Semi-Elliptical Slotted UWB MIMO Antenna with Multiple Notch Characteristics and High Isolation

Hemalatha T [(1)], Bappadittya Roy* [(1)], Venkata Lakshmaiah Y [(2)], Uma Maheswari [(1)]
(1) School of Electronics Engineering, VIT-AP University, Inavolu, India – 522241
(2) Department of ECE, Narasaraopeta Engineering College, Narasaraopeta - 522601
*bappadittya.roy@vitap.ac.in

Abstract

Wireless communication continues to evolve rapidly, with ongoing advancements in technology, increased data rates, and improved coverage. In this article, a novel compact Semi-Elliptical shaped Slotted (SES) ultra-wideband (UWB) Multiple-Input Multiple-Output (MIMO) antenna with the size of 15 x 30 mm^2 is designed using HFSS software. Two slots were incorporated on the patch elements to generate the notch bands at X-band and Ku-band. A slotted parasitic strip engraved on the Partial Ground Plane (PGP) to generate the third notch at Ka-band and to enhance the isolation. The proposed design achieved the operating bandwidth of 38.15 GHz with triple notch characteristics. It also achieved the reflection coefficient (S_{11}) of -28.26 dB at 17.28 GHz frequency and isolation of ≤ -17 dB for the entire ultra wideband. It also achieved the gain of 8.45 dBi with good radiation pattern.

Keywords: Elliptical, Slotted, UWB, MIMO, Notch, Isolation.

1. Introduction

Ultra Wideband (UWB) is a wireless communication method that uses an extremely wide band of frequencies. Due to its capacity to transmit data over a broad frequency range, UWB technology is well suited for a number of uses, including high-speed data transfer, precise location and positioning, and short-range communication.

Extremely-Wideband MIMO antennas are a critical component of advanced wireless communication systems. These antennas are designed to work within this frequency range and provide enhanced capabilities for various wireless applications, including high-speed data transfer, positioning systems, radar, and more. Researchers in the field explore innovative solutions to the challenges of these antennas like interference mitigation, energy efficiency, miniaturization, etc., and the commercial adoption of UWB MIMO technology in various applications. There have been significant breakthroughs in UWB MIMO technology operating in notch bands in the past year. Typical notch band techniques include: Stub or Parasitic element [1], Defected Ground Structure (DGS) [2], band-stop filter [3], loading filter structures [4], notch band elements like additional dipoles or patches, slots [5], Frequency Selective Surface (FSS) [6]. Some of the most exciting recent developments in this field are Tapered fed slotted antenna with inverted L-shaped slits, to generate notches at IEEE INSAT and WLAN [7], miniaturized 4-port MIMO with a common rhombic slot and electromagnetic band gap [8], Circular slotted radiator with defected ground structure (DGS) for super UWB [9], multi-port central radiator for V2X communications [10].

Current innovations that are particularly fascinating the UWB MIMO technology for interference mitigation includes Chipless UWB-RFID Tags [11], H and U-slots on the truncated patch with gap sleeves [12], four port antenna elements with L-shaped feed line for UWB, etched with two C-shaped slits for WLAN and X-band notch bands [13]. Square ring patch [14], Symmetrical H-shaped DGS [15], Inverted L-shaped branches on the non-grounded portion [16], Electromagnetic band gap structures (EBG) [17] are few isolation enhancement techniques.

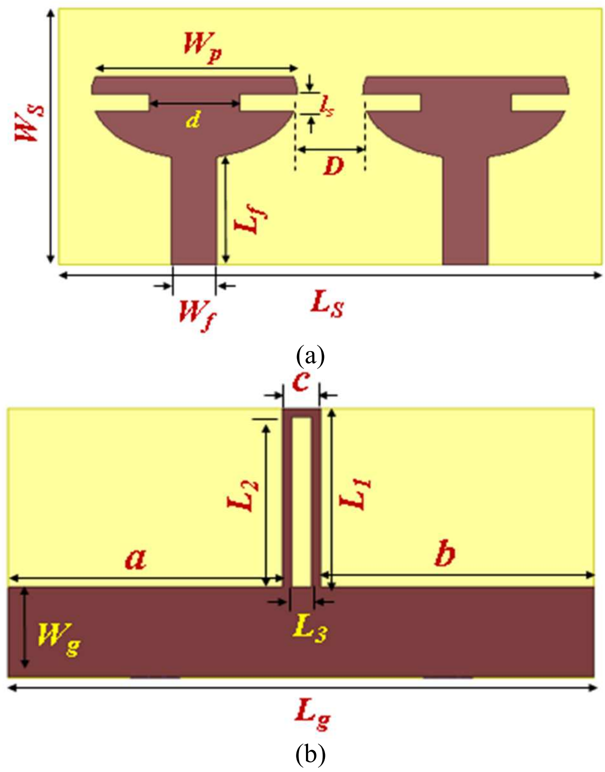


Figure 1. (a) Front view and (b) Rear view of the Proposed SES Antenna with notch characteristics

Table I. Dimensions of the proposed structure (in millimeter)

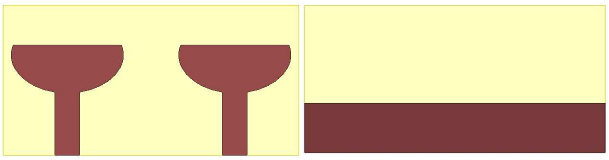
Parameters	L_S	W_S	L_g	W_g	L_1	L_2	L_3	d	W_p	a	b	c	l_s	L_f	W_f	D
Dimensions	*30*	*15*	*30*	*5*	*10*	*9.5*	*1*	*5*	*11*	*14*	*14*	*1*	*1*	*6.29*	*3*	*5.7*

In this paper, a compact SES UWB MIMO antenna is designed with high isolation and triple notch characteristics at X, Ku, Ka bands. Section II describes the proposed antenna design evolution. The achieved result reports are discussed in Section III.

2. Proposed SES UWB MIMO Antenna Design

Figure 1 represents the proposed highly isolated SES MIMO antenna with triple band notched characteristics. The proposed antenna having dimensions of 15 x 30 x 1.6 mm^3, comprises of two semi-elliptical radiating elements with PGP united with parasitic strip to enhance the isolation. The substrate utilized in the proposed antenna is FR4-epoxy having dielectric constant (ϵ_r) 4.4 with tan δ (0.02). The optimized design parameters and its dimensions are tabulated in Table I.

Figure 2 illustrates the geometry of reference antenna, comprising of semi-elliptical extremely wideband MIMO antenna comprising of dual patch elements with PGP. The partial ground's length and width are represented by L_g and W_g respectively.



(a) (b)

Figure 2. Reference Antenna (a) Front view (b) Rear view

3. Results and Discussion

The UWB MIMO designed without slots (as shown in Figure 2) achieved the impedance bandwidth of 34.44 GHz (6.85 to 41.29 GHz) with multiple resonant frequencies and high return loss (|S_{11}|) of 28.73 dB at 14.45 GHz frequency, depicted in Figure 3.

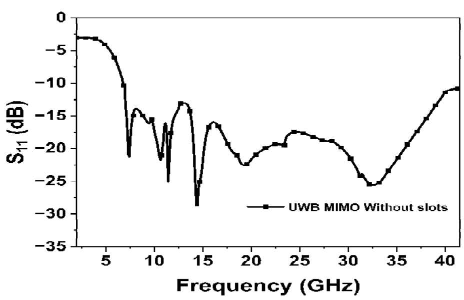


Figure 3. S_{11} (dB) of the reference antenna

A. Notch Band Characteristics

Notch bands play a crucial role in MIMO systems by reducing interference, enhancing signal quality, and improving the collective performance and reliability of the system. Triple notch band features are achieved by carving two slots on the radiating elements and one slot on the parasitic strip united to the partial ground.

Two rectangular slots with width (l_s) = 1 mm acts as a $\lambda/2$ resonator embedded on the patch elements to generate the notch bands of X-band (8.8 to 10.55 GHz), Ku-band (11.53 to 12.99 GHz) with a center frequencies of 9.67 GHz and 12.26 GHz respectively. As a result of rectangular slots on the patch, the way current is distributed on antennas impacts the overall system performance, which includes the bandwidth usage. It enhanced the bandwidth from 34.44 GHz to 38.15 GHz (3.145 GHz to 41.295 GHz).

The third notch in Ka-band (32.49 to 34.93 GHz) with the center frequency 33.71 GHz is achieved by incorporating the slot on the parasitic strip which is united to the PGP to enhance the isolation between the radiating components. This slot acts as $\lambda/4$ resonator. The wavelength can be calculated using (1) [18]. Using (2), the notch bands' center frequency is determined.

$$\lambda = \frac{c}{f\sqrt{\epsilon_{reff}}} \tag{1}$$

$$f_{cNB} = \frac{c}{L \times \sqrt{\epsilon_{reff}}} \tag{2}$$

The achieved impedance bandwidth from 3.145 to 41.295 GHz with three notch bands is shown in Figure 4.

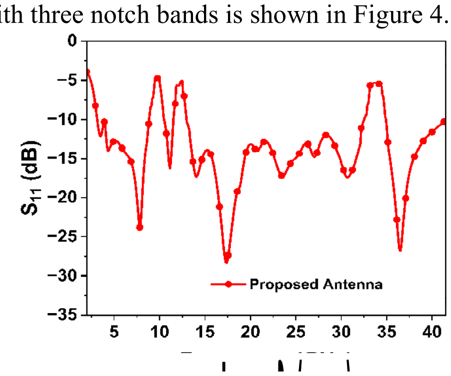


Figure 4. S_{11} (dB) vs. Frequency (GHz) of the proposed SES structure

Isolation is essential for achieving the full potential of MIMO technology by ensuring that the antennas can operate independently and without interfering with each other. A parasitic slotted strip with 2 mm width etched on the ground to increase the isolation to ≤ -17dB. The isolation between the patch elements is represented with S_{12} and S_{21} dB. Figure 5 represents the comparison between the isolation parameters with and without parasitic strip on the PGP. The effect of surface current distribution on the patch elements after incorporation of the parasitic strip is shown in Figure 6.

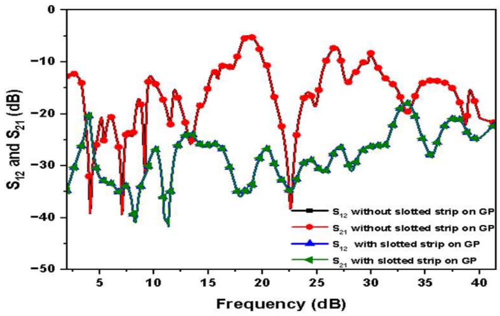


Figure 5. S_{12} and S_{21} comparison plot with and without slotted parasitic strip

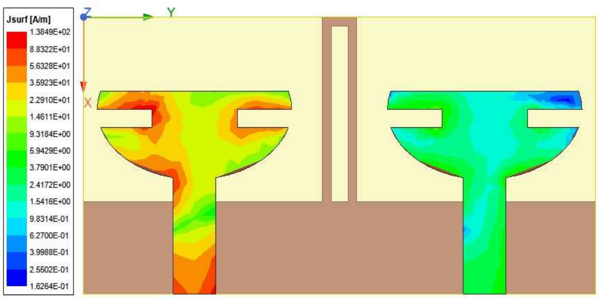
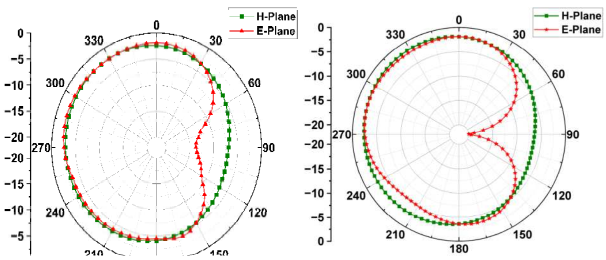


Figure 6. Surface current distribution

The 2d radiation patterns of the proposed antenna at Phi = 0 and 90 deg (E-Plane and H-Plane) for two different frequencies 7.82 GHz and 17.28 GHz is depicted in Figure 7 (a) and (b). The radiation pattern is measured at one port when the other port is connected to 50 Ω matched load.



(a) (b)

Figure 7. 2D Radiation pattern (E-Plane and H-Plane) (a) 7.82 GHz (b) 17.28 GHz

Envelope Correlation Coefficient (ECC) is a metric used to assess the degree of correlation between the magnitude of signals received or transmitted by multiple antennas in a MIMO system. It can be calculated using (3) [19],

$$ECC = \frac{\left|\iint_{4\pi}[E_i(\theta,\phi) \text{x} E_j(\theta,\phi)]d\Omega\right|^2}{\iint_{4\pi}|E_i(\theta,\phi)|^2 d\Omega \text{ x } \iint_{4\pi}|E_j(\theta,\phi)|^2 d\Omega} \quad (3)$$

The proposed design achieved ECC < 0.02, depicted in Figure 8.

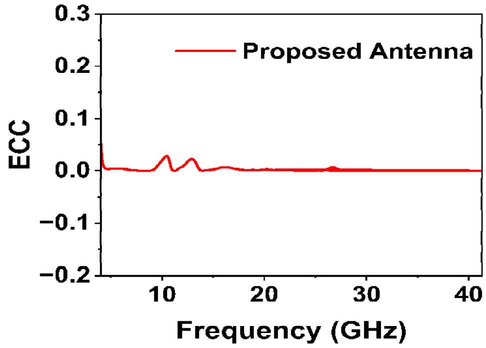


Figure 8. ECC vs. Frequency

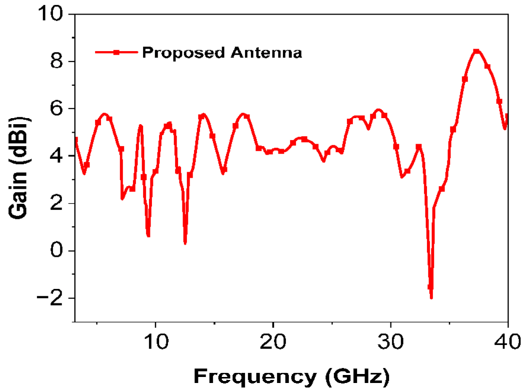
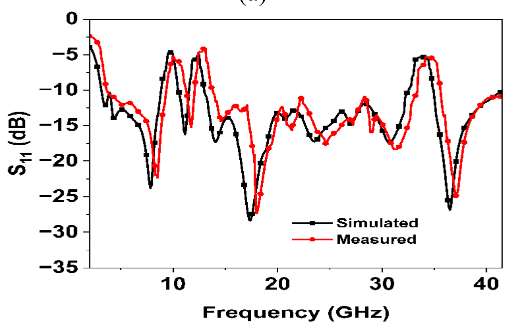


Figure 9. Gain (dBi) vs. Frequency (GHz) of the SES UWB MIMO

Figure 9 represents the gain versus frequency plot of the proposed design. From the figure, it is clearly evident that the proposed antenna achieved 8.45 dBi gain and the lower gain is observed at the notch frequency bands.

(a)



(b)

Figure 10. (a) Fabricated prototype with measurement setup (b) Simulated vs. Measured comparison plot

Table II. Comparative analysis of the proposed antenna with conventional designs

Ref.	Patch Structure	Dimensions (mm^2)	Frequency range (GHz)	Bandwidth (GHz)	Gain (dBi)	ECC	Notch bands
[4]	Square Monopole antennas with T-shaped ground stub	22 x 36	3.1-11	7.9	-10	<0.1	1
[7]	Tapered microstrip slot antenna with slits	18 x 34	2.93-20	17.07	7	<0.01	2
[12]	Gap sleeve truncated edge patch	80 x 80	2.1-20	17.9	5.8	<0.02	2
[19]	Square Monopole antennas with T-shaped ground stub	55.6 x 50.5	1.5-40	38.5	7.6	<0.005	1
Proposed work	Semi-elliptical slotted with slotted parasitic strip	15 x 30	3.145-41.295	38.15	8.45	<0.02	3

The fabricated prototype of the proposed design and the comparison plot of simulated vs. measured results is depicted in Figure 10. The measured and simulated results are in good agreement. Slight variation in the measured result is observed due to the fabrication losses. The comparative parametric analysis of the proposed antenna with other traditional antennas in terms of size of the antenna, bandwidth, gain, ECC and no. of notch bands is illustrated in Table II. From the analysis, it is clearly noticed that the designed antenna is compact in size without compromising the antenna performance parameters.

4. Conclusion

A novel compact SES UWB-MIMO antenna is designed and simulated. The proposed structure achieved the UWB of 38.15 GHz frequency with Triple notch characteristics at X, Ka, Ku bands by etching the slots on the radiating elements. It also achieved the S_{11} of -28.26 dB at 17.28 GHz frequency and by incorporating the slotted parasitic strip on the PGP, achieved isolation of $\leq$ -17 dB for the entire ultra wideband. The proposed structure achieved the gain of 8.45 dBi, suitable for advanced wireless applications. The comparative parametric analysis is listed in Table II.

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References

[1] L. Yang, W. -W. Choi, K. -W. Tam and L. Zhu, ``Novel Wideband Bandpass Filter with Dual Notched Bands Using Stub-Loaded Resonators," in IEEE Microwave and Wireless Components Letters, vol. 27, no. 1, pp. 25-27, Jan. 2017.

[2] S. Mitra and S. Ray, ``Analysis and synthesis of microstrip band-stop notch filter using hairpin DGS," in IEEE Applied Electromagnetics Conference (AEMC), Guwahati, India, 2015, pp. 1-2, doi: 10.1109/AEMC.2015.7509214.

[3] M. Abu Khater, P. Adhikari, M. Thorsell, S. Gunnarsson, B. Edward and D. Peroulis, ``Bandpass Filter With Tunable/Switchable In-Band Interference Rejection," in IEEE Microwave and Wireless Components Letters, vol. 31, no. 10, pp. 1115-1118, Oct. 2021, doi: 10.1109/LMWC.2021.3107304.

[4] L. Liu, S. W. Cheung, and T. I. Yuk, ``Compact MIMO antenna for portable UWB applications with band-notched characteristic," in IEEE Trans. Antennas Propag, vol. 63, no. 5, pp. 1917–1924, May 2015.

[5] S. R. Emadian and J. Ahmadi-Shokouh, ``Very Small Dual Band-Notched Rectangular Slot Antenna with Enhanced Impedance Bandwidth," in IEEE Transactions on Antennas and Propagation, vol. 63, no. 10, pp. 4529-4534, Oct. 2015, doi: 10.1109/TAP.2015.2456905.

[6] S. S. Sampath and R. Sivasamy, ``A Single-Layer UWB Frequency-Selective Surface with Band-Stop Response," in IEEE Transactions on Electromagnetic Compatibility, vol. 62, no. 1, pp. 276-279, Feb. 2020, doi: 10.1109/TEMC.2018.2886285.

[7] E. Fritz-Andrade, J. A. Tirado-Mendez and H. Jardon-Aguilar, "Tapered Fed Compact UWB MIMO-Diversity Antenna With a Dual Band-Notched Characteristics" in IEEE Transactions on Antennas and Propagation, vol. 68, no. 1, pp. 614-614, Jan. 2020, doi: 10.1109/TAP.2019.2950090.

[8] Z. Chen, W. Zhou and J. Hong, "A Miniaturized MIMO Antenna With Triple Band-Notched Characteristics for UWB Applications," in IEEE Access, vol. 9, pp. 63646-63655, 2021, doi: 10.1109/ACCESS.2021.3074511.

[9] S. Rahim, A. A. Elobied, W. Huang and X. -X. Yang, "Super-UWB MIMO antenna with dual band-notched and high gain," in Radio Science, vol. 57, no. 11, pp. 1-9, Nov. 2022.

[10] K. Zhang, Z. H. Jiang, W. L. Zhou, P. Peng and W. Hong, "A Compact, Band-Notched Ultra-Wideband Fully-Recessed Antenna With Pattern Diversity for V2X Communications," in IEEE Open Journal of Antennas and Propagation, vol. 3, pp. 1302-1312, 2022.

[11] S. Jayant, G. Srivastava and M. Khari, "8-Port MIMO Antenna Having Two Notched Bands for Chipless UWB-RFID Tags," in IEEE Journal of Radio Frequency Identification, vol. 6, pp. 355-360, 2022, doi: 10.1109/JRFID.2022.3180196.

[12] V. S. D. Rekha, P. Pardhasaradhi, B. T. P. Madhav and Y. U. Devi, "Dual Band Notched Orthogonal 4-Element MIMO Antenna With Isolation for UWB Applications," in IEEE Access, vol. 8, pp. 145871-145880, 2020, doi: 10.1109/ACCESS.2020.3015020.

[13] S. Jayant and G. Srivastava, "Close-Packed Quad-Element Triple-Band-Notched UWB MIMO Antenna With Upgrading Capability," in IEEE Transactions on Antennas and Propagation, vol. 71, no. 1, pp. 353-360, Jan. 2023.

[14] A. Ramachandran, S. Valiyaveettil Pushpakaran, M. Pezholil and V. Kesavath, ``A Four-Port MIMO Antenna Using Concentric Square-Ring Patches Loaded with CSRR for High Isolation," in IEEE Antennas and Wireless Propagation Letters, vol. 15, pp. 1196-1199, 2016, doi: 10.1109/LAWP.2015.2499322.

[15] Zicheng , Hou Zhang , Qiang Chen , and Tao Zhong, ``Isolation Enhancement in Closely Coupled Dual-Band MIMO Patch Antennas," in IEEE ANTE AND WIRELESS PROP LET, VOL. 18, NO. 8, AUG 2019.

[16] Shoaib, Nosherwan Shoaib, Sultan \& Shoaib, Imran Chen, Xiaodong \& Parini, Clive, ``MIMO antennas for mobile handsets," in IEEE Anten- nas and Wireless Propagation Letters,14. 10.1109/LAWP.2014.2385593.

[17] T. Hemalatha, B. Roy, ``A comparative study on efficient mimo antennas in wireless communication," in Microwave Review, vol. 29 (1) (2023) 33–43.

[18] Keller, R.B., ``Frequency and Wavelength. In: Design for Electromagnetic Compatibility," in \emph{In a Nutshell. Springer, Cham.}, 2023, https://doi.org/10.1007/978-3-031-14186-7$_$4.

[19] Saxena, Gaurav, Priyanka Jain, and Yogendra Kumar Awasthi, ``High diversity gain super - wideband single band - notch MIMO antenna for multiple wireless applications," in \emph{IET Microwaves, Antennas \& Propagation}, 14.1 (2020): 109-119.