45–18.45	WLAN X	Via Parasitic	NR	1.9–3.5
[23]	16 × 21	3.73–16.7	X 9.53–11.17	Parasitic	NR	2–4.26
[24]	28 × 30	3–15.7	WLAN X	Slots	NR	3–7
[25]	30 × 30	4.8–11.31	WLAN X	Slots	NR	4–6
[26]	18 × 17	2.9–12	5G X	Slots	NR	2–6
[27]	40 × 22	3.18–11.26	WiMAX WLAN	Slot Stub	NR	1–5
Proposed	**32 × 32**	**2.8–10.6**	WiMAX WLAN	**Slots**	**7** **9.5**	**3–5**

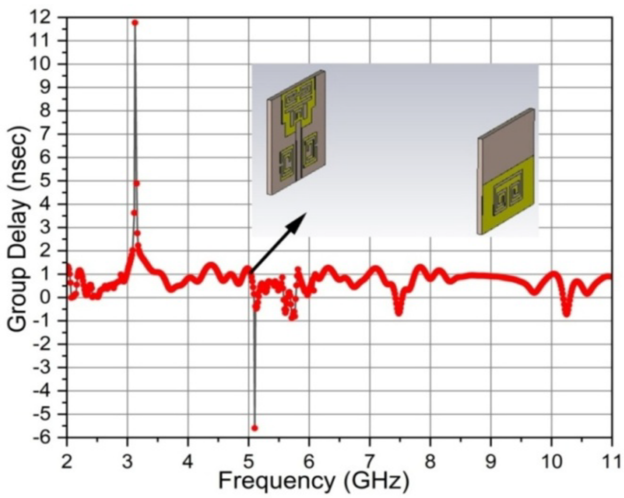


Figure 17. Measured group delay side by side.

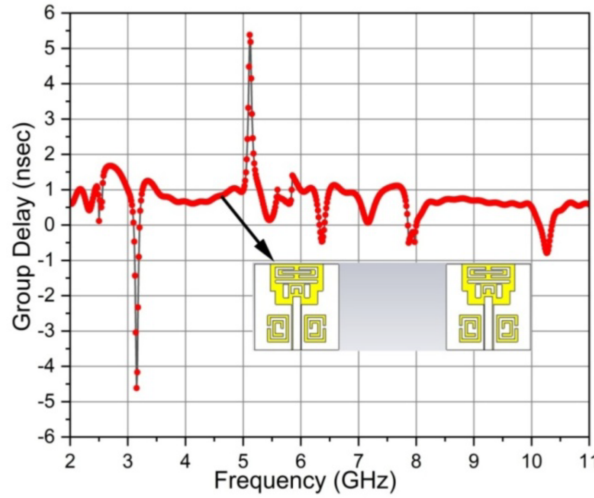


Figure 18. Measured group delay face to face.

6. CONCLUSION

A multi-slot UWB aerial with two notched bands is shown in this article (WLAN and WiMAX). A rectangular slit on the radiator and a folded stepped resonator are buried in the ground to introduce band rejection characteristics. The suggested UWB antenna construction is simpler to develop and is compatible with other portable microwave devices. The simulated findings and the measured results agree fairly well. The developed antenna might therefore be a good option for upcoming portable wireless communication applications.

REFERENCES

1. Chu, Q. X. and Y. Y. Yang, "3.5/5.5 GHz dual band-notch ultra-wideband antenna," *Electron Lett.*, Vol. 44, No. 3, 172–174, January 2008.
2. Yu, D., G. Xie, Z. Liao, and W. Zhai, "Novel dual band-notched omni-directional UWB antenna on double substrates crossing," *Proceedings from 4th IEEE Int. Symp. on Microw., Antenna, Propag. and EMC Technologies for Wireless Comm.*, 95–97, China, November 2011.
3. Mehranpour, M., J. Nourinia, C. Ghobadi, and M. Ojaroudi, "Dual band-notched square monopole antenna for ultra wideband applications," *IEEE Antennas Wire. Propag. Lett.*, Vol. 11, 172–175, February 2012.
4. Sahoo, S., M. N. Mohanty, and L. P. Mishra, "Bandwidth improvement of compact planar antenna for UWB application with dual notch band performance using parasitic resonant structure," *Progress In Electromagnetics Research M*, Vol. 66, 29–39, 2018.
5. Jiang, W. and W. Che, "A novel UWB antenna with dual notched bands for WiMAX and WLAN applications," *IEEE Antennas Wire. Propag. Lett.*, Vol. 11, 293–296, March 2012.
6. Ojaroudi, N. and M. Ojaroudi, "Novel design of dual band-notched monopole antenna with bandwidth enhancement for UWB applications," *IEEE Antennas Wire. Propag. Lett.*, 698–701, May 2013.
7. Ojaroudi, N., M. Ojaroudi, and N. Ghadimi, "Dual band-notched small monopole antenna with novel W-shaped conductor backed-plane and novel T-shaped slot for UWB applications," *IET Microw. Antennas Propag.*, Vol. 7, No. 1, 8–14, January 2013.
8. Azim, R., M. T. Islam, and A. T. Mobashsher, "Design of a dual band-notch UWB slot antenna by means of simple parasitic slits," *IEEE Antennas Wire. Propag. Lett.*, Vol. 12, 1412–1415, November 2013.

9. Liu, H. W., X. Zhan, S. Li, J. H. Lei, and F. Qin, "Dual-band bow-tie slot antenna fed by coplanar waveguide," *Electron Lett.*, Vol. 50, No. 9, 1338–1340, September 2014.
10. Jahromi, M. N., A. Falahati, and R. M. Edwards, "Application of fractal binary tree slot to design and construct a dual band-notch CPW-ground fed ultra-wide band antenna," *IET Microw. Antennas Propag.*, Vol. 5, No. 12, 1424–1430, September 2011.
11. Ojaroudi, M., N. Ojaroudi, and N. Ghadimi, "Dual band-notched small monopole antenna with novel coupled inverted U-ring strip and novel fork-shaped slit for UWB applications," *IEEE Antennas Wire. Propag. Lett.*, Vol. 12, 182–185, January 2013.
12. Abedian, M., S. K. A. Rahim, S. Danesh, S. Hakimi, L. Y. Cheong, and M. H. Jamaluddin, "Novel design of compact UWB dielectric resonator antenna with dual-band-rejection characteristics for WiMAX/WLAN bands," *IEEE Antennas Wire. Propag. Lett.*, Vol. 14, 245–248, September 2014.
13. Siddiqui, J. Y., C. Saha, and Y. M. M. Antar, "Compact dual-SRR-loaded UWB monopole antenna with dual frequency and wideband notch characteristics," *IEEE Antennas Wire. Propag. Lett.*, Vol. 14, 100–103, September 2014.
14. Zhu, F., S. Gao, A. T. S. Ho, C. H. See, R. A. Abd-Alhameed, J. Li, and J. Xu, "Dual band-notched tapered slot antenna using $\lambda/4$ band-stop filters," *IET Microw. Antennas Propag.*, Vol. 6, No. 15, 1665–1673, May 2012.
15. Patel, A. and M. S. Parihar, "UWB monopole antenna with triple-band notch rejection," *IEEE Conference on Information and Communication Technology*, Allahabad, India, 2019, doi: 10.1109/CICT48419.2019.9066183.
16. Abdel-Rahman, A. B., A. Z. El Dein, H. H. El Tamaly, and M. A. Mostafa, "Design of UWB printed monopole antenna with dual band notch filter," *IEEE Middle East Conference on Antennas and Propagation*, Cairo, Egypt, 2010, doi: 10.1109/MECAP.2010.5724191.
17. Mehranpour, M., J. Nourinia, Ch. Ghobadi, and M. Ojaroudi, "Dual band-notched square monopole antenna for ultrawideband applications," *IEEE Antennas Wire. Propag. Lett.*, Vol. 11, 172–175, 2012, doi: 10.1109/LAWP.2012.2186552.
18. Venkata, S. G. and S. R. K. Kalva, "UWB monopole antenna with dual notched bands verified by Characteristic Mode Analysis (CMA)," *Progress In Electromagnetics Research C*, Vol. 121, 39–48, 2022.
19. Koteswara Rao Devana, V. N. and A. M. Rao, "Design and analysis of dual band-notched UWB antenna using a slot in feed and asymmetrical parasitic stub," *IETE Journal of Research*, Vol. 69, No. 1, 284–294, September 2020.
20. Rajkumar, S., K. T. Selvan, and P. H. Rao, "Compact 4 element Sierpinski Knopp fractal UWB MIMO antenna with dual band notch," *Microw. Opt. Technol. Lett.*, Vol. 60, No. 4, 1023–1030, April 2018.
21. Srivastava, K., A. Kumar, B. K. Kanaujia, S. Dwari, and S. Kumar, "A CPW-fed UWB MIMO antenna with integrated GSM band and dual band notches," *Int. J. RF Microw. Comput. Aided Eng.*, Vol. 29, No. 1, January 2019.
22. Koteswara Rao Devana, V. N. and A. M. Rao, "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.*, Vol. 63, No. 2, 556–563, February 2021.
23. Koteswara Rao Devana, V. N. and A. M. Rao, "A compact fractal dual high frequency band notched UWB antenna with a novel SC-DGS," *Analog Integrated Circuits and Signal Processing*, Vol. 107, No. 1, 145–153, April 2021.
24. You, X., C. Du, and Z. Yang, "A flexible CPW 2-port dual notched-band UWB-MIMO antenna for wearable IoT applications," *Progress In Electromagnetics Research C*, Vol. 128, 155–168, 2023.
25. Ahmed, M. F., M. A. G. Mohamed, A. H. A. Shaalan, and W. S. El-Deeb, "A novel compact dual notch with high-gain multi-layer dielectric resonator antenna for ultrawide-band applications," *Progress In Electromagnetics Research M*, Vol. 112, 127–137, 2022.
26. Nan, J., J.-Y. Zhao, and Y. Wang, "A compact dual notch-band frequency reconfigurable UWB monopole antenna," *Progress In Electromagnetics Research M*, Vol. 106, 215–226, 2021.

27. Koteswara Rao Devana, V. N. and A. M. Rao, "A novel dual band notched MIMO UWB antenna," *Progress In Electromagnetics Research Letters*, Vol. 93, 65–71, 2020.