Grenze International Journal of Engineering and Technology, June Issue

# Design of Wearable Antenna for Breast Tumor Detection using MIMO

Sushana Grace Manoj[1], B. Priyalakshmi[2], Shivani Rajesh[3] and Shweta Sharma[4]
[1-4]SRM Institute of Science and Technology-ECE, Katankulathur, India
Email: sushana.manoj4u@gmail.com, priyalab@srmist.edu.in, rs2332@srmist.edu.in, sr4752@srmist.edu.in

***Abstract*—The goal of this study is to create a flexible, wearable antenna that employs non-invasive microwave imaging to detect breast tumors early. This method uses microwave signals to provide a safer and more comfortable alternative to standard mammography, which depends on ionizing radiation. The ultra-wideband (UWB) frequency range, which roughly spans 3.1 GHz to 10.6 GHz, is where the intended antenna operates. It improves efficiency and performance by utilizing multiple-input multiple-output (MIMO) technology. RT5870 is the substrate used in its design, guaranteeing peak performance with no signal loss. By adapting to the curves of the body, the antenna enhances skin contact and facilitates greater communication with the breast tissues. It can successfully differentiate between malignant and healthy cells by examining differences in dielectric characteristics. In order to evaluate impedance matching and efficiency, the study looks at important characteristics like S11, proving the antenna's capacity for accurate and trustworthy tumor identification. Early breast cancer screening could be enhanced by this novel, radiation-free method, which would also make it more patient-friendly and accessible.**

***Index Terms*— MIMO, RT5870, S11 parameter, ECC, Bending Analysis, UWB (Ultra-Wide Band).**

## I. INTRODUCTION

Breast cancer remains one of the leading causes of mortality among women globally. Early and accurate detection is paramount for effective treatment and improved survival rates. Traditional imaging techniques, such as mammography, often involve ionizing radiation, high costs, and patient discomfort, making them less suitable for frequent monitoring. Microwave imaging has emerged as a promising alternative, offering a non-invasive, cost-effective, and radiation-free approach to breast tumor detection.
This study focuses on the design of a wearable Multiple-Input Multiple-Output (MIMO) antenna system tailored for microwave imaging-based breast tumor detection. The MIMO configuration enhances data reliability, imaging resolution, and detection accuracy by utilizing multiple signal paths. The wearable nature of the antenna ensures better conformity to the body, reducing signal loss and increasing sensitivity. The technique leverages the dielectric contrast between healthy and malignant breast tissues to identify abnormalities. Previous studies have demonstrated the efficacy of Ultra-Wideband (UWB) MIMO antennas in improving localization accuracy and imaging outcomes [1], [2]. Incorporating advanced isolation techniques further enhances the performance of these antenna systems [3]. The proposed antenna design undergoes rigorous modelling and experimental validation to assess its effectiveness, aiming to contribute to the advancement breast tumor detection.

*Grenze ID: 01.GIJET.11.2.508*

II. LITERATURE SURVEY

“A Planar Ultrawideband Patch Antenna Array for Microwave Breast Tumor Detection” – Amran Hossain & Mohammad Tariqul Islam (2020). This study proposed a 16-element UWB antenna array, where one antenna transmits and the rest receive backscattered signals from a breast phantom. The use of the IC-DAS algorithm enabled effective tumor detection. The array-based approach serves as a foundation for high-resolution imaging systems [1].

“UWB Printed Rectangular-Based Monopole Antenna for Biological Tissue Analysis” – Andrea Martínez-Lozano & Carolina Blanco-Angulo (2021). A four-element antenna array was placed around a realistic breast phantom with layered dielectric properties. The design proved effective for tissue analysis, emphasizing the importance of spatial antenna configuration and realistic phantom modelling [2].

“Circular Slotted Patch with Defected Grounded Monopole Patch Antenna for Microwave-Based Head Imaging Applications” - Md Samsuzzamana & Md Siam Talukder (2022). This paper presented a circular slotted patch antenna with low SAR and minimal signal distortion, suitable for biomedical imaging. It highlights the significance of safety and signal clarity in medical applications [3].

“A Systematic Investigation of Four-Port MIMO Antenna on Flexible Material for UWB Networks” – Ahmed A. Ibrahim & Mohamed I. Ahmed (2022). Flexible CPW-fed MIMO antennas were tested under bending. The design retained performance and demonstrated suitability for wearable applications, which is relevant for breast-mounted imaging systems [4].

“An Ultra-Wideband MIMO Antenna System with Enhanced Isolation for Microwave Imaging Application” – Saad Hassan Kiani & Huseyin Serif Savci (2023). A compact two-port UWB MIMO antenna using RO5880 substrate achieved strong isolation and efficient performance, leading to precise imaging. This study supports substrate choice and isolation-focused design in our project [5].

“A Novel Compact UWB MIMO Antenna with Defected Ground Structure for Microwave Imaging” - A. Franklin Alex Joseph (2025). This paper introduces a compact UWB MIMO antenna that incorporates a defected ground structure (DGS). The DGS is often used to enhance antenna performance, such as bandwidth and isolation, which are beneficial for microwave breast imaging [6].

III. ANTENNA STRUCTURE AND DESIGN EVOLUTION

Wearable antennas are essential components for emerging body-centric wireless communication systems, offering compactness, and reliable performance. This paper presents a low-profile 4-port MIMO wearable antenna based on the Rogger 5880 substrate, selected for its low dielectric constant and minimal loss tangent, which support efficient signal transmission and mechanical flexibility for conformal use. The antenna employs a novel elliptical-shaped monopole radiator, designed by combining elliptical geometries to enhance bandwidth and radiation efficiency. Design modifications such as chamfered notches, slits, and ground plane cut-outs are incorporated to reduce mutual coupling, improve impedance matching, and support wideband performance. A microstrip line feed and optimized ground structure contribute to effective signal delivery and high isolation between antenna elements. The MIMO configuration enhances diversity gain and reliability, ensuring robust communication performance even under bending conditions.

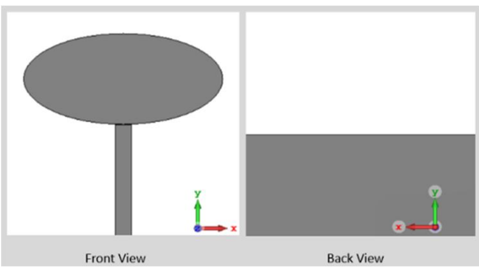



Figure 1. Base Antenna

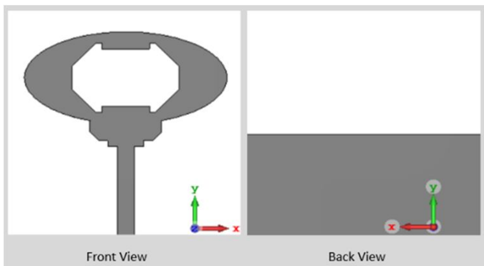



Figure 2. Antenna with step

Fig. 1, Fig. 2, Fig. 3 and Fig. 4 shows the evolution of the antenna design. Table I shows the dimension details of the antenna.

Simulation results confirm the antenna's suitability for wearable applications, demonstrating favourable metrics in terms of bandwidth, return loss, radiation pattern, and isolation. The proposed antenna is a promising candidate for next-generation body-centric networks, including health monitoring and IoT-based wearable systems.

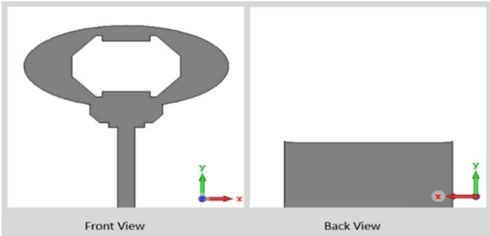



Figure 3. Antenna with ground resizing

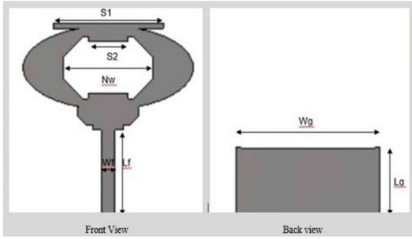



Figure 4. Final Antenna Design

TABLE I. DIMENSIONS OF THE PROPOSED ANTENNA

| Parameters | Measurements |
|---|---|
| Wf: Width of feed | 1.4 mm |
| Lf:  Length of feed | 10 mm |
| S1:  Length of slit | 11 mm |
| S2: Length of slit 2 | 4 mm |
| Wg: Width of ground | 14 mm |
| Lg: Length of ground | 12 mm |
| Nw: width of Notch | 9 mm |
| Nh: height of notch | 8 mm |

## IV. ANALYSIS OF S11 PARAMETER

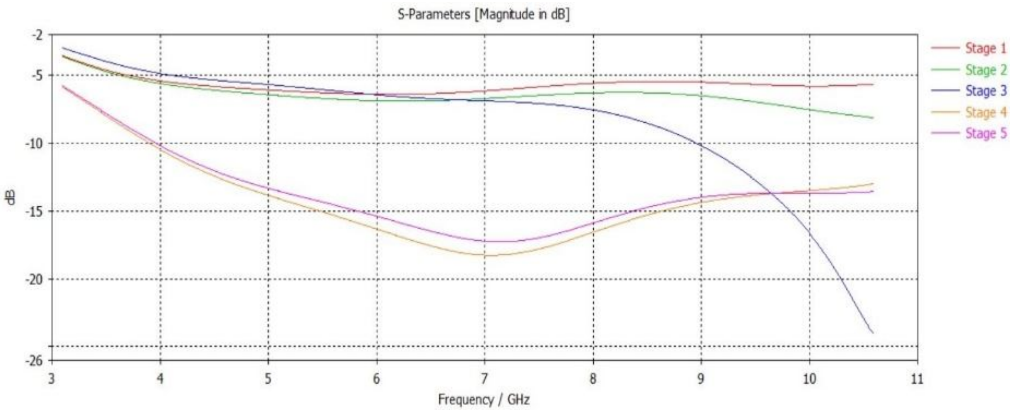



Figure 5.   S11 parameter comparison chart of Antenna evolution (S parameter Vs Frequency)

Figure 5 shows the return loss performance over five progressive design phases of a wearable UWB antenna for breast tumor detection. Every stage denotes structural improvements meant to improve impedance matching, such as adjusting dimensions, adding slots, altering the ground plane, or including parasitic components. The return loss stays above -10 dB in the early stages, especially in Stages 1 and 2, which suggests subpar performance because of significant signal reflection and ineffective energy delivery. While S11 performs poorly at lower frequencies, Stage 3 starts to improve, particularly at higher frequencies beyond 7 GHz, when it dips precipitously to -25 dB. With S11 values continuously below -10 dB from around 5.5 GHz to 9.5 GHz, Stage 4 offers a major advancement and is appropriate for UWB breast imaging. With a smoother and more stable S11 response below -10 dB over a broad frequency range of around 5.5 GHz to 10 GHz, Stage 5 is by far the most optimized version. This guarantees dependable data collection, less signal reflection, and improved energy penetration into tissue—all important components in raising diagnostic precision. In clinical conditions, Stage 5 is the best design for wearable breast cancer detection antennas because to its broad bandwidth, flatter curve, and high impedance matching.

## V. 4 PORTS MIMO DESIGN

The proposed 4-port wearable MIMO antenna, depicted in Fig. 6, is designed for microwave imaging-based breast tumor detection. Constructed on a flexible Rogger 5880 substrate, known for its low dielectric constant and minimal signal loss, the antenna ensures efficient signal transmission and adaptability to the human body's contours. The design integrates four crescent-shaped radiating elements strategically positioned to enhance radiation efficiency, broaden operational bandwidth, and minimize mutual coupling between elements. The compact form factor facilitates comfortable skin contact, making it suitable for wearable applications. Employing MIMO technology, the system can simultaneously transmit and receive multiple signals, thereby improving spatial resolution and increasing the accuracy of tumor detection. This configuration underscores the antenna's potential for effective integration into body-centric medical diagnostic systems.

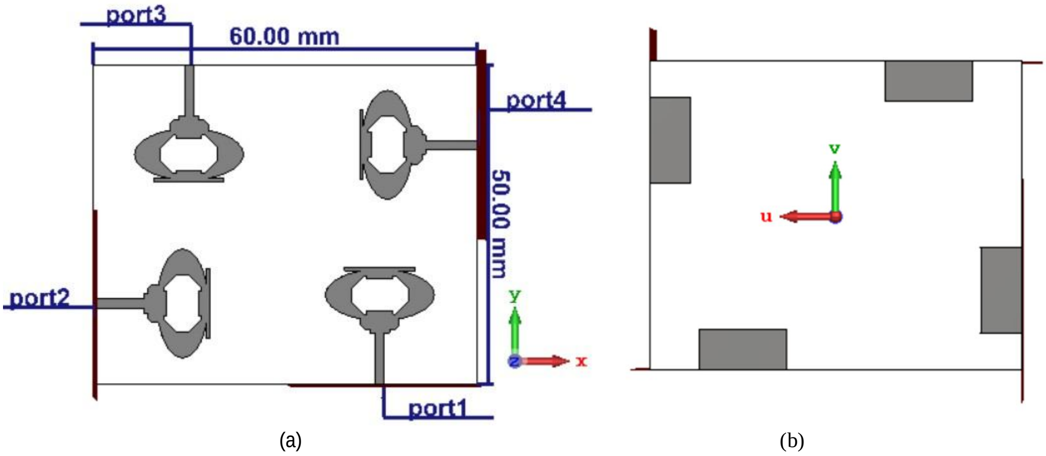



Figure 6. Four Port MIMO design (a) Front View (b) Back View

## VI. RESULT AND DISCUSSION

### *A. S parameter*

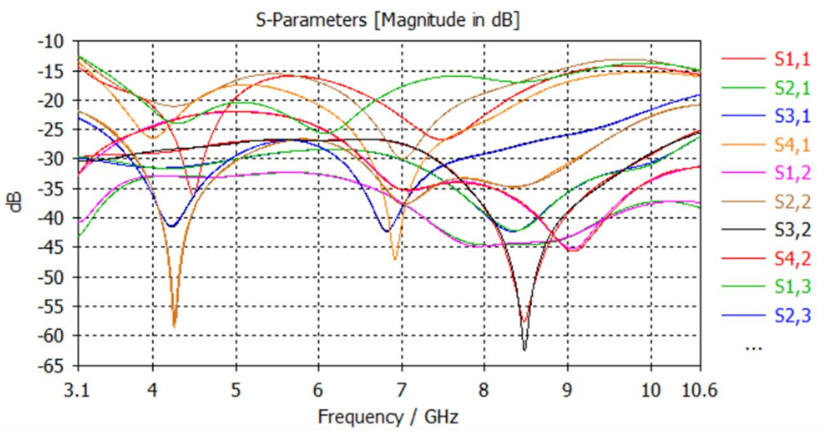



Figure 7. S Parameter of 4 Port MIMO ( S parameter Vs Frequency)

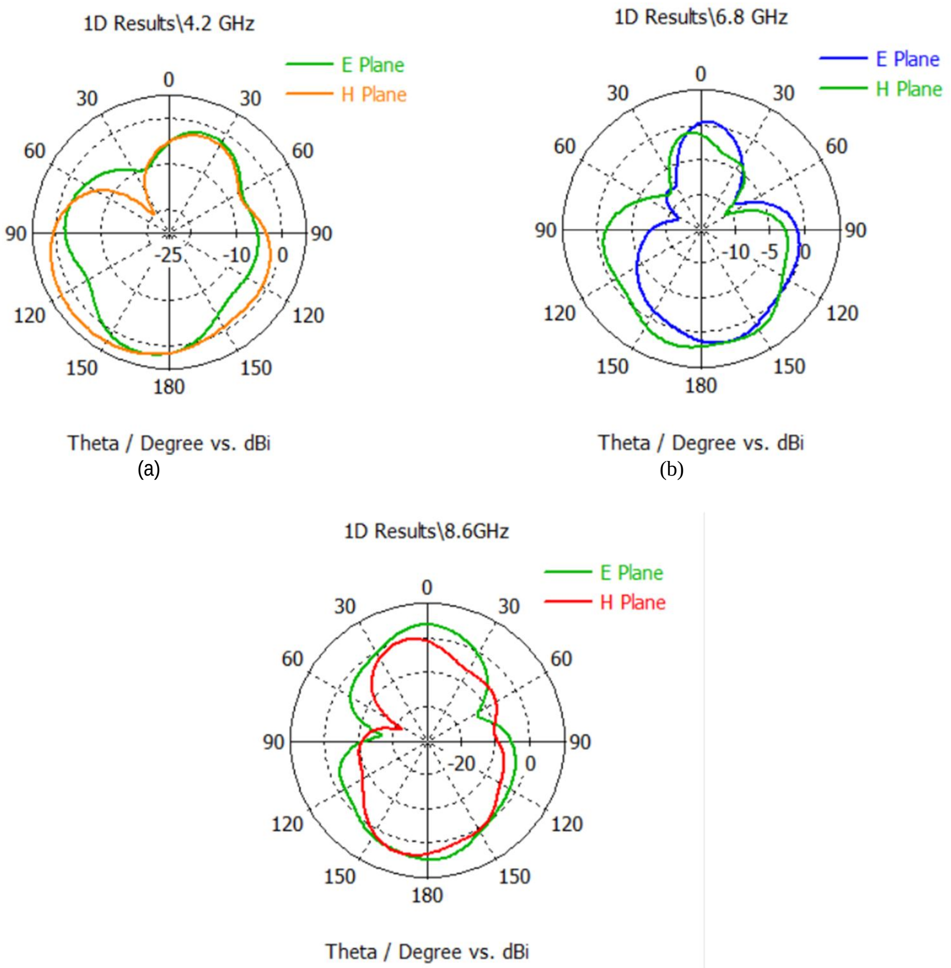
To assess how well the proposed 4-port MIMO antenna performs, we analyzed its S-parameters over a wide frequency range from 3.1 GHz to 10.6 GHz. These parameters help us understand how much of the input signal is reflected back or transferred between ports — key indicators for both antenna efficiency and isolation.

From the simulation results shown in Fig. [7], the return loss (S11, S22, S33, and S44>) remains well below the standard -10 dB benchmark across a large portion of the ultra-wideband (UWB) range. For instance, S11 dips below -40 dB around 4.3 GHz, indicating excellent impedance matching and minimal signal reflection. This confirms that the antenna is effectively tuned to operate over a wide frequency range, which is essential for high-resolution imaging.

The mutual coupling values (Sij>, where i ≠ j) are also quite low — mostly staying under -20 dB and even dropping further around resonance points. This high level of isolation between antenna elements is critical in MIMO systems, as it helps reduce interference and improve overall performance. These results are a reflection of careful antenna design, particularly the element placement and the use of isolation-enhancing structures.
Overall, the S-parameter analysis confirms that the antenna is well-suited for use in breast tumor detection. Its wide operating bandwidth and strong isolation between ports make it a promising candidate for microwave imaging systems that require both accuracy and reliability.

### *B. Analysis of radiation pattern result*

The far-field radiation characteristics of the proposed MIMO antenna were evaluated in both the E-plane and H-plane at three key resonant frequencies: 4.2 GHz, 6.8 GHz, and 8.6 GHz, as shown in Fig. [8]. The analysis provides insight into the directionality and stability of the radiation pattern across the operating band, which is essential for reliable tumor localization in biomedical imaging.
Overall, the radiation patterns across the examined frequencies illustrate the antenna’s frequency-dependent beam behaviour, transitioning from omnidirectional to more directive as the frequency increases. This behaviour is advantageous in medical imaging, where both wide coverage and focused penetration are required at different stages of scanning. Furthermore, the stable and symmetric nature of the patterns indicates good radiation efficiency and minimal distortion, reinforcing the antenna's suitability for breast tumor detection applications.



(c)

Figure 8. The radiation pattern of the designed antenna at (a) 4.2 **GHz (b) 6.8 GHz (c) 8.6 GHz**

### *C. Envelop correlation coefficient*

The MIMO performance parameters of the proposed UWB MIMO system is shown in Fig. 9. ECC (envelope correlation coefficient) and diversity gain play crucial roles in assessing the antenna’s performance [5][12][11].

The ECC is a measure of the correlation between the signals received or transmitted by different antenna elements. In the case of the studied UWB MIMO antenna, the obtained ECC values are exceptionally low, being less than 0.005 as shown in Figure 10, which indicates a minimal correlation between the two radiating elements. We see the ECC value of the antenna with respect to port 1-2, port 1-3, and port 1-4 over the range of 3.1 to 10.6 GHz. This low ECC value signifies improved spatial diversity and reduced interference, leading to enhanced system performance. As well, the ECC values can be taken and calculated from the S-parameters as the Formula (1)

$$\text{ECC} = \rho_e = |\rho_{ij}| = \frac{|S_{ii*}S_{ij} + S_{ij*}S_{jj}|^2}{(1-(|S_{ii}|^2 + |S_{ji}|^2))(1-(|S_{jj}|^2 + |S_{ij}|^2))} \tag{1}$$

The ECC values for port pairs (1,2), (1,3), and (1,4) remain consistently below 0.0015 across the entire UWB frequency range (3.1–10.6 GHz), as shown in the simulated results. The ECC remains well below the acceptable threshold of 0.5, confirming that the antenna provides superior isolation and is highly suitable for high-capacity UWB MIMO systems.

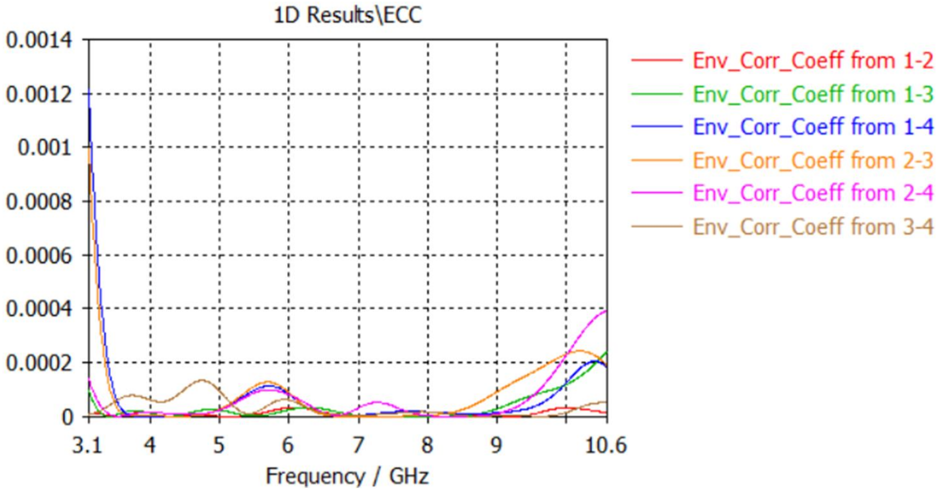



Figure 9. ECC output of 4 port MIMO

*D. Dıversıty gaın*

Diversity gain, a crucial parameter for any antenna, quantifies its efficiency in directing radio waves in a specific direction compared to a theoretical isotropic antenna that radiates equally in all directions. This ability to focus power is vital; without it, signals would dissipate in unwanted directions, weakening the signal strength where it's needed [5][12][11].

The Diversity Gain (DG) plot in Fig. 10 illustrates the performance of the proposed 4-port UWB MIMO antenna in terms of signal decorrelation and multipath fading mitigation. As observed, all DG values for port combinations (2,1), (3,1), and (4,1) stay consistently close to the optimal 10 dB across the UWB band (3.1–10.6 GHz), with only minor dips observed below 4 GHz. These slight degradations, particularly in the (3,1) simulated case around 3.5 GHz, remain within acceptable limits and do not significantly impact the antenna's diversity performance. The close agreement between simulated and measured results further validates the accuracy of the design and fabrication process. This high DG confirms that the antenna maintains low mutual coupling and high isolation, ensuring efficient spatial diversity and reliable operation for UWB applications such as short-range high-speed communication and medical imaging.

$$\text{DG} = 10 * \sqrt{(1 - |\text{ECC}|)} \tag{2}$$

The DG is linked with the ECC over the equation (2) to confirm the MIMO system diversity.

## VII. Conclusion and Future Scope

Excellent performance metrics make the suggested 4-port UWB MIMO antenna ideal for diagnostic applications, especially the detection of breast tumours. With return loss values well below -10 dB and mutual

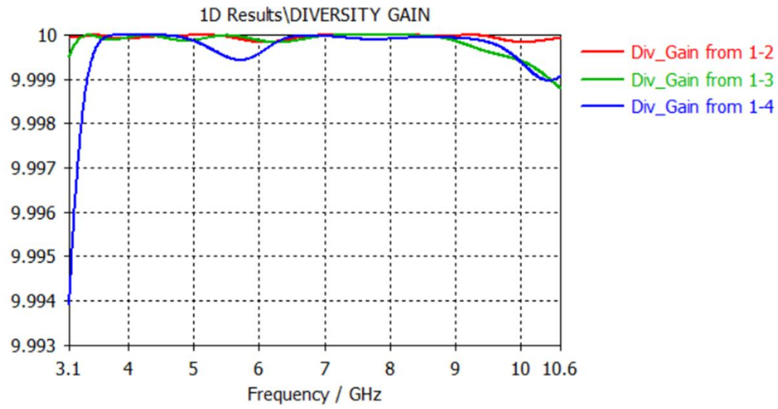



Figure 10. ECC output of 4 port MIMO

coupling continuously below -20 dB, the S-parameter study validates a wide impedance bandwidth, suggesting little signal reflection and efficient isolation. It is advantageous to achieve both coverage and penetration during imaging because the far-field radiation patterns are steady, symmetric, and frequency-dependent, changing from quasi-omnidirectional at lower frequencies to more directive at higher frequencies. Throughout the whole 3.1–10.6 GHz spectrum, the envelope correlation coefficient (ECC) is remarkably low (<0.0015), guaranteeing minimal signal correlation and excellent spatial variety. Additionally, the diversity gain (DG) stays near the optimal 10 dB, confirming the antenna's effectiveness in reducing multipath fading. Together, these findings demonstrate that the antenna design is dependable, strong, and well-isolated for UWB MIMO-based diagnostic systems that need high resolution and dependability.

## REFERENCES


[1] Hossain, A.; Islam, M.T.; Islam, M.T.; Chowdhury, M.E.H.; Rmili, H.; Samsuzzaman, M. A Planar Ultrawideband Patch Antenna Array for Microwave Breast Tumor Detection. *Materials* 2020, *13*, 4918.

[2] Martínez-Lozano, A.; Blanco-Angulo, C.; García-Martínez, H.; Gutiérrez-Mazón, R.; Torregrosa-Penalva, G.; Ávila-Navarro, E.; Sabater-Navarro, J.M. UWB-Printed Rectangular-Based Monopole Antenna for Biological Tissue Analysis. *Electronics* 2021

[3] M. Samsuzzaman, S. Talukder, A. Alqahtani, A.G. Alharbi, R. Azim, M.S. Soliman, Mohammad Tariqul Islam Circular slotted patch with defected grounded monopole patch antenna for microwave-based head imaging applications, Alexandria Eng. J., 65 (2023), pp. 41-57

[4] Ibrahim, A.A., Ahmed, M.I. & Ahmed, M.F. A systematic investigation of four ports MIMO antenna depending on flexible material for UWB networks. *Sci Rep* 12, 14351 (2022).

[5] Kiani, S.H.; Savci, H.S.; Munir, M.E.; Sedik, A.; Mostafa, H. An Ultra-Wide Band MIMO Antenna System with Enhanced Isolation for Microwave Imaging Applications, *Micromachines* 2023, *14*, 1732.

[6] A. Franklin Alex Joseph1 , B. Jothi , R. Shantha Sheela, N. Anitha- A Novel Compact CPW-fed Octagonal-Shaped Slotted Antenna for UWB Applications, Indonesian Journal of Electrical Engineering and Informatics (IJEEI) Vol. 13, No. 1, March 2025, pp. 239~248 (2025)

[7] Lee, H.; Park, Y.B. Wideband Ring-Monopole Flexible Antenna with Stub for WLAN/C-Band/X-Band Applications. *Appl. Sci.* 2022, *12*, 10717

[8] Elsheakh, D.M., Alsherif, S.A. & Eldamak, A.R. Textile monopole sensors for breast cancer detection. *Telecommun Syst* 82, 363–379 (2023).

[9] H. M. E. Misilmani, T. Naous, S. K. A. Khatib and K. Y. Kabalan, "A Survey on Antenna Designs for Breast Cancer Detection Using Microwave Imaging," in *IEEE Access*, vol. 8, pp. 102570-102594, 2020.

[10] M. M. Hasan Mahfuz, A. M. Mahfouz, E. Baladi and A. A. Kishk, "Microstrip Patch Antennas for Breast Tumor/Cancer Cell Detection–Challenges, Designs, and Future Opportunities: A Review," in *IEEE Access*, vol. 12, pp. 172297-172324, 2024

[11] Irshad Khan, M.; Khattak, M.I.; Rahman, S.U.; Qazi, A.B.; Telba, A.A.; Sebak, A. Design and Investigation of Modern UWB-MIMO Antenna with Optimized Isolation. *Micromachines* 2020

[12] Ibrahim, A.A., Ahmed, M.I. & Ahmed, M.F. A systematic investigation of four ports MIMO antenna depending on flexible material for UWB networks. *Sci Rep* 12, 14351 (2022)

[13] Elsheakh, D.N.; Mohamed, R.A.; Fahmy, O.M.; Ezzat, K.; Eldamak, A.R. Complete Breast Cancer Detection and Monitoring System by Using Microwave Textile Based Antenna Sensors. *Biosensors* 2023, *13*, 87.

[14] Kiani, S.H.; Savci, H.S.; Munir, M.E.; Sedik, A.; Mostafa, H. AnUltra-Wide Band MIMO Antenna System with Enhanced Isolation for Microwave Imaging Application s. Micromachines 2023, 14, 1732.

[15] Ibrahim, A.A.; Abdalla, M.A.; Abdel-Rahman, A.B.; Hamed, H.F. Compact MIMO antenna with optimized mutual coupling reduction using DGS. Int. J. Microw. Wirel. Technol. 2014, 6, 173–180.
[16] Ali, W.A.; Ibrahim, A.A. A compact double-sided MIMO antenna with an improved isolation for UWB applications. Aeu-Int. J. Electron. Commun. 2017, 82, 7–13.
[17] Toktas, A.; Akdagli, A. Compact multiple-input multiple-output antenna with low correlation for ultra-wide-band applications. Iet Microw. Antennas Propag. 2015, 9, 822–829.
[18] Zhao, Y.; Zhang, F.S.; Cao, L.X.; Li, D.H. A Compact Dual Band-Notched MIMO Diversity Antenna for UWB Wireless Applications. Prog. Electromagn. Res. 2019, 89, 161–169.