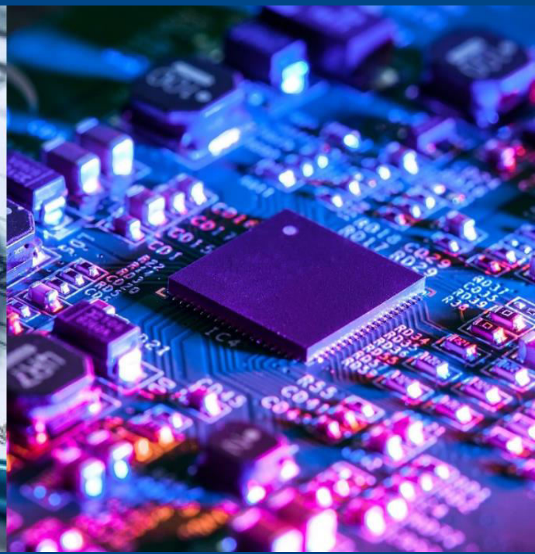
IJMRSET

ISSN: 2582-7219





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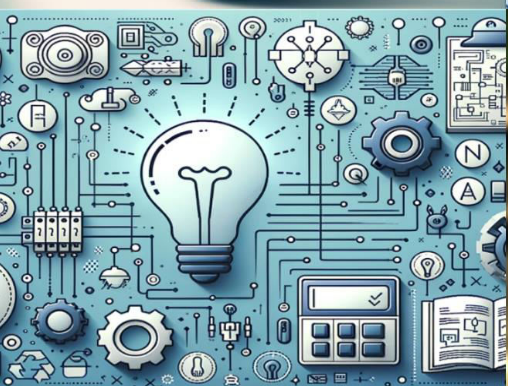

Impact Factor: 8.206

Volume 9, Issue 4, April 2026

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© 2026 IJMRSET | Volume 9, Issue 4, April 2026| DOI:10.15680/IJMRSET.2026.0904155

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

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A Miniaturized Highly Isolated Triple Bandnotched UWB MIMO Antenna

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ABSTRACT: A close-packed 4-port multiple-input multiple- output (MIMO) antenna with three notched bands (NBs) is designed for ultra-wideband (UWB) applications. The presented antenna contains four monopole antenna elements (AEs) with rectangular radiators, each fed by an L-shaped microstrip line.

The compact size of 35.9 × 35.9 × 0.8 mm is attained by cropping the lower axis of the antenna and optimization. The isolation greater than 19 dB is accomplished by the orthogonal direction of AEs and cross-shaped decoupling structure (CSDS). The designed antenna can realize wireless local area network (WLAN) and X- band NBs by etching two C-shaped slits from each radiator and Worldwide Interoperability for Microwave Access (WiMAX) NB by introducing an L-shaped slit in the ground. By placing these NBs in appropriate positions, their efficiencies are decreased for their better rejection. The value of $|S_{ii}| < -10$ dB is from 3.2 to 10.8 GHz (except for three NBs). Also, the 4-port MIMO antenna is upgraded to a 16-port MIMO antenna by arranging the four identical 4-port MIMO antennas side by side with a small gap of 8 mm. The upgraded antenna gives bandwidths from 3.38 to 10.56 GHz with three NBs, isolation >20.9 dB, and size 79.8 × 79.8 mm^2, which is appropriate for future wireless communications.

KEYWORDS: Envelope correlation coefficient (ECC), iso- lation, multiple-input multiple-output (MIMO), notched band (NB), ultra- wideband (UWB).

I. INTRODUCTION

Ultra-wideband (UWB) technology is widely used due to its high data rate, large bandwidth, and low cost, especially in short-range communication, tracking, and radar. However, UWB antennas suffer from interference with existing bands like WiMAX, WLAN, and X-band, which necessitates the use of notched bands (NBs) to suppress these frequencies. Various techniques such as resonators, metamaterials, slots, stubs, and filter structures are used to create NBs. Recently, UWB antennas have been integrated with MIMO technology to improve channel capacity, data throughput, and reduce multipath fading. To enhance isolation between antenna elements in MIMO systems, methods like diversity techniques, defected ground structures, parasitic elements, neutralization lines, electromagnetic bandgap structures, and decoupling structures are commonly employed.

Low mutual coupling, compact size, and effective notched band (NB) performance are key challenges in designing four- port UWB MIMO antennas. As antenna size decreases, isolation between antenna elements degrades, affecting performance and making it difficult to achieve strong NB rejection in a limited space. Previous works either do not report NB efficiency or show poor rejection, with some antennas having positive gain and moderate efficiency at NB frequencies, indicating unwanted radiation. Although a few designs achieve low efficiency and gain at NBs, they suffer from larger size. Overall, existing designs fail to effectively suppress all three NBs, as indicated by non-zero gain and average radiation efficiency at the notched frequencies.

Increasing the number of antenna elements (AEs) in UWB MIMO systems improves link reliability and system robustness. Recent designs have explored antennas with more than four AEs, using techniques like defected structures, metallic vias, fractal geometries, and modified ground planes to enhance isolation and impedance matching. Some works achieved notched bands (NBs), but only limited designs include them, and even then, important bands like WiMAX are often missing.Additionally, many of these antennas are relatively large in size. Overall, compact UWB MIMO antennas with more than eight AEs and effective NBs for commonly used bands have not been successfully.The main contributions of the proposed 4-port antenna are explained as follows.

© 2026 IJMRSET | Volume 9, Issue 4, April 2026| DOI:10.15680/IJMRSET.2026.0904155

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| ESTD Year: 2018|

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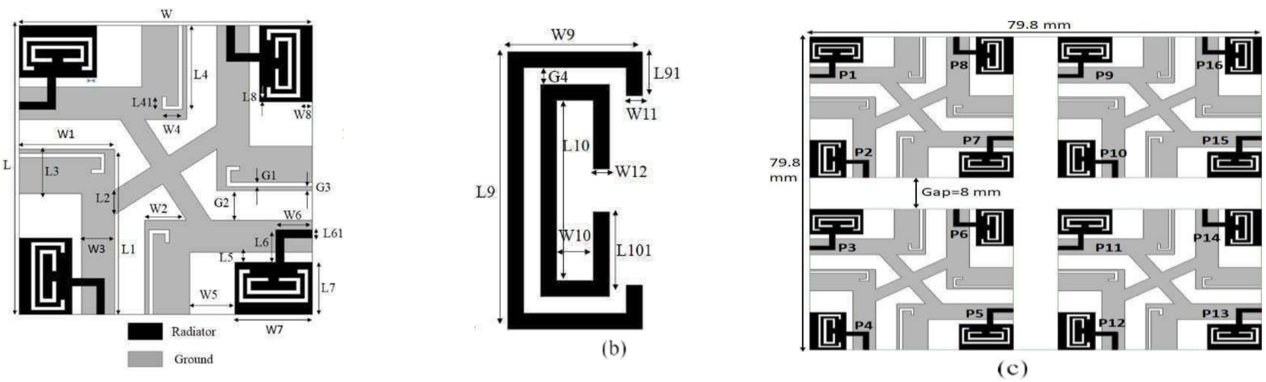
1) The antenna size is reduced using a simple miniaturization technique by trimming the lower portion (bottom axis). The position of this cut is optimized to balance compact size and good reflection coefficient, resulting in a 24.07% size reduction in AE2 compared to AE1.
2) Effectively Rejected Notched Bands (NBs): Notched bands are created by introducing an L-shaped slit in the ground (for 3.5 GHz WiMAX) and two C-shaped slits in the patch (for 5.5 GHz WLAN and 7.5 GHz X-band). The slit dimensions are designed as λ/4 (L-slit) and λ/2 (C-slits) resonators. Parameters G3 and W8 are optimized to minimize radiation at these bands. As a result, low radiation efficiency (46.7%, 34.8%, 38.1%) and negative gain (−4,−1.3, −3.1 dB) are achieved, ensuring effective rejection.
3) Cross-Shaped Decoupling Structure (CSDS) for High Isolation:A cross-shaped decoupling structure is connected to the four ground planes to improve isolation. It creates an additional coupling path that generates an opposite current, which cancels the original mutual coupling between antenna elements. This significantly reduces interference and achieves a minimum isolation of about 19 dB.
4) MIMO Upgradability:The proposed design can be easily extended from a 4-port to a 16-port MIMO antenna by arranging identical elements horizontally or vertically. This increases transmission capacity, improves link reliability. and provides flexibility for future wireless systems, with the possibility of further expansion.



PM	OV(M M)	PM	OV(M M)	PM	OV(M M	PM	OV(M M)
L	35.9	W	35.9	W4	2.5	L5	1.2
L1	20.5	W1	11.7	W5	5.5	L6	4
L2	3	W2	5.1	W6	4.5	L61	1
L3	5.5	W3	4	W7	9.5	L7	6.5
L4	10.5	W8	1.5	W12	0.5	L8	0.5
L41	1.625	W9	4.1	G1	1.5	L9	8.5
W10	1.1	G2	3.7	L91	1.35	L101	2.6
W11	0.5	G4	0.5	L10	5.5	G3	0.5

➢ PROPOSED MIMO ANTENNA STRUCTURE

The proposed 4-port UWB-MIMO antenna is built on an FR4 substrate (εr = 4.4, thickness 0.8 mm, tanδ = 0.02) and consists of four orthogonally placed L-shaped microstrip feeds, four rectangular radiators, and a cross-shaped decoupling structure (CSDS) connected to L-shaped ground planes. Three notched bands (WiMAX, WLAN, and X-band) are achieved by introducing slits in the ground and patch. The design is further extended to a 16-port MIMO antenna by arranging four identical 4-port units side by side with an 8 mm gap.

➢ 4-PORT UWB-MIMO ANTENNA DESIGN

The evolution of the 4-port UWB MIMO antenna is carried out in three stages. Initially (MIMO 1), four UWB antenna elements are placed orthogonally, achieving a bandwidth of 3.48–11 GHz with isolation greater than 15 dB. In the next stage (MIMO 2), a cross-shaped decoupling structure (CSDS) is added to the ground, which improves isolation to more than 17.5 dB but slightly reduces the bandwidth to start from 3.8 GHz due to impedance mismatch at lower frequencies. To overcome this, the patch and ground are modified in MIMO 3 to restore the desired bandwidth.

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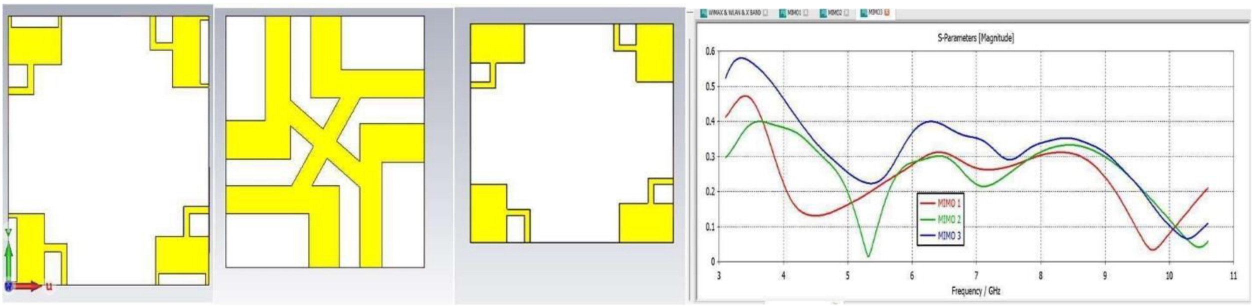

a) MIMO 1 b) MIMO 2 c)MIMO 3 d) |S11|

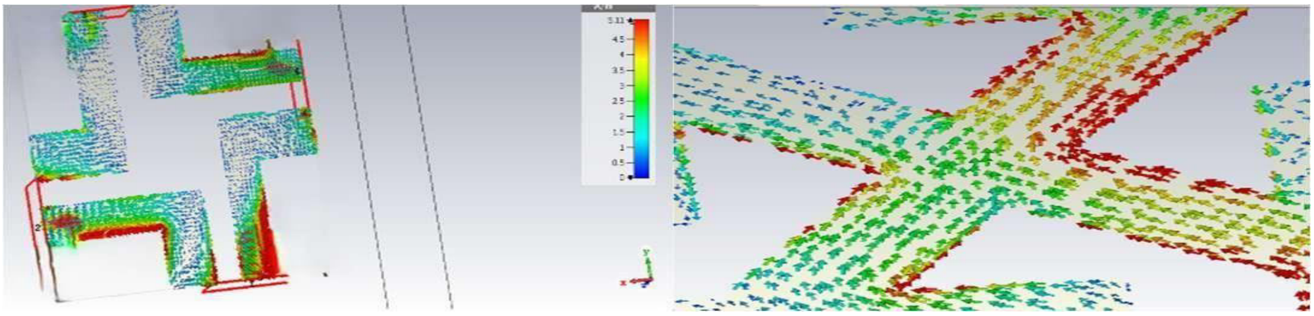

Fig. 2. (a) MIMO evolution stages (b) |S11| (c) Surface vector current distribution of MIMO with and without CSDS at 4.5 GHz.

Analysis of S-parameters shows that the CSDS slightly improves isolation between adjacent ports and significantly enhances isolation between diagonal ports (especially around 4.5 GHz). Current distribution results reveal that without CSDS, strong currents are induced in neighboring elements, causing high coupling. With CSDS, an opposite (reverse) current is generated, which cancels the original coupling current. This reduces mutual coupling and achieves high isolation between closely spaced antenna elements

II. DESIGN FOR REJECTION OF THREE NARROW BANDs

For rejecting the interference of narrow bands within the UWB range, the NBs are designed by adding two C-slits on each patch and an L-slit on each ground plane.

Designing of Etched Slits:The design steps for slits are displayed in Fig. 3(a). An NB from 3.4 to 3.8 GHz (centered at 3.55 GHz) is obtained by etching an L-slit on each ground of AE. The L-slitis referred to as a λ/ 4 resonator, and the slit length can be measured as

$$\lambda = \frac{c}{4f\sqrt{\frac{\varepsilon r + 1}{2}}}$$

The NBs from 5.2 to 5.9 and 7.3 to 7.85 GHz, which are centered at 5.5 and 7.5 GHz, are obtained by etching two closely spaced C shaped slits on each radiating patch of AE. The length of the two C-shaped slits is equal to a halfwavelength resonator, which can be calculated as

$$\lambda = \frac{c}{2f\sqrt{\frac{\varepsilon r + 1}{2}}}$$

Fig. 4(b) shows the second and third NBs that are generated near 5.5 and 7.5 GHz , respectively. The formulabased and optimized length of the slit is compared in Table II. Without loss, the value of VSWR at 3.5,5.5, and 7.5 is 10.9, 18.5,

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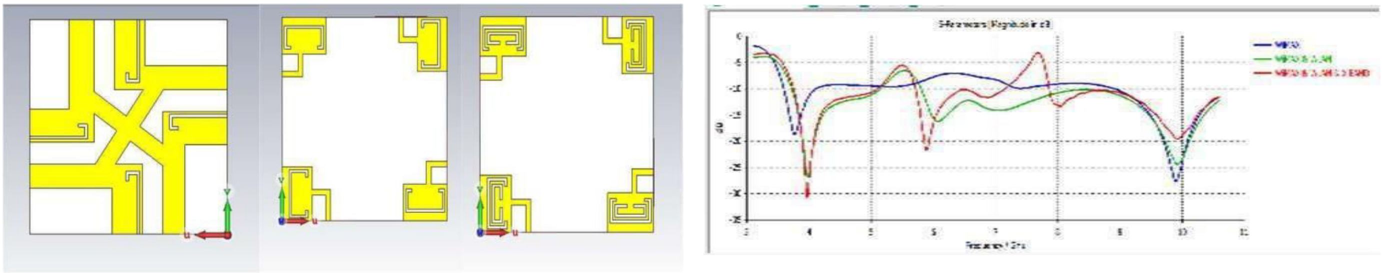
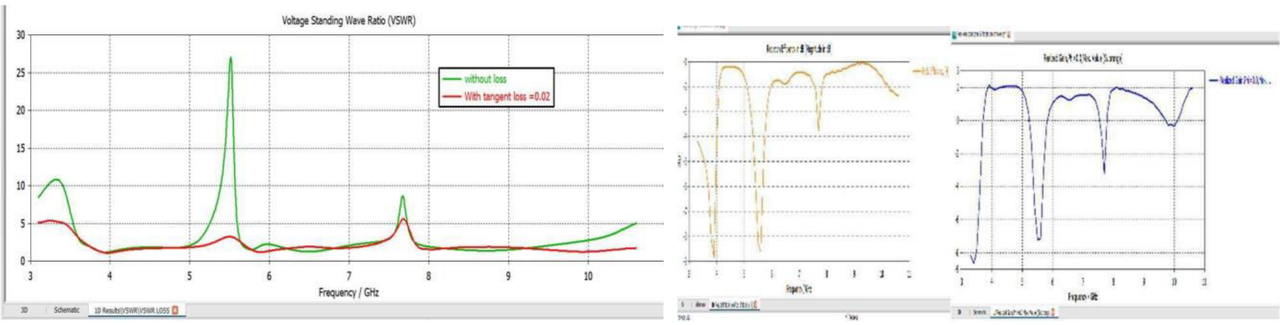
and 13.8, respectively . The value of VSWR with loss tangent = 0.02 at 3.5, 5.5, and 7.5 GHz is 7.85, 6.36, and 4.57, respectively, as displayed in Fig. 3(c) Parametric Analysis for Desired NBs Fig. 4(a) and (b) indicates the influence of the length of the G3 and W8 on the efficiency of the NBs, respectively. When the G3 length is reduced a) from 1.5 to 0.5 mm, the efficiency of the WiMAX NB is decreased from 60.7% to 5.6%. In addition, when the W8 length is changed from 0.5 to 1.5 mm, the efficiency of the WLAN NB is decreased from 43.05% to 34.4%, and the efficiency of the X-band NB is reduced from 45.7% to 37.4%. The generation of notched bands (NBs) is explained using current distribution on the antenna. When Port 1 is excited at the NB frequencies, the surface current concentrates around the slits. At 3.5 GHz, strong current flows around the L-shaped slit in opposite directions on its edges, which cancels radiation and suppresses signal transmission. Similarly, at 5.5 GHz and 7.5 GHz, the currents around the C-shaped slits flow in opposite directions, resulting in minimal radiation. The current concentration around specific slits (L-slit for 3.5 GHz, outer C-slit b) for 5.5 GHz, and inner C-slit for 7.5 GHz) confirms that each slit is responsible for rejecting its corresponding frequency band.



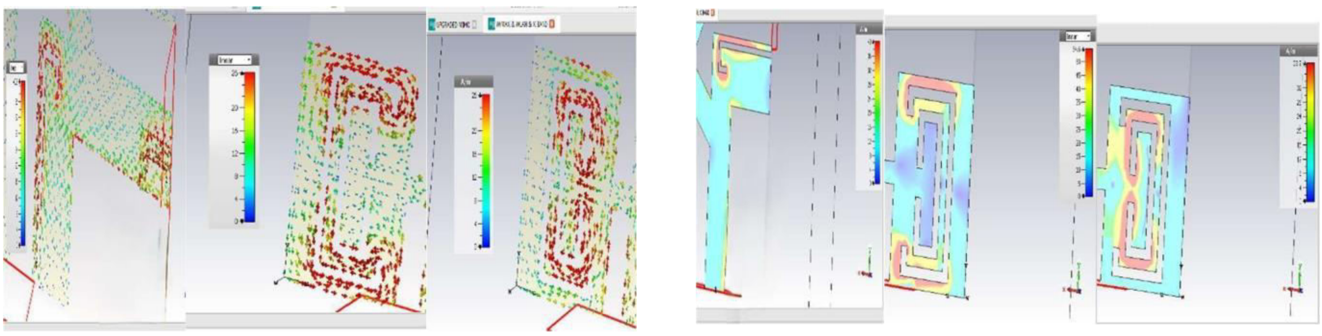
a) b)



b) d)

fig 3.(a)NB design ,(b) S-parameters with NBs, (c) VSWR.(d) a) Peak realized gain. And Radiation efficiency

At 3.5GHZ At 5.5GHZ At 7.5ghz At 3.5GHZ At 5.5GHZ At 7.5ghz



a) b)

Fig. 6. (a) Vector current distribution. (b) Surface current distribution of the presented antenna.

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- 4-PORT MIMO ANTENNA RESULTS AND DISCUSSION

Fig. 6 shows the performance of the designed 4-port UWB MIMO antenna. The reflection coefficient (|S11|) is below −10 dB over 3.2–10.8 GHz, except at the three notched bands (3.4–3.8, 5.2–6.4, and 7.1–8.8 GHz). The antenna achieves high isolation of more than 19dB. The gain ranges from 1 to 4.7 dB in the operating band, while it drops to negative values (−8.6, −3.5, −1.39 dB) at the notched bands, confirming effective signal suppression. Similarly, radiation efficiency is high (87.5%–94.5%) in the passband but significantly reduced (46.7%, 34.8%, 38.1%) at WiMAX, WLAN, and X-band, indicating proper rejection of unwanted frequencies.

Fig. 7 displays the 2-D radiation patterns of the presented antenna at phi = 0◦ and phi = 90◦ when Port 1 is energized at 3.3, 4.5, 6.5, and 9.5 GHz. Because of the symmetrical design of the antenna, the radiation patterns of Port 2–Port 4 are identical to that of Port 1. The radiation patterns are quite stable around low frequencies. In the rest of the frequency range, the radiation characteristics modify due to the CSDS. The envelope correlation coefficient (ECC), an important MIMO diversity parameter, is calculated using radiation patterns. The results show that ECC remains below 0.49 for both adjacent and diagonal antenna elements over the 3–11 GHz range. This indicates low correlation between elements, which is within cceptable limits, ensuring good diversity performance and reliable operation of the antenna as an effective MIMO system.

III. UPGRADED MIMO ANTENNA RESULTS AND DISCUSSION

The proposed design is extended to a 16-port UWB MIMO antenna by arranging four identical 4-port antennas side by side with an 8 mm gap, without altering the original structure or degrading performance. Due to the symmetric arrangement, certain antenna element pairs exhibit identical S-parameters, and reciprocity is maintained (|Sij| = |Sji|). The upgraded antenna achieves a wide bandwidth of 3.38–10.56 GHz with three notched bands. It also provides improved isolation greater than 20.9 dB, which is higher than the 4-port design due to increased spacing and modified current distribution. Overall, the antenna maintains good gain and efficiency while offering enhanced performance and scalability. The upgraded 16-port MIMO antenna provides a gain of 1.4–5.1 dB in the operating band, with low gain at notched bands(−8.1,−2.47,−1dB), confirming effective rejection. Radiation efficiency is high (87%–93%) in the passband and reduced (33.6%, 30%, 36.7%) at WiMAX, WLAN and X-band. The radiation pattern remains similar to the 4-port design, showing that the antenna can be expanded from 4 to 16 ports with minimal performance change. The ECC of the upgraded 16-port MIMO antenna is less than 0.36 over the 3–11 GHz range, indicating low correlation between adjacent elements and good diversity performance.

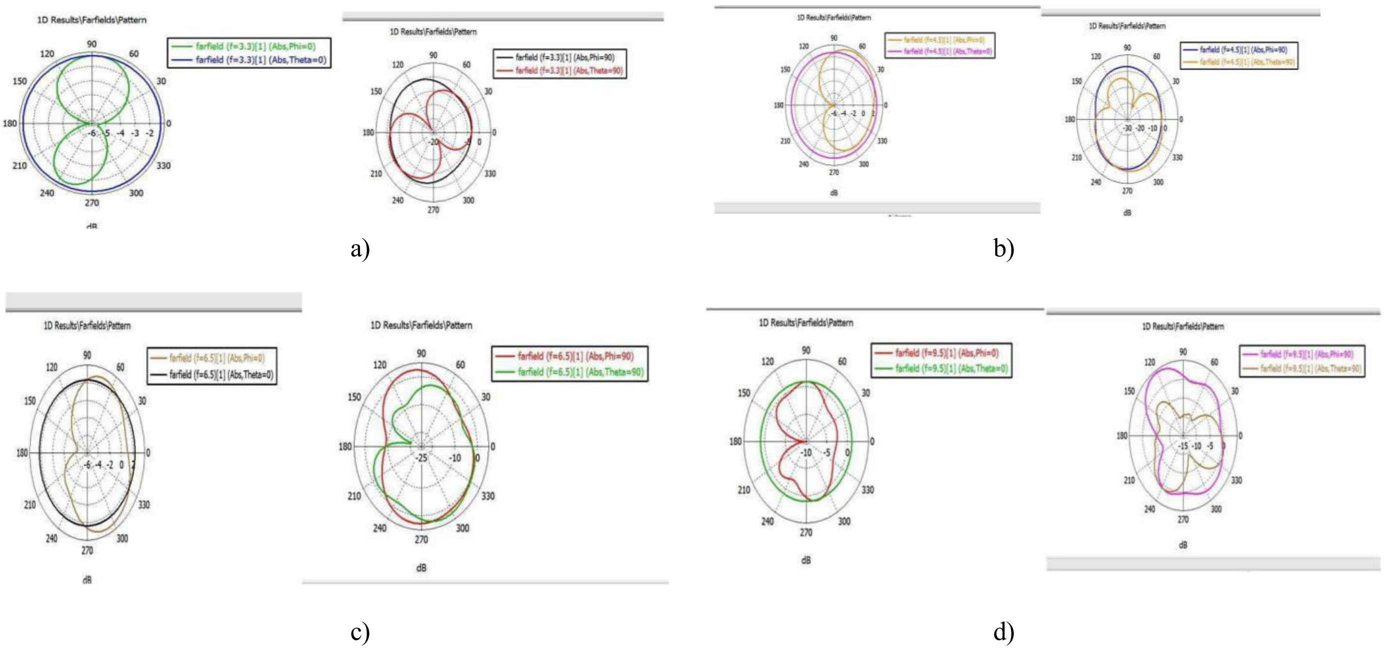

Fig.8.Simulation and measurement radiation patterns. At (a) 3.3, (b) 4.5, (c) 6.5, and (d) 9.5 GHz.

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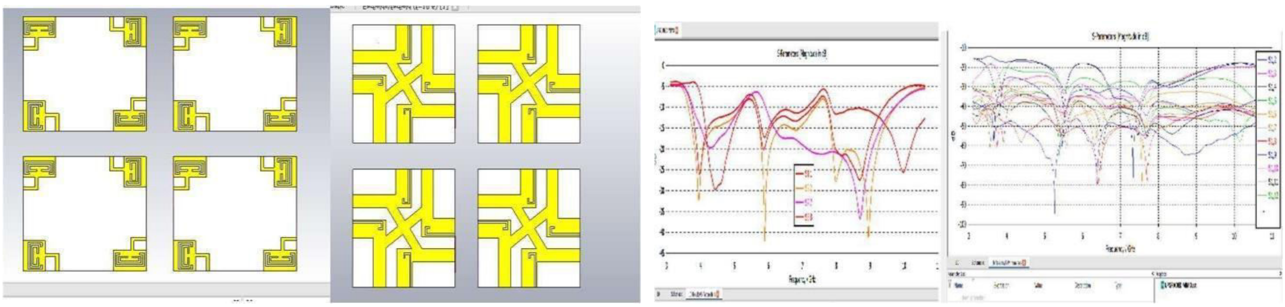
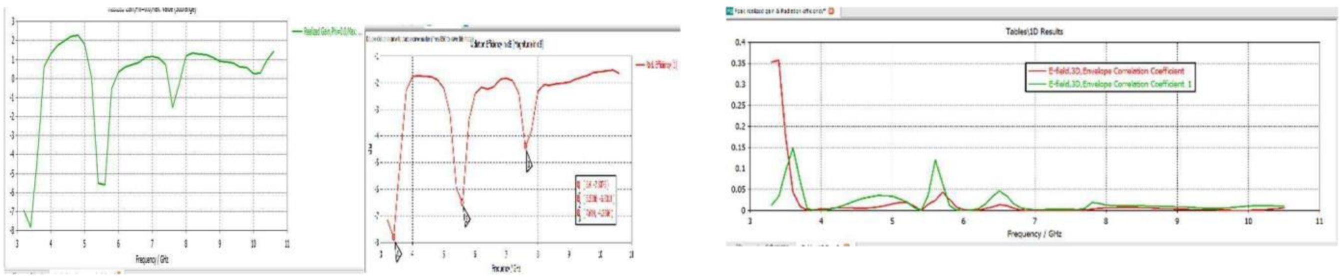


a) b)



c) d)

Fig. 8 Upgraded MIMO antenna. (a) Fabricated structure, (b) measured reflection coefficient, measured isolation, (c) measured gain, and radiation efficiency . (d) ECC varies with frequency

- COMPARATIVE ANALYSIS

Compared to existing works, the proposed UWB antenna is more compact and achieves three well-rejected notched bands with high isolation. The 4-port design can be easily upgraded to a 16-port MIMO antenna without performance loss, in bot horizontal and vertical arrangements. The key novelty lies in its compact size, effective NB rejection, high isolation, and scalable design, which has not been previously reported for a 16-element UWB-MIMO system.

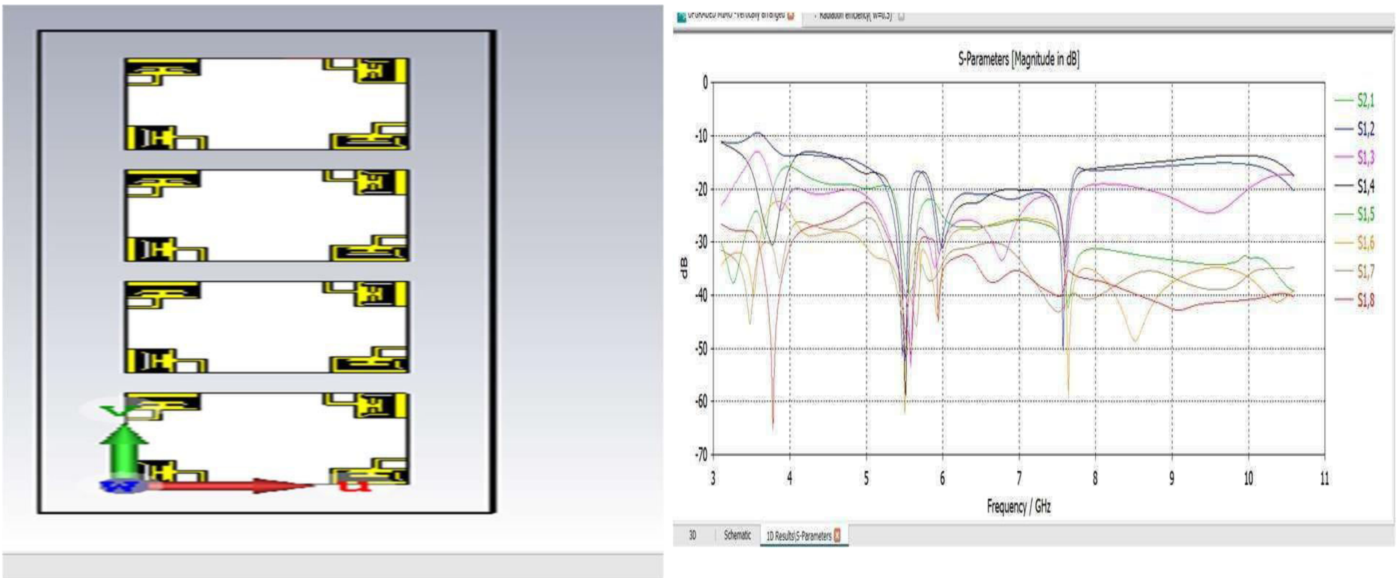


Fig. 10 (a) Vertically arranged four-port MIMO antennas. (b) Simulated reflection coefficients

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➢ Characteristic Mode Analysis (CMA)

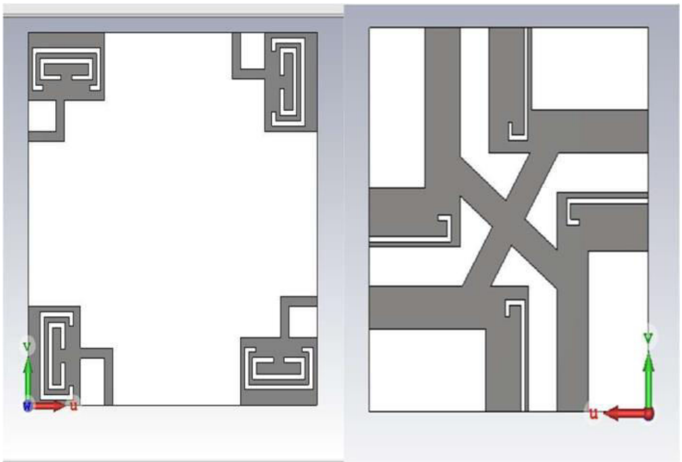
CharacteristicModeAnalysis (CMA)isapowerfultechniqueused to analyze and design antennas based on their natural resonant modes. It is derived from the Computational Electromagnetics and helps in understanding the current distribution on the antenna structure without requiring excitation sources The key parameters used in CMA are:

1. Eigenvalue (λ):Eigenvalue indicates the resonance behavior of each mode.λ = 0 → Mode is at resonance λ > 0 → Mode is inductive λ < 0 → Mode is capacitive A mode resonates when the stored electric and magnetic energies are equal.

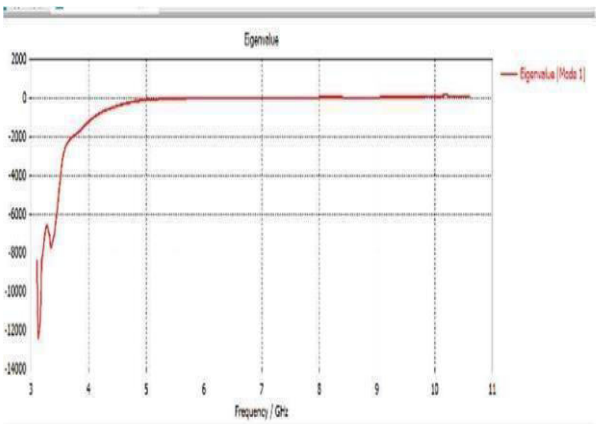
2. Characteristic Angle (α): haracteristic angle provides information about the phase of the mode. $\alpha = 180\circ - \tan -1(\lambda)$ d) α

= 180° → Resonance condition α between 90° and 180° → Inductive region α between 180° and 270° Capacitive region This parameter helps identify the resonant frequency of each mode.

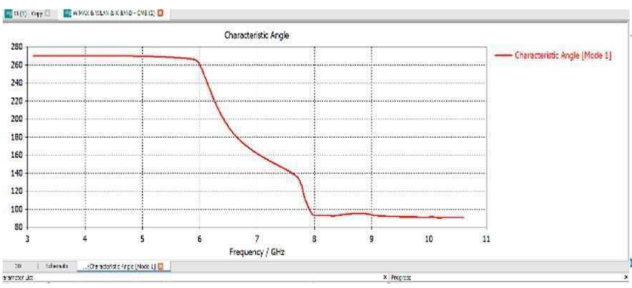
3. Modal Significance (MS): Modal significance indicates how strongly a mode contributes to radiation. $MS = \surd 1 + \lambda 2$ MS = 1 → Strong resonance MS > 0.7 → Significant radiation MS < 0.5 → Weak mode Modes with higher MS values are preferred for antenna operation

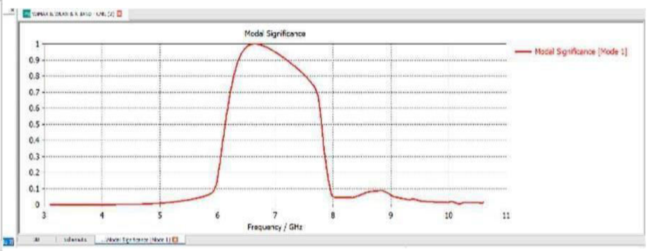


a)



b)





b) d)

c)

Fig. 11 (a) design (b) Eigenvalue (c) Characteristic Angle (d) Modal Significance (MS)

IV. CONCLUSION

The antenna is miniaturized by trimming the lower part, optimizing the cut to balance size and reflection coefficient, achieving a 24.07% size reduction. Parameters G3 and W8 are tuned to minimize radiation at the three notched bands, resulting in low efficiency (46.7%, 34.8%, 38.1%) and negative gain (−4, −1.3, −3.1 dB). A cross-shaped decoupling structure (CSDS) improvesisolatios to at least 19 dB

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