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A Four Element UWB MIMO Antenna with Band - Notched Characteristics for Wireless Communication Applications

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Abstract: This study proposes an innovative approach to enhance isolation in a four-element Ultra Wide Band (UWB) range Multiple Input Multiple Output (MIMO) antenna system. The design employs unique rhombic and cross-shaped slot structures to achieve compactness, with dimensions of 34 mm × 34 mm × 1.6 mm. To minimize mutual coupling, the antenna incorporates orthogonally placed feed lines alongside a parasitic strip measuring 17 mm × 1 mm × 1.6 mm. The antenna effectively suppresses interference from specific bands, including WiMAX, WLAN, and X-band, through the integration of L-shaped and C-shaped slits combined with Electromagnetic Band Gap (EBG) elements. Simulation results, verified through practical testing, confirm an operational bandwidth 2 GHz to 12 GHz, excluding the targeted notched bands. The design achieves superior isolation (S11 < -10 dB), a peak gain of 2.5–5 dB, and excellent interference rejection capabilities. These features establish the antenna as a highly efficient option for next-generation UWB-MIMO wireless communication applications.
Keywords: Isolation, UWB-MIMO Antenna, Electromagnetic Band Gap (EBG), Triple Band-Notched Characteristics, Radiator (Microstrip Feed Line), Compact size.

I. INTRODUCTION

The progress in Wireless Communication has leads to the creation of Technologies such as Multiple Input Multiple Output (MIMO) and Ultra Wide Band (UWB), which aim to satisfy the growing need for faster and more efficient data transmission [1]-[2]. MIMO technology is widely acknowledged for its ability to address multipath fading and boost data rates, making it essential for contemporary communication networks. Similarly, UWB technology, known for its extensive frequency range and low power consumption, has diverse applications, including short-range communication, radar, and precise positioning systems [3]-[6]. The combination of MIMO and UWB technologies leverages their unique strengths to enable systems with improved spectral efficiency and greater dependability. However, challenges such as mutual coupling between antenna components and interference with pre-existing communication systems continue to affect system performance, requiring innovative design methodologies to overcome these issues [7]-[12]. To tackle these challenges, the study introduces a Compact UWB MIMO Antenna design. The proposed antenna features a small footprint of 34 mm × 34 mm × 1.6 mm and integrates innovative design elements, including rhombic and cross-shaped slots, parasitic structures, and notched bands. These features contribute to achieving a compact design, improved operational performance, and reduced interference [13]-[17].This study provides a well-researched approach that addresses the key technical challenges faced by UWB-MIMO systems, offering improved performance and reliability for advanced wireless communication applications [18]-[20].

II. ANTENNA DESIGN AND ANALYSIS

The UWB-MIMO Antenna, as shown in Figure 1, features Measurements of 34 mm × 34 mm × 1.6 mm and is fabricated on a substrate.

Key performance enhancements include:

1) Isolation Improvements: Parasitic strips achieve a 4-5 dB reduction in coupling across key frequency ranges.
2) Notched Bands: Slits and EBG structures ensure effective suppression of specific interference bands.
3) Compact Design: The small footprint supports seamless integration into modern communication systems. The antenna's design consists of four microstrip lines arranged orthogonally to each other, which helps expand the impedance bandwidth at lower frequencies. This configuration also improves, the compact design of the antenna leads to high Mutual Coupling between the Antenna elements.

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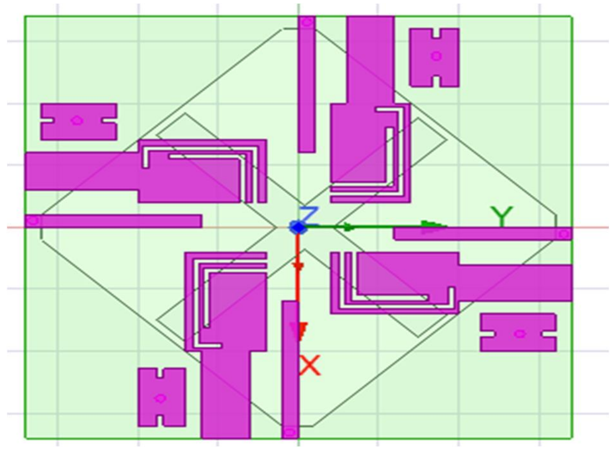
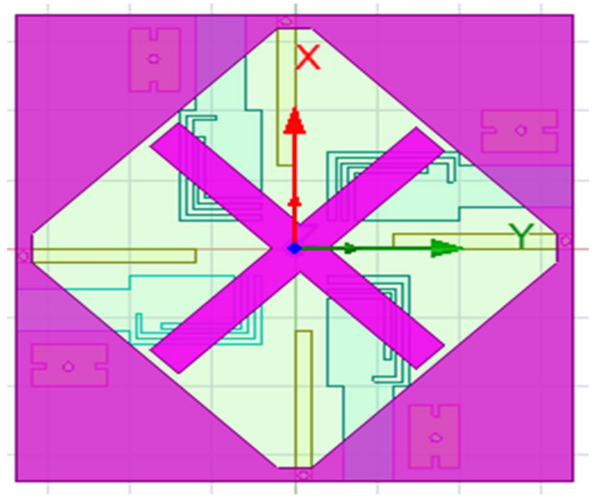
To improve isolation and mitigate this effect, parasitic strips are strategically placed between the adjacent microstrip-fed lines. This approach effectively reduces Mutual Coupling, improves the overall Performance of the Antenna System.



(a)



(b)

Figure 1 : The Geometry of Proposed UWB MIMO Antenna
(a) Top Layer, (b) Bottom Layer

Table 1 : Measurements of Parameters for Proposed UWB MIMO Antenna

PARAMETER	POSITION	AXIS
Substrate	(-17 x -17 x 0) mm	X=34mm Y=34mm Z=1.6mm
Microstrip lines (Radiator)	(17 x -17 x 1.6) mm	X=-7mm Y=3mm
Parasitic strips	(17 x -1 x 1.6) mm	X=-11mm Y=1mm

EBG structure	(17 x -10 x 1.6) mm	X=-4.6mm Y=2.9mm
Rhombic slot	(-17 x -17 x 0) mm	X=34mm Y=34mm
Cross Shaped Slot	(-1 x-11.49 x 0) mm	X=2.5mm Y=22.99mm

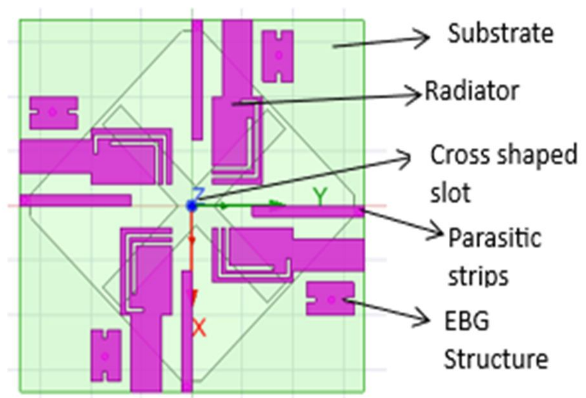


Figure 2: Antenna with name of Parameters

III. DESIGN OF UWB MIMO ANTENNA ELEMENTS

The design features a compact structure that accommodates four microstrip lines arranged orthogonally. This arrangement serves to broaden the impedance bandwidth at lower frequencies and improves the Isolation between the Antenna elements. Although small size of the Antenna could lead to significant mutual coupling, the design includes parasitic strips placed between the adjacent microstrip feed lines to mitigate this issue.

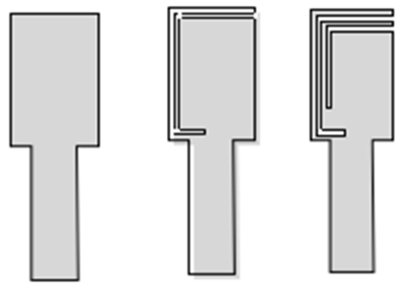


Figure 3: Design of Evolution of Multiple Notched Bands

To improve isolation, additional parasitic strips are placed on top of the substrate between the microstrip lines, supplementing those already located between the microstrip lines. These additional structures act as decoupling elements, leading to a significant reduction in mutual coupling, as shown by the simulated S-parameters. The introduced parasitic strips achieve an isolation improvement of about 5 dB within the 4–6 GHz frequency range and approximately 4 dB within the 5–8 GHz frequency range.
To implement the antenna's triple band-notched behaviour, L-shaped and C-shaped slits are etched into each radiator, and Electromagnetic Bandgap (EBG) structures are strategically positioned near the microstrip feed points. The L-shaped slit is designed to block radiation near the 5.5 GHz frequency, while the C-shaped slit targets radiation at 3.6 GHz.

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Additionally, the placement of EBG structures reduces radiation at 8 GHz, contributing further to the antenna's overall performance by mitigating undesired frequency emissions.

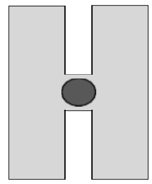
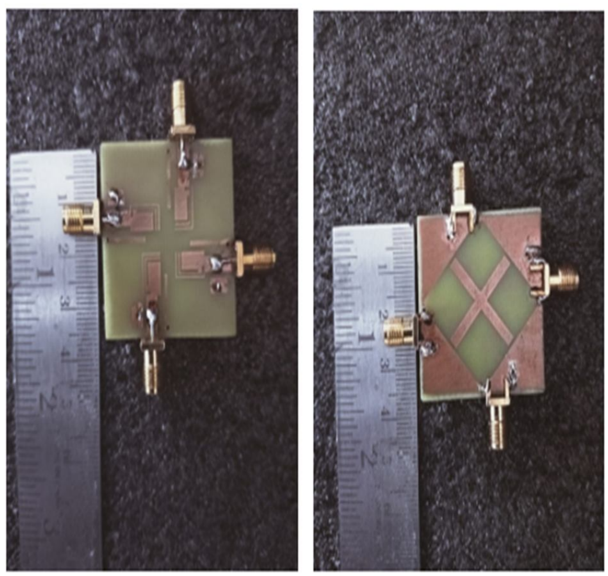


Figure 4: EBG Structure

This design approach effectively addresses challenges such as mutual coupling and unwanted radiation, offering enhanced performance in the desired frequency ranges while maintaining a compact antenna footprint suitable for modern communication systems.



(a) Top layer (b) Bottom Layer

Figure 5: Physical Design of the Proposed Antenna

IV. RESULTS AND DISCUSSION

Thorough testing and simulations were performed to assess the antenna's functionality, leading to significant insights and key results.

A. S-PARAMETERS:

S-Parameters or Scattering Parameters are a tool used to evaluate the performance of Antennas and Electronic Systems. S-Parameters are a set of interconnected measurement that describe how waves reflect in a Network.

S-Parameters help Engineers to understand how efficiently Antennas Radiate or Receive Electromagnetic Waves and how well they matched with a Transmission line.

They can also be used to optimize Antenna designs to achieve Desired Radiation Patterns. S-parameters are a method of representing systems using general wave quantities rather than voltages and currents. The S_11 is also known as the Reflection Coefficient.

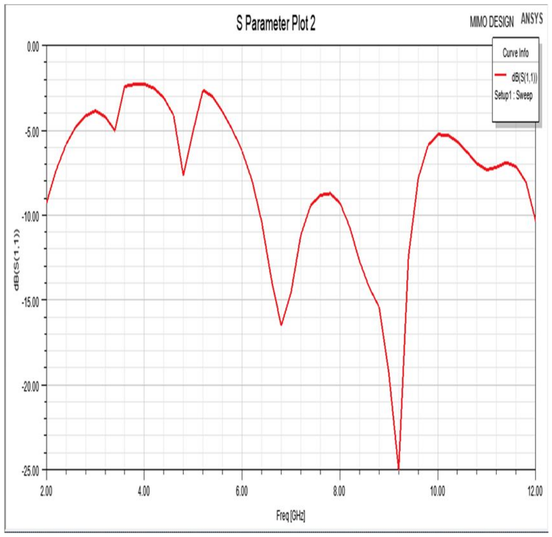


Figure 6: Simulated S11 Parameter

S_11 related to Return Loss. It describes how the waves are Radiated or Transmitted from/through the device.

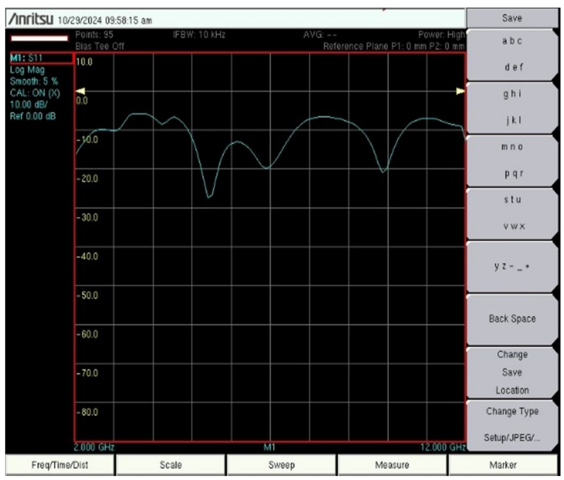


Figure 7: Measured S11 Parameter

In an Antenna, S-Parameters S13, S23, S24, S22 can be Related to Signal Transmission and Reflection measurements.

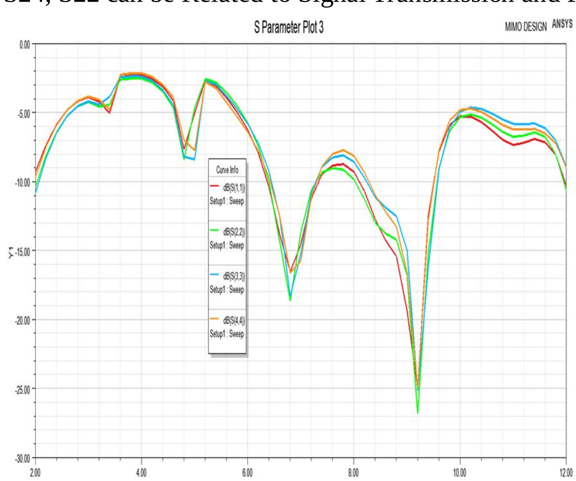


Figure 8: Simulated S-Parameters S11, S22, S33

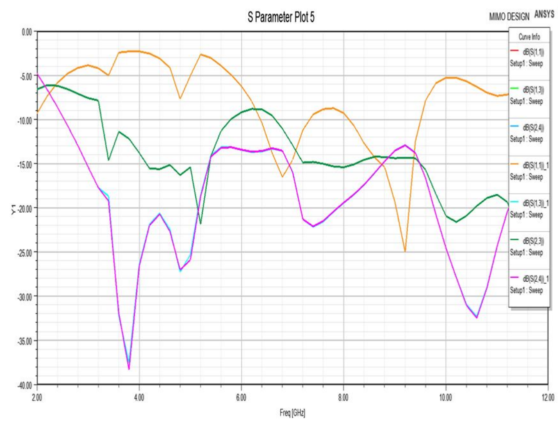


Figure 9: Simulation of S-Parameters S11, S13, S22, S23, S24

Freq [GHz	dB(S(1,1))	dB(S(1,3))	dB(S(2,4))	dB(S(1,1))	dB(S(1,3))	dB(S(2,3))	dB(S(2,4))_1
2	-9.33666	-4.81462	-4.81076	-9.33666	-4.81462	-6.60761	-4.81076
2.2	-7.3669	-6.62997	-6.62734	-7.3669	-6.62997	-6.13841	-6.62734
2.4	-5.87414	-8.61881	-8.61618	-5.87414	-8.61881	-6.20392	-8.61618
2.6	-4.82176	-10.7288	-10.7252	-4.82176	-10.7288	-6.58868	-10.7252
2.8	-4.18203	-12.9571	-12.951	-4.18203	-12.9571	-7.09944	-12.951
3	-3.88712	-15.3741	-15.3638	-3.88712	-15.3741	-7.59432	-15.3638
3.2	-4.21896	-17.7137	-17.7203	-4.21896	-17.7137	-7.86672	-17.7203
3.4	-5.04134	-18.6769	-19.2096	-5.04134	-18.6769	-14.6344	-19.2096
3.6	-2.44567	-32.182	-31.8949	-2.44567	-32.182	-11.3892	-31.8949
3.8	-2.32603	-37.5347	-38.2571	-2.32603	-37.5347	-12.1825	-38.2571
4	-2.31679	-26.3834	-26.579	-2.31679	-26.3834	-13.7819	-26.579
4.2	-2.56116	-21.8673	-21.981	-2.56116	-21.8673	-15.5294	-21.981
4.4	-3.11782	-20.6041	-20.7099	-3.11782	-20.6041	-15.6149	-20.7099
4.6	-4.1482	-22.4326	-22.6526	-4.1482	-22.4326	-15.1417	-22.6526
4.8	-7.69888	-27.2431	-26.9991	-7.69888	-27.2431	-16.292	-26.9991
5	-5.06505	-25.2675	-25.8625	-5.06505	-25.2675	-15.4033	-25.8625
5.2	-2.66037	-18.5447	-18.7304	-2.66037	-18.5447	-21.8541	-18.7304
5.4	-3.05749	-14.0872	-14.2338	-3.05749	-14.0872	-14.1603	-14.2338
5.6	-3.93679	-13.1434	-13.209	-3.93679	-13.1434	-11.289	-13.209
5.8	-4.98149	-13.1409	-13.1537	-4.98149	-13.1409	-9.93243	-13.1537
6	-6.25274	-13.4446	-13.424	-6.25274	-13.4446	-9.19295	-13.424
6.2	-7.94757	-13.6913	-13.6509	-7.94757	-13.6913	-8.82015	-13.6509
6.4	-10.3994	-13.6151	-13.5653	-10.3994	-13.6151	-8.85888	-13.5653
6.6	-13.8065	-13.3024	-13.255	-13.8065	-13.3024	-9.58225	-13.255

Table 2.1 : S Parameters Values

6.8	-16.5195	-13.5528	-13.5385	-16.5195	-13.5528	-11.0503	-13.5385
7	-14.5528	-15.911	-15.9774	-14.5528	-15.911	-12.9173	-15.9774
7.2	-11.197	-21.2855	-21.2812	-11.197	-21.2855	-14.8814	-21.2812
7.4	-9.44339	-22.1333	-22.0795	-9.44339	-22.1333	-14.7988	-22.0795
7.6	-8.83878	-21.5339	-21.469	-8.83878	-21.5339	-15.0206	-21.469
7.8	-8.73706	-20.4322	-20.3851	-8.73706	-20.4322	-15.3139	-20.3851
8	-9.29967	-19.43	-19.3961	-9.29967	-19.43	-15.403	-19.3961
8.2	-10.7203	-18.4885	-18.4563	-10.7203	-18.4885	-15.0813	-18.4563
8.4	-12.7268	-17.3868	-17.3553	-12.7268	-17.3868	-14.5575	-17.3553
8.6	-14.2797	-16.0857	-16.0636	-14.2797	-16.0857	-14.2285	-16.0636
8.8	-15.4098	-14.7305	-14.726	-15.4098	-14.7305	-14.2394	-14.726
9	-19.3371	-13.5158	-13.5321	-19.3371	-13.5158	-14.3876	-13.5321
9.2	-24.9896	-12.8965	-12.9286	-24.9896	-12.8965	-14.3312	-12.9286
9.4	-12.4438	-13.7542	-13.7863	-12.4438	-13.7542	-14.3816	-13.7863
9.6	-7.83673	-16.6327	-16.6533	-7.83673	-16.6327	-15.7015	-16.6533
9.8	-5.91143	-20.7238	-20.7332	-5.91143	-20.7238	-18.4356	-20.7332
10	-5.2808	-24.5606	-24.5708	-5.2808	-24.5606	-20.9198	-24.5708
10.2	-5.30293	-27.8367	-27.8703	-5.30293	-27.8367	-21.5948	-27.8703
10.4	-5.69681	-30.9164	-31.0128	-5.69681	-30.9164	-20.8743	-31.0128
10.6	-6.31768	-32.2739	-32.4429	-6.31768	-32.2739	-19.7857	-32.4429
10.8	-6.97997	-28.9277	-29.0131	-6.97997	-28.9277	-18.8724	-29.0131
11	-7.35249	-24.2742	-24.2982	-7.35249	-24.2742	-18.5133	-24.2982
11.2	-7.19352	-20.3544	-20.3705	-7.19352	-20.3544	-19.3448	-20.3705
11.4	-6.91851	-17.6943	-17.7531	-6.91851	-17.6943	-22.7453	-17.7531
11.6	-7.16433	-17.0187	-17.2106	-7.16433	-17.0187	-29.1637	-17.2106
11.8	-8.06094	-19.5726	-20.0613	-8.06094	-19.5726	-25.7229	-20.0613
12	-10.351	-27.4056	-27.9592	-10.351	-27.4056	-22.1995	-27.9592

Table 2.2 : S Parameters Values

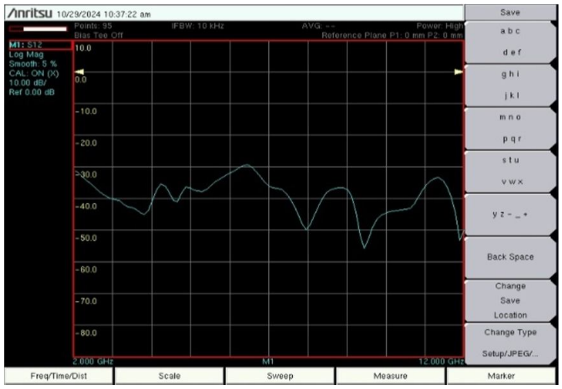


Figure 10: Measured S13 Parameter

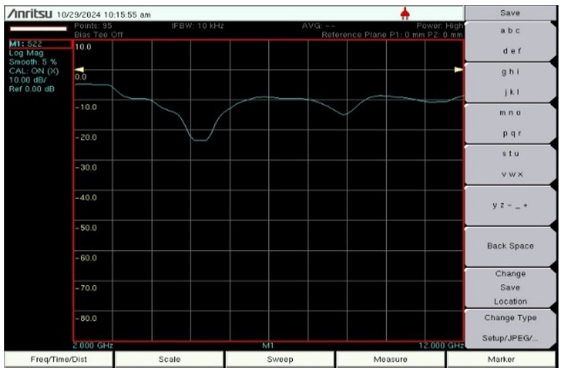


Figure 11: Measured S22 Parameter

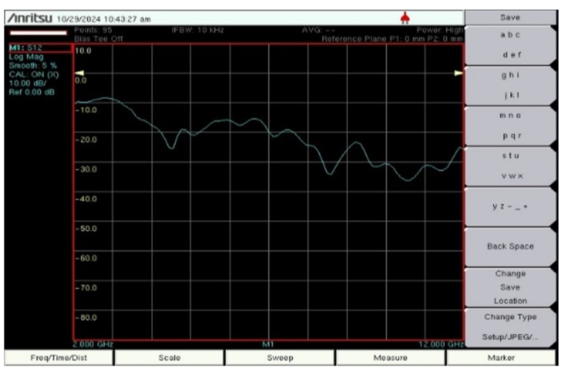


Figure 12: Measured S23 Parameter

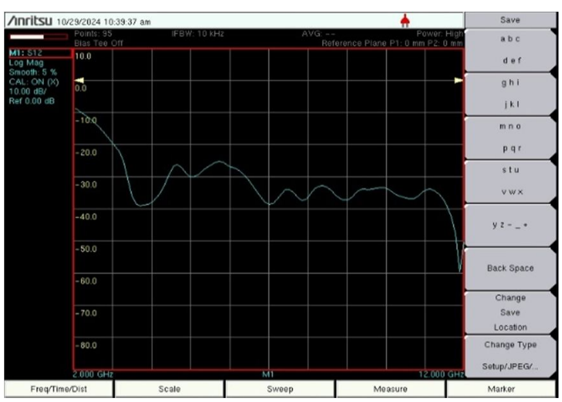


Figure 13: Measured S24 Parameter

S13 and S23 are Scattering coefficients, these are equal if the junction is symmetrical in plane ,S11or S22 indicates a signal reflection measurement.S21or S12 indicate Transmission measurements.

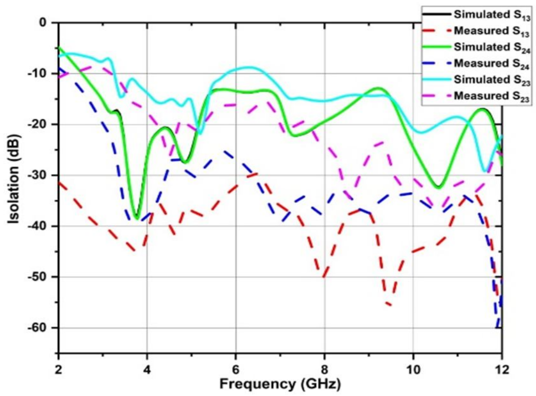


Figure 14: Simulated & Measured S-Parameters

B. SMITH CHART:

The Smith Chart is utilized to represent the antenna's impedance across varying frequencies, facilitating efficient impedance matching.

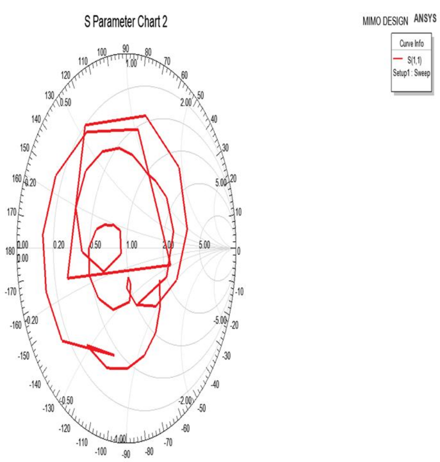


Figure 15: Simulated of Smith Chart

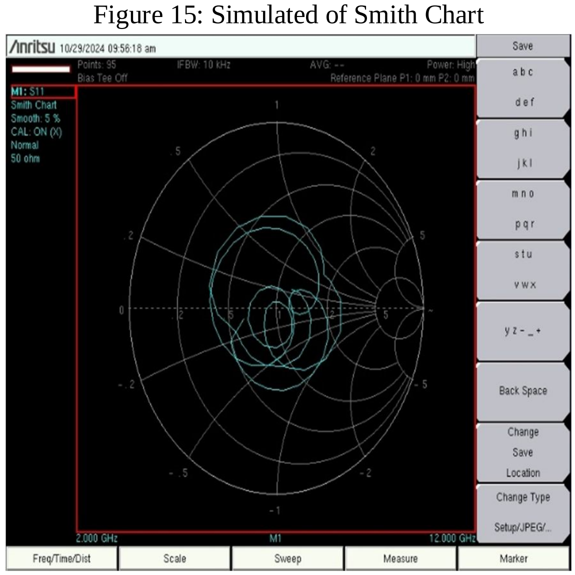


Figure 16: Measured Smith Chart of Antenna

Freq [GHz]	S(1,1) []
2	0.301494348333237 - 0.160010587711828i
2.2	0.307562311297167 - 0.297939281016405i
2.4	0.266973394184666 - 0.432781597293433i
2.6	0.162941737194455 - 0.550387260747123i
2.8	0.00662603101124404 - 0.617836206500206i
3	-0.176733121105692 - 0.614292712524192i
3.2	-0.362271137798551 - 0.497285146443988i
3.4	-0.111043181606735 - 0.548544655990689i
3.6	-0.586514335193316 - 0.474785202699547i
3.8	-0.731694975710716 - 0.223489827916333i
4	-0.762543658517937 + 0.0714043126927831i
4.2	-0.644181154872369 + 0.373508281266361i
4.4	-0.36157821272326 + 0.597523859262398i
4.6	0.105583355050938 + 0.611231124509619i
4.8	0.403183923749101 - 0.0855032974423816i
5	-0.536555177250048 - 0.153735966788368i
5.2	-0.375600243302476 + 0.633150518976992i
5.4	0.175678153783435 + 0.680980087610833i
5.6	0.480568025014791 + 0.415930792455907i
5.8	0.55507514353152 + 0.0973147321813848i

Table 3.1: Smith Chart Values

The Smith Chart is instrumental in achieving the desired frequency response characteristics by adjusting component values and performing impedance transformations.

8	-0.342780013836334 + 0.000671084414033339i
8.2	-0.274173530231237 + 0.0977065861402193i
8.4	-0.195966468285497 + 0.122351683745595i
8.6	-0.153839799119598 + 0.116881141168291i
8.8	-0.118966491486713 + 0.120922477180112i
9	-0.0568876416553448 + 0.0917222232930018i
9.2	-0.0484445852544707 - 0.0286872915167385i
9.4	-0.20635869791864 - 0.119925091103073i
9.6	-0.405319525383143 - 0.0166499107320279i
9.8	-0.461714763984319 + 0.207806336211351i
10	-0.370913525382105 + 0.398561691651097i
10.2	-0.218105532314463 + 0.49734489805481i
10.4	-0.0658755669904953 + 0.514792742072865i
10.6	0.0543952994138459 + 0.48011600891147i
10.8	0.134697323581406 + 0.426972301235278i
11	0.192338160099669 + 0.383376982508587i
11.2	0.265883792616942 + 0.346606742836791i
11.4	0.367599948213062 + 0.261104674945047i
11.6	0.429573068973841 + 0.0870886211349016i
11.8	0.367259988525806 - 0.146291037541991i
12	0.107033766870538 - 0.284217170868572i

Table 3.2: Smith Chart Values

C. VSWR:

The Voltage Standing Wave Ratio (VSWR) remains below, ensuring minimal reflection and maximum signal transfer.

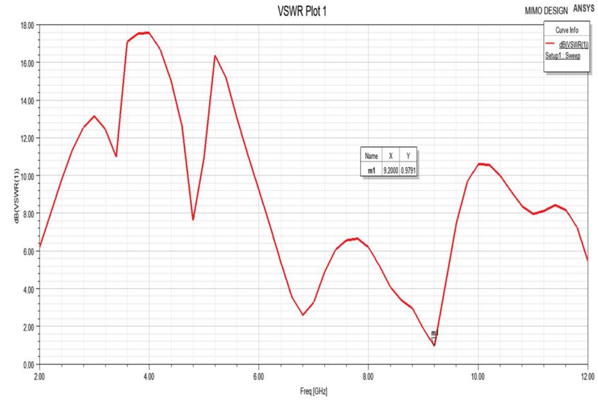


Figure 17: Simulated VSWR of Antenna

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The Voltage Standing Wave Ratio (VSWR) is a vital parameter that evaluates the alignment of impedance between an antenna and a transmission line, providing insight into the effectiveness of power transfer.

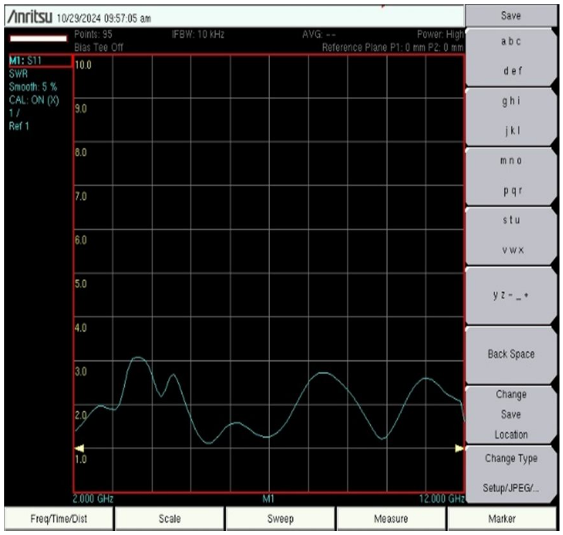

Figure 18: Measured VSWR of Antenna

Freq [GHz	dB(VSWR(1)) [
2	6.177242
2.2	7.951075
2.4	9.740492
2.6	11.35191
2.8	12.5347
3	13.14762
3.2	12.46123
3.4	10.98512
3.6	17.08604
3.8	17.51628
4	17.55043
4.2	16.69077
4.4	15.01244
4.6	12.60262
4.8	7.612298
5	10.94657
5.2	16.36559
5.4	15.17864
5.6	13.04098
5.8	11.08332

Table 4.1: VSWR Values

8	6.205895
8.2	5.206797
8.4	4.087103
8.6	3.399024
8.8	2.975586
9	1.882291
9.2	0.979089
9.4	4.227753
9.6	7.476935
9.8	9.689528
10	10.60481
10.2	10.57065
10.4	9.988029
10.6	9.157263
10.8	8.370396
11	7.966207
11.2	8.135563
11.4	8.439589
11.6	8.16716
11.8	7.263044
12	5.447686

Table 4.2: VSWR Values

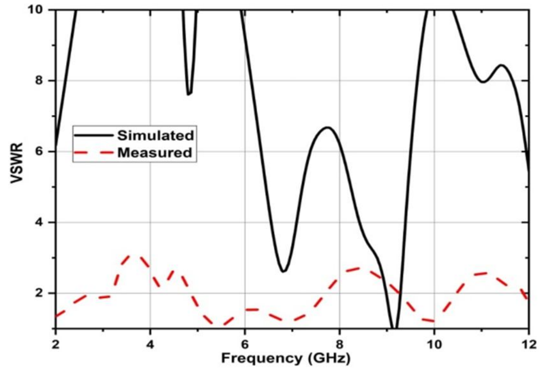

Figure 19: Simulated & Tested VSWR of Antenna

D. IMPEDANCE(Z-PARAMETER):

Antenna impedance consists of two parts: the real part, known as resistance, and the imaginary part, called reactance.

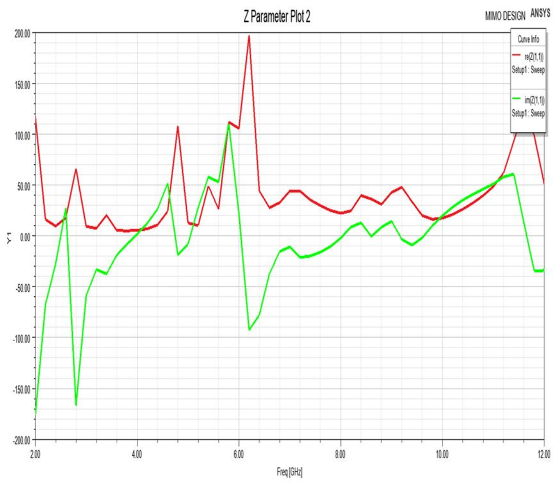

Figure 20: Simulated Impedance of Antenna

E. IMPEDANCE REAL PART:

The real component of the antenna's impedance represents the power that is either emitted as radiation or absorbed by the antenna itself.

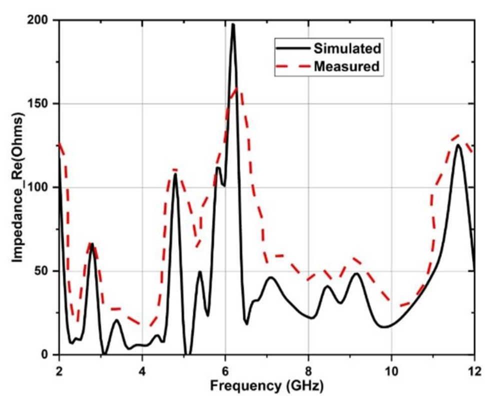

Figure 21: Simulated & Tested real part of Antenna

F. IMPEDANCE IMAGINARY PART:

The Imaginary Part of impedance corresponds to the power stored within the antenna's near-field area.

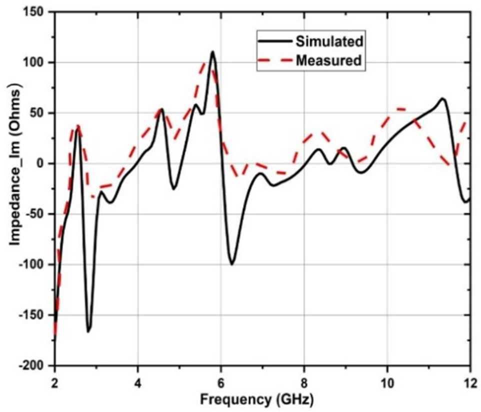

Figure 22: Simulated & Tested Imaginary part of Antenna

G. GAIN:

The Antenna provides a Gain between 2.5 to 5 dB over its operational bandwidth, with consistently high radiation efficiency maintained across the entire range.

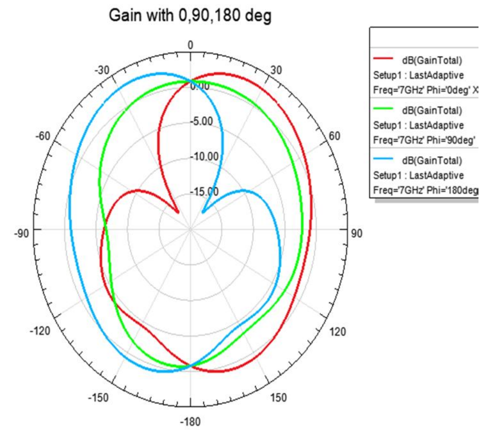

Figure 23: Gain of Antenna

These results highlight the antenna’s capability to deliver reliable performance, high isolation, and efficient signal transmission for modern UWB-MIMO systems.

V. CONCLUSION

This study introduces a unique UWB-MIMO antenna design that effectively tackles challenges related to size, mutual coupling, and interference in wireless communication technologies. The proposed antenna covers an extensive operational frequency varies from 2 GHz to 12 GHz while maintaining excellent isolation and effectively reducing interference from WiMAX, WLAN, and X-band signals.

Key design advancements, such as the inclusion of parasitic strips, specialized notched filters, and innovative slot shapes, play a significant role in achieving the antenna's high performance. Both simulation and experimental testing have confirmed the design's effectiveness, demonstrating its potential for practical deployment in real-world wireless communication scenarios.

For future work, research efforts can focus on enhancing the antenna’s functionality by incorporating reconfigurable elements or developing even smaller, more versatile designs to address the evolving requirements of wireless communication systems.

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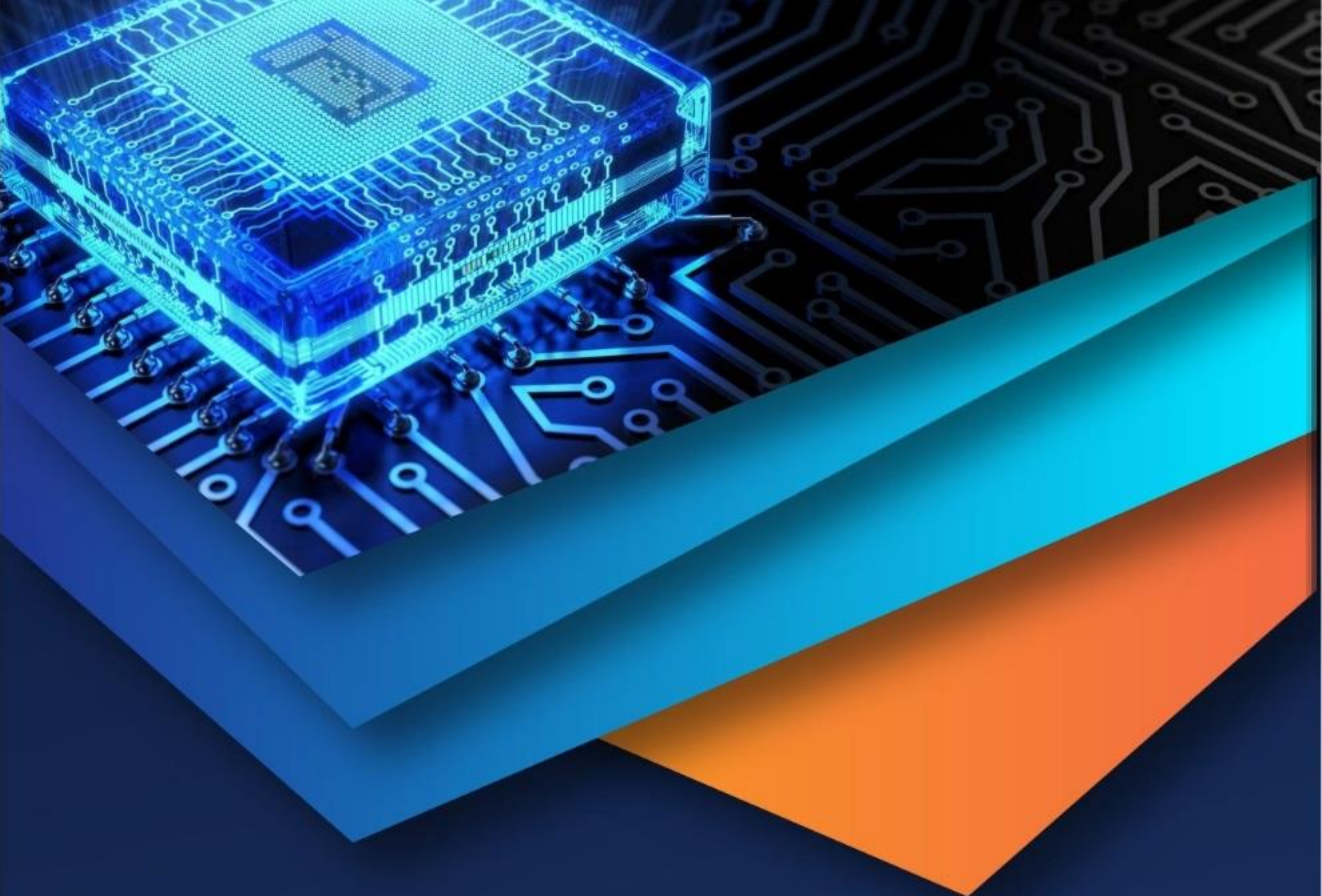

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