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Miniaturized Low-Interference CPW-Fed MIMO Antenna on Jeans Textile for Wearable Biomedical Applications in the 5.8 GHz ISM Band

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***Abstract*— In this work, a compact dual-port CPW-fed textile monopole MIMO patch antenna is proposed for biomedical applications operating in the 5.8 GHz ISM band. The antenna integrates split-ring resonator (SRR) based metasurfaces and is fed by a 50-ohm standard coplanar waveguide. The radiating elements are fabricated on a jeans textile substrate, experimentally characterized with a relative permittivity of 1.6 and a thickness of 1 mm. The overall antenna structure, including the SRR configuration and inter-element spacing, is optimized using CST Studio Suite to enhance impedance matching and minimize mutual coupling between elements. The proposed antenna occupies a compact area of 54 mm × 25 mm. The simulated impedance bandwidth ranges from 4.87 GHz to 7.21 GHz, while the measured bandwidth extends from 4.35 GHz to 7 GHz. The antenna demonstrates high isolation with a simulated S_{12}/S_{21} lower than -15 dB and achieves a peak gain of 7.05 dBi. Furthermore, key MIMO performance metrics such as Envelope Correlation Coefficient (ECC), Channel Capacity Loss (CCL), Diversity Gain (DG), Mean Effective Gain (MEG), and Total Active Reflection Coefficient (TARC) confirm the suitability of the antenna for wearable biomedical devices operating in the 5.8 GHz ISM band. These features highlight the potential of the design for reliable body-centric wireless communication.**

***Keywords*— Low-interference MIMO antenna; jeans textile, ISM band, CPW-Fed, wearable biomedical applications.**

I. Introduction

With the rise of wearable technologies, textile antennas are gaining increasing attention, particularly in fields such as healthcare, defense, sports, and aerospace. Thanks to their flexibility and compatibility with clothing, these antennas enable efficient wireless communication, especially in biomedical applications involving external or implantable devices [1–3]. To operate effectively on the human body, such antennas must maintain good electromagnetic performance despite deformations caused by body movements. This requires them to be flexible, lightweight, robust, and discreet, allowing easy integration into garments or wearable equipment [4].

However, body integration introduces several challenges, particularly related to mechanical deformation, optimal antenna placement, and manufacturing constraints [5–6]. These factors directly affect antenna performance, making the design phase especially critical. To meet the growing demand for data throughput and communication reliability, Multiple-Input Multiple-Output (MIMO) technology is widely adopted. It relies on the simultaneous use of multiple antennas for signal transmission and reception, thereby improving channel capacity, spatial diversity, and link robustness [7–8]. Nevertheless, integrating multiple antenna elements in a limited space increases mutual coupling, which can degrade the overall system performance. Therefore, optimizing isolation between elements becomes essential.

Numerous portable MIMO antennas with high inter-element isolation have been reported in the literature [9]–[14]. For instance, Diwakar Kumar et al. proposed a flexible MIMO antenna measuring 140 × 60 mm², operating from 5.55 to 6.06 GHz, with a peak gain of 5.8 dB [9]. Rigeng Wu et al. developed a wearable metasurface-based MIMO antenna on a polytetrafluoroethylene (PTFE) substrate of 80 × 40 mm², covering the 4.9–6.17 GHz band and achieving a gain of 7.95 dBi [10]. Pendli Pradeep et al. introduced a two-port octagonal patch MIMO antenna fabricated on a denim substrate measuring 40 × 50 mm², operating in the 4.35–7 GHz band, with a gain of 6.7 dB [11]. Ijaz Khan et al. designed a square patch MIMO antenna with angular cuts on an FR-4 substrate of 22.5 × 50 mm², covering the 5.23–6.42 GHz band with a gain of 3.87 dBi [12]. Sourav Roy et al. implemented two- and four-element textile MIMO structures with dual polarization and dual wideband operation on a denim substrate measuring 60 × 97 mm², achieving a gain of 5 dB over the 4.1–6.1 GHz range [13]. Finally, Badisa Anil Babu et al. designed a compact textile MIMO antenna for ISM-band wearable applications on a jeans substrate measuring 30 × 40 mm², achieving a gain of 4.08 dBi over the 5.14–6.85 GHz range [14].

In this context, this paper proposes a compact dual-element textile MIMO antenna based on a CPW-fed design, specifically tailored for biomedical applications in the 5.8 GHz ISM band. The antenna features two ground planes and SRR (Split Ring Resonator) metasurface structures symmetrically arranged on a flexible substrate, and is fed by standard 50-ohm coplanar waveguides. To enhance bandwidth and reduce mutual coupling, an optimized distance between the two antenna elements is introduced on the same substrate. The proposed antenna achieves isolation greater than 15 dB within the operating band, while offering strong diversity performance, thus meeting the requirements of portable MIMO systems for medical use.

II. Antenna Design and Configuration

The proposed MIMO antenna structure consists of a compact dual-element textile antenna based on a coplanar waveguide (CPW)-fed design, specifically developed for biomedical applications operating in the 5.8 GHz ISM band. The antenna incorporates two ground planes and integrates split-ring resonator (SRR) metasurface structures symmetrically arranged to enhance isolation and impedance matching. It is fabricated on a jeans substrate characterized by a relative permittivity (εr) of 1.6 and a low loss tangent of 0.01, making it suitable for wearable applications. The antenna features compact dimensions of 54 × 25 mm² and covers a wide operational bandwidth from 4.87 GHz to 7.21 GHz. The design was optimized using CST Microwave Studio, as illustrated in Figure 1, and the key geometrical and electrical parameters are summarized in Table 1.

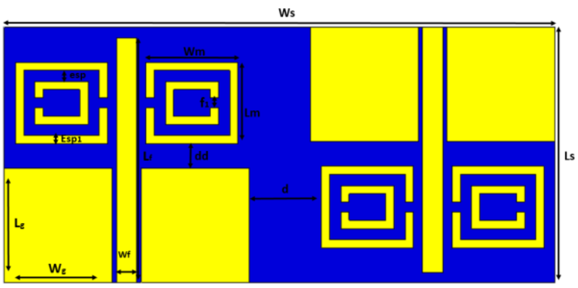


Fig.1. Proposed MIMO antenna .

III. Antenna Design and Configuration

A. Off-Body Analysis

The reflection (S11, S22) and transmission (S21, S12) coefficients of the designed MIMO antenna are presented in Figure 2. The simulated results indicate an impedance bandwidth extending from 4.87 GHz to 7.21 GHz, with a resonant frequency located at 5.8 GHz. At resonance, the antenna provides a return loss of approximately –25 dB, demonstrating efficient impedance matching. The isolation between ports remains less than –15 dB, confirming reduced mutual coupling. These features highlight the potential of the antenna for wearable and on-body MIMO applications in the 5.8 GHz ISM band.

TABLE I. Optimized parameters of the proposed MIMO antenna.

Para.	Value (mm)	Para.	Value (mm)	Para.	Value (mm)
Ws	54	Wg	10.6	esp	1.1
Ls	25	Lg	11.2	Esp1	0.8
Wm	9	Wf	2	d	6
dd		Lf	24	f1	1

Figure 3 depicts the gain and radiation efficiency of the proposed structure. A maximum gain of 7.05 dBi and radiation efficiency up to 99% are achieved, underlining its capability for integration in wireless communication systems.

Figure 4 presents the simulated radiation patterns in the XZ, YZ, and XY planes at three operating frequencies: 5.2 GHz, 5.8 GHz, and 6.8 GHz. The obtained results show stable and consistent radiation performance over the entire operating band, which supports the suitability of the antenna for wearable and body-centric applications.

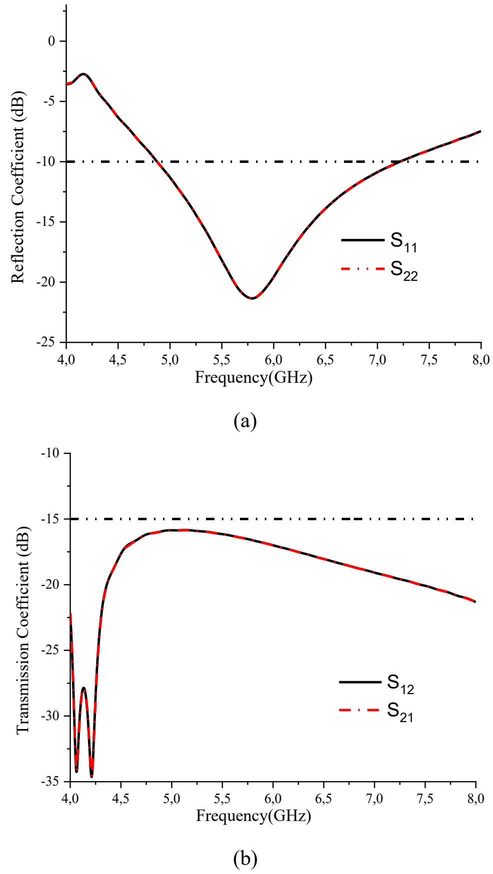


Fig.2. Simulated S-parameters of the proposed MIMO antenna: (a) reflection coefficients (S_{11}, S_{22}), (b) transmission coefficients (S_{12}, S_{21}).

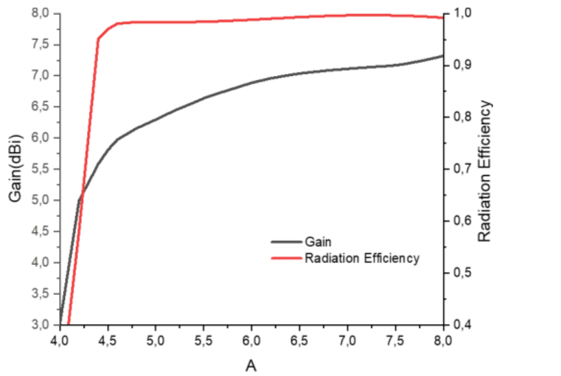


Fig.3. Gain and radiation efficiency versus frequency for the proposed MIMO antenna.

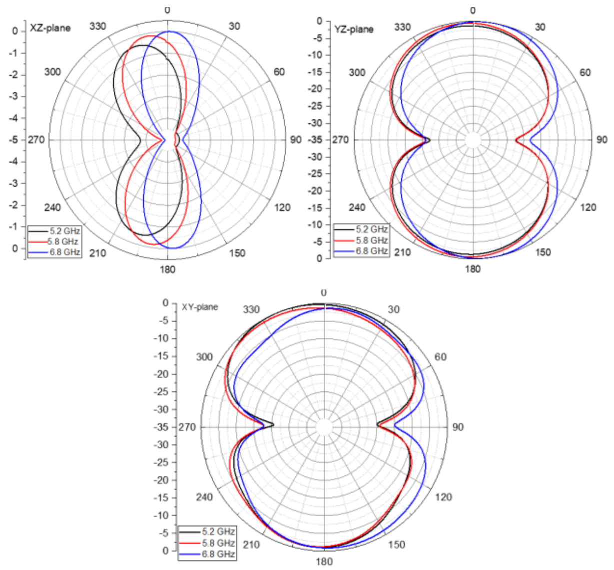


Fig.4. 2D radiation patterns of the proposed MIMO antenna at 5.2 GHz, 5.8 GHz, and 6.8 GHz.

B. Binding Performance

The bending analysis aims to evaluate the impact of mechanical deformations on the electromagnetic performance of a flexible antenna made of denim fabric, particularly in terms of resonant frequency, bandwidth, and impedance matching. Figure 5 shows the antenna configuration under three different bending scenarios, corresponding to angles θ = 20°, θ = 30°, and θ = 40°, in order to simulate realistic on-body usage conditions. As illustrated in Figure 6, although the impedance matching remains generally stable during operation, the resonant frequency experiences slight shifts toward higher or lower values. These variations are caused by the bending-induced changes in the effective electrical length of the radiating structure, which directly affect the antenna's radiation characteristics.

Fig.5. Bended configuration of the MIMO antenna at theta= 40°.

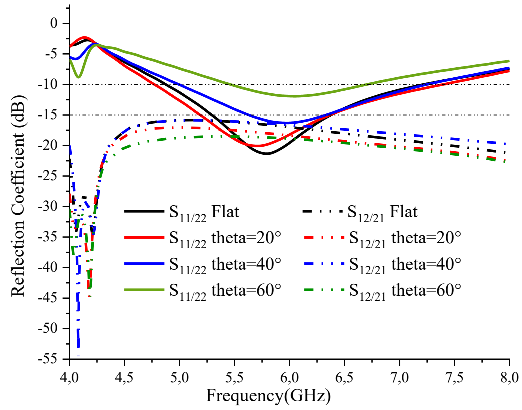


Fig.6. S-parameters of bending antenna.

C. On-Body Analysis

To evaluate the potential effects of electromagnetic exposure on the human body more accurately, a biologically inspired, multilayer human tissue model was implemented in the CST simulation environment. The model, measuring 140 × 70 mm², consists of three distinct layers: skin, adipose tissue, and muscle. This structure enables realistic analysis of how electromagnetic waves interact with human tissues. As shown in Figure 7, the MIMO antenna is positioned in direct contact with the tissue model to mimic actual wearable conditions. Table 2 outlines the dielectric properties of the tissues, including relative permittivity and conductivity at 5.8 GHz.

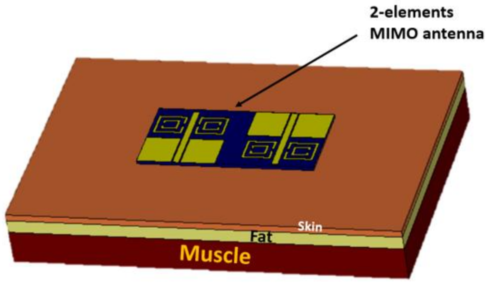
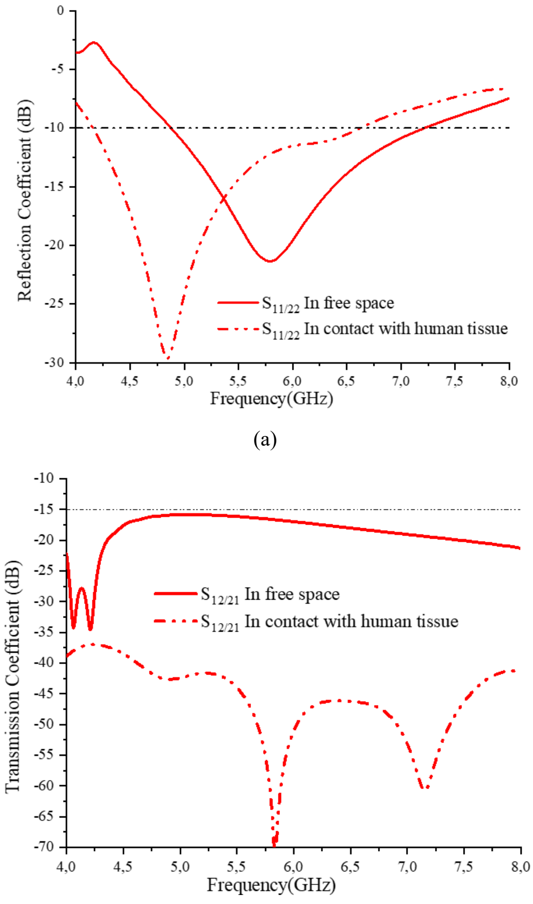


Fig.7. Bended designed antenna of the proposed MIMO.

TABLE II. HUMAN TISSUE DIELECTRIC PROPERTIES AT 5.8 GHZ FREQUENCY [15].

Human Tissue	**Thickness (mm2)**	**Conductivity (S/m)**	**Relative Permitivity**	**Density (Kg/m3)**
Skin	2	1.49	37.95	1001
Fat	4	0.11	5.27	900
Muscul	10	0.82	52.67	1006

Figure 8 ((a) and (b)) shows the simulated reflection (S11,S22) and transmission (S21 S12) coefficients of the proposed MIMO antenna in free space and in contact with human tissue, respectively. In free space, the antenna resonates at 5.8 GHz with a return loss of −25 dB and an isolation of −16 dB. When placed in contact with human tissue, the resonance shifts to 5.5 GHz, with a return loss below −10 dB and enhanced isolation of −26 dB due to the dielectric loading effect. These results demonstrate the antenna’s suitability for on-body MIMO applications in the 5.8 GHz ISM band.



(b)

Fig.8. S-parameters of the MIMO on-body antenna (a) S_{11} & S_{22}, (b) S_{12} & S_{21}.

The electromagnetic exposure of the proposed antenna was evaluated using Specific Absorption Rate (SAR) at 5.8 GHz. The measured SAR values remain well below international safety limits (1 W/kg over 1 g and 2 W/kg over 10 g), confirming safe operation within the antenna's active bandwidth [16].

IV. DIVERSITY PERFORMANCE

In this section, the performance of the designed MIMO antenna is evaluated through various diversity parameters, which are crucial for determining its applicability in multipath propagation scenarios. The considered metrics include the Envelope Correlation Coefficient (ECC), Diversity Gain (DG), Total Active Reflection Coefficient (TARC), Mean Effective Gain (MEG), and Channel Capacity Loss (CCL). Taken together, these parameters provide a complete assessment of the antenna's capability to function efficiently in MIMO communication environments.

The Envelope Correlation Coefficient (ECC), extracted from the simulated S-parameters, quantifies the correlation between the antenna ports. As shown in Figure 9, the ECC values are well below the conventional threshold of 0.5, with values dropping under 0.005 across the frequency band. This confirms very low correlation, excellent port isolation, and strong diversity performance of the antenna.

The Diversity Gain (DG) describes the enhancement in reception achieved using diversity techniques. Figure 10 shows that the simulated DG remains close to the theoretical value of 10 dB, varying between 9.99 dB and 10 dB over the entire operating range. This demonstrates negligible performance degradation and effective mitigation of multipath fading.

The Total Active Reflection Coefficient (TARC) represents the overall reflection when multiple antenna ports are simultaneously excited with different phase shifts. As illustrated in Figure 11, the TARC is calculated for phase differences of 30°, 60°, 90°, 120°, 150°, and 180°. The results show that TARC stays below –10 dB across the operating band, validating the antenna's stable impedance performance and robust behavior under different excitation conditions.

The Mean Effective Gain (MEG), shown in Figure 12, assesses the power received by each antenna element relative to an ideal isotropic radiator. The MEG values are consistently below −3 dB, indicating uniform power reception and good performance in multipath environments.

Lastly, the Channel Capacity Loss (CCL) quantifies the reduction in MIMO channel capacity due to mutual coupling and correlation. As shown in Figure 13, the CCL remains well below the recommended threshold of 0.4 bit/s/Hz, with values under 0.02 bit/s/Hz across the entire frequency range. This confirms that the proposed antenna imposes minimal loss on the system capacity, ensuring high spectral efficiency.

In summary, the proposed MIMO antenna demonstrates excellent diversity characteristics across all evaluated metrics, making it highly suitable for wearable and body-centric wireless communication systems operating in the 5.8 GHz ISM band.

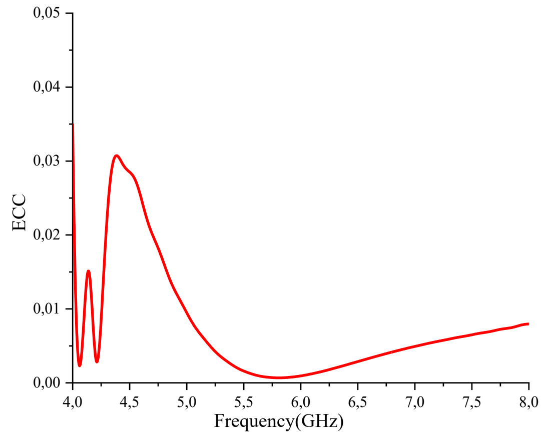


Fig.9. Simulated ECC designed MIMO antenna.

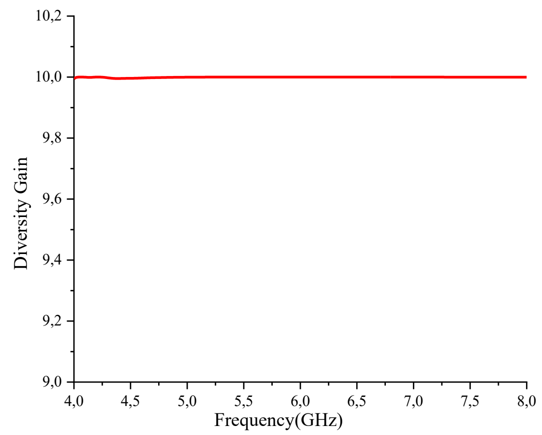


Fig.10. Simulated DG designed MIMO antenna.

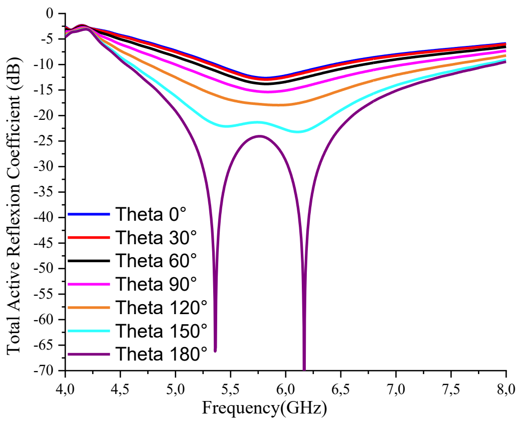


Fig.11. Simulated TARC designed MIMO antenna.

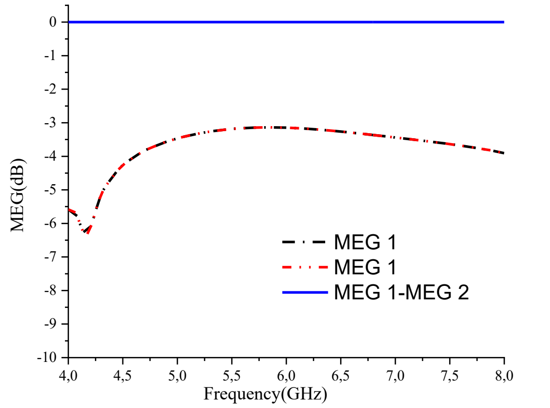


Fig.12. Simulated MEG1,MEG2 and MEG designed MIMO antenna.

TABLE III. COMPARATIVE PERFORMANCE WITH EXISTING TWO-ELEMENT MIMO ANTENNAS

Ref	No. of ports	Size (mm^2)	BW (GHz)	Gain (dBi)	Material	Isolation (dB)	Efficency (%)	MEG (dB)	DG (dB)	ECC	CCL	SAR (W/Kg)
[9]	2	140 × 60	5.55-6.06	5.8	Denim	>20	40	>3	10	0.20	<0.07	0.08
[10]	2	80 × 40	4.9-6.17	7.95	Polytetrafluor-oethylene (PTFE)	19.8	>90	NR	9.98	0.35	NR	NR
[11]	2	40 × 50	4.35-7	6.7	jeans	12	>95	NR	NR	0.0005	NR	1.93
[12]	2	22.5 ×50	5.23- 6.42	3.87	FR-4	>20	>80		9.99	0.005	NR	None
[13]	2	60 × 97	4.1-6.1	5	jeans	25	>70	>3	>9.9	<0.1	NR	1.6
[14]	2	40×30	5.14-6.85	4.08	jeans	25	92	NR	NR	NR	NR	0.96
Our work	2	54 × 25	4.87-7.21	7.05	jeans	>15	99		>9.9	0.005	0.0009	0.53

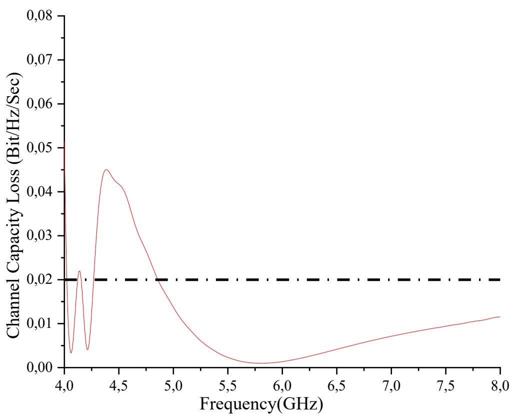


Fig.13. Simulated CCL designed MIMO antenna.

V. CONCLUSION

In this study, a compact dual-element CPW-fed textile MIMO antenna was proposed for wearable biomedical applications operating in the 5.8 GHz ISM band. The antenna was designed on a flexible jeans substrate, chosen for its favorable dielectric properties, mechanical flexibility, and compatibility with wearable environments. The integration of split-ring resonator (SRR) metasurfaces and an optimized inter-element spacing enabled improved impedance matching, enhanced isolation (>15 dB), and stable radiation patterns. Simulation and experimental results demonstrated a wide operational bandwidth from 4.87 GHz to 7.21 GHz, high radiation efficiency (99%), and a peak gain of 7.05 dBi. The antenna also showed excellent MIMO performance through key metrics such as ECC, DG, MEG, TARC, and CCL, making it suitable for body-centric wireless communication. Additionally, the antenna maintained reliable performance under bending conditions, confirming its applicability in real-world wearable scenarios. These findings highlight the antenna's potential as a practical and efficient solution for next-generation wireless wearable biomedical systems, and future work will address the fabrication and measurement of the structure as well as its evaluation on realistic breast phantoms to further validate its effectiveness in biomedical sensing applications.

ACKNOWLEDGMENT

Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency. Neither the European Union nor the granting authority can be held responsible for them. Besides that, this publication has emanated from research jointly funded by Taighde Éireann – Research Ireland under Grant number 13/RC/2094_2, the European Union's Marie Skłodowska-Curie Actions under grant number 101126578 and was supported in part by University of Galway.

REFERENCES

[1] C. L. G. Monti and L. Tarricone, "Wearable antennas: Nontextile versus fully textile solutions," IEEE Antennas Propag. Mag., vol. 61, no. 2, pp. 71–83, 2019.

[2] D. Sharma, M. Singh, S. A. Rawat, and S. K. Kher, "A pocket-integrated miniature, dual-band, and high gain textile MIMO antenna for 5G and WiFi wearable applications," Sci. Rep., vol. 15, no. 1, p. 5061, 2025.

[3] D. Sharma and S. Kumar, "Metamaterial based wearable and implantable antennas," in Handbook of Nano-Metamaterials. Metamaterials Science and Technology, B. Choudhury, V. K. Tewary,

and V. K. Kanth, Eds. Singapore: Springer, 2024, pp. 1–43. [Online]. Available: https://doi.org/10.1007/978-981-13-0261-9_50-1

[4] M. Roudjane, A. B. Kouki, and M. R. Gharsallah, “New generation wearable antenna based on multimaterial fiber for wireless communication and real-time breath detection,” in Photonics, vol. 5, no. 4, MDPI, 2018.

[5] M. El Gharbi, M. S. Boujelben, A. T. A. Zaidi, and A. Gharsallah, “A review of flexible wearable antenna sensors: Design, fabrication methods, and applications,” Materials, vol. 13, no. 17, p. 3781, 2020.

[6] A. Kumar, A. De, and R. K. Jain, “Circular polarized two-element textile antenna with high isolation and polarization diversity for wearable applications,” Int. J. Microw. Wirel. Technol., 2022. [Online]. Available: https://doi.org/10.1017/S1759078722000184

[7] R. Sourav, G. Soumendu, S. P. Soumya, and C. Ujjal, “Dual-polarized textile-based two/four element MIMO antenna with improved isolation for dual wideband application,” Int. J. RF Microw. Comput. Aided Eng., vol. 30, no. 9, p. e22292, 2020.

[8] A. A. Ibrahim, J. Machac, and R. M. Shubair, “UWB MIMO antenna for high speed wireless applications,” Appl. Comput. Electromagn. Soc. J. (ACES), vol. 34, no. 9, pp. 1294–1299, 2019.

[9] D. Kumar, S. P. Ghosh, M. Mitra, and M. R. Karim, “Multiband flexible MIMO antenna for NB-IoT/ISM/5G and wearable applications,” Results Eng., vol. 17, p. 106088, 2025.

[10] R. Wu, J. Dong, and M. Wang, “Wearable polarization conversion metasurface MIMO antenna for biomedical applications in 5 GHz WBAN,” Biosensors, vol. 13, no. 1, p. 73, 2023.

[11] P. Pradeep, K. C. Ravi, S. C. Jaya, and A. Kumar, “Development of wearable textile MIMO antenna for sub-6 GHz band new radio 5G applications,” Micromachines, vol. 15, no. 5, p. 651, 2024.

[12] I. Khan, M. F. Khan, M. A. Awan, and A. A. Laghari, “Designed circularly polarized two-port microstrip MIMO antenna for WLAN applications,” Appl. Sci., vol. 12, no. 3, p. 1068, 2022.

[13] S. Roy, S. Ghosh, S. P. Mandal, and U. Chatterjee, “Dual-polarized textile-based two/four element MIMO antenna with improved isolation for dual wideband application,” Int. J. RF Microw. Comput. Aided Eng., vol. 30, no. 9, p. e22292, 2020.

[14] B. A. Babu, P. S. Pokkunuri, M. Boddapati, S. S. Srigakolapu, M. Chintha, and T. S. C. Donepudi, “Design and analysis of a compact textile MIMO antenna for ISM band wearable applications,” in Proc. 2022 IEEE Delhi Section Conf. (DELCON), pp. 1–5, Feb. 2022

[15] P. B. Saha, R. K. Dash, and D. Ghoshal, “A CPW-fed trapezoidal shape wideband antenna with partial ground for WLAN and WiMAX applications,” in *Proc. 2020 7th Int. Conf. on Signal Processing and Integrated Networks (SPIN)*, 2020.

[16] J. C. Lin, “RF health safety limits and recommendations [Health Matters],” *IEEE Microw. Mag.*, vol. 24, no. 6, pp. 18–77, 2023.