



Design and Optimization of a Dual-Port UWB Implantable Antenna for Biomedical Applications

S Bhoopalan¹, B Monika², S Monisha³, S Gopika⁴

Assistant Professor, Department of Electronics and Communication Engineering, Muthayammal Engineering College,
Rasipuram, India¹

Student, Department of Electronics and Communication Engineering, Muthayammal Engineering College,
Rasipuram, India^{2,3,4}

Publication History: Received: 25.02.2026; Revised: 20.03.2026; Accepted: 25.03.2026; Published: 28.03.2026.

ABSTRACT: This paper presents a compact dual-port ultra-wideband (UWB) implantable antenna designed for biomedical telemetry and wireless body area network (WBAN) applications. The proposed antenna is realized on an FR4 substrate with a relative permittivity of $\epsilon_r = 4.4$ and occupies a compact volume of $13.75 \times 17.25 \times 1.6 \text{ mm}^3$. A seamless circular geometric pattern is introduced on the radiating patch to enhance impedance bandwidth, current distribution, and radiation efficiency while maintaining compactness. The dual-port configuration supports simultaneous transmission and reception with high isolation. The antenna performance is evaluated under two different biological conditions, namely with and without a fat-equivalent substrate. Simulation results demonstrate good impedance matching, strong port isolation, acceptable voltage standing wave ratio (VSWR), and stable operation in lossy tissue environments, confirming the suitability of the proposed antenna for implantable biomedical communication systems.

KEYWORDS: Implantable antenna, Ultra-wideband (UWB), Dual-port antenna, Biomedical telemetry, WBAN

I. INTRODUCTION

Implantable medical devices have gained significant attention due to their ability to enable continuous health monitoring, diagnosis, and therapeutic applications. Wireless communication is a key requirement for such devices, necessitating the development of compact, efficient, and biocompatible antennas. Ultra-wideband (UWB) technology is particularly attractive for biomedical applications because of its low power consumption, high data rates, and reduced interference. However, antenna design for implantable environments is challenging due to strict size constraints, high tissue losses, and detuning effects caused by surrounding biological tissues. To address these challenges, this paper proposes a compact dual-port tri-band UWB implantable antenna with a seamless circular geometric pattern to improve bandwidth and radiation performance.

II. ANTENNA DESIGN AND CONFIGURATION

The proposed antenna is designed as a dual-port microstrip patch antenna fabricated on an FR4 epoxy substrate with a thickness of 1.6 mm and a dielectric constant of 4.4. The overall antenna dimensions are $13.75 \text{ mm} \times 17.25 \text{ mm}$, making it suitable for integration within implantable medical devices as shown in the figure 1. A seamless circular-geometric tiling pattern is etched on the radiating patch to achieve uniform current distribution and multi-resonant behavior. This pattern is periodic in nature, ensuring smooth edge continuity and reduced surface wave losses. The dual-port feeding structure enables independent excitation of the antenna ports, thereby supporting simultaneous transmission and reception with improved isolation.

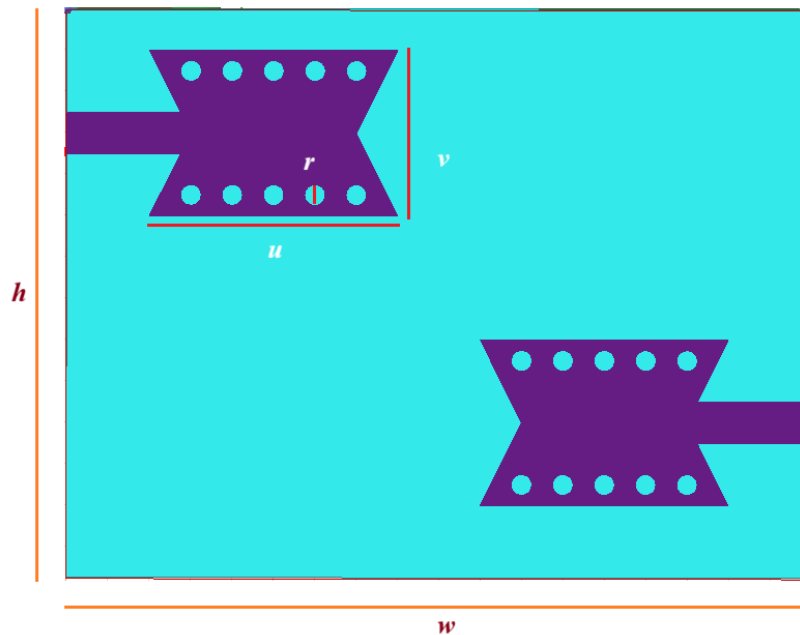


Figure 1: Proposed UWB implantable antenna

III. MATHEMATICAL MODELING OF SEAMLESS GEOMETRIC PATTERN

The seamless circular–geometric tiling pattern employed in the antenna design is based on periodic mathematical functions that repeat smoothly along both horizontal and vertical directions. Such patterns can be described using trigonometric functions with defined spatial periods, ensuring continuity at the boundaries. By incorporating circular and radial symmetry, the proposed pattern facilitates enhanced electromagnetic coupling and stable resonant characteristics. This approach contributes to tri-band operation and improved impedance bandwidth without increasing the antenna size.

Step 1: Seamless Cartesian Periodicity

A simple seamless base pattern along the Cartesian axes is defined as:

$$f(u, v) = \sin\left(\frac{2\pi u}{r_u}\right) + \sin\left(\frac{2\pi v}{r_v}\right) \quad (1)$$

This equation ensures periodicity and seamless repetition along the u and v directions. However, it produces linear wave patterns and lacks circular symmetry.

Step 2: Transformation to Circular / Radial Geometry

To introduce radial symmetry, the Cartesian coordinates are transformed into a radial distance:

$$\rho = \sqrt{u^2 + v^2} \quad (2)$$

Substituting this into a trigonometric function yields the circular seamless pattern can be written as:

$$f(u, v) = \cos\left(2\pi\sqrt{\left(\frac{u}{r_u}\right)^2 + \left(\frac{v}{r_v}\right)^2}\right) \quad (3)$$

Equation (3) produces concentric circular waveforms, ensuring seamless tiling while improving symmetry and current distribution.

Step 3: Introduction of Angular Modulation

To generate complex geometric tiling such as mandala- or flower-like structures, angular dependency is introduced using polar coordinates:

$$\theta = \tan^{-1}\left(\frac{v}{u}\right) \quad (4)$$

The angular modulation term is defined as:

$$\sin(k \cdot a \tan^2(v, u)) \quad (5)$$



where k controls the number of rotational symmetries. Combining radial and angular components gives:

$$f(u, v) = \sin(k \cdot a \tan 2(v, u)) \cdot \cos\left(\frac{2\pi}{r} \sqrt{u^2 + v^2}\right) \quad (6)$$

This equation produces intricate rotationally symmetric geometric patterns.

Step 4: Final Seamless Circular–Geometric Tiling Function

Replacing the sine angular term with a cosine function for smoother symmetry and expressing the angular dependency explicitly yields of a seamless circular–geometric tiling function with rotational symmetry can be expressed as:

$$f(u, v) = \sin\left(\frac{2\pi}{r} \sqrt{u^2 + v^2}\right) \cdot \cos\left(k \tan^{-1}\left(\frac{v}{u}\right)\right) \quad (7)$$

Where

- u, v : Cartesian coordinates on the radiating patch
- r : Radial repetition period (controls circular tiling density)
- k : Number of rotational symmetries (controls floral / mandala structure)
- $\sqrt{u^2 + v^2}$: Radial distance from the patch center
- $\tan^{-1}\left(\frac{v}{u}\right)$: Angular component ensuring circular symmetry

IV. RESULTS AND DISCUSSION

The result was taken with two different condition. Figure 2(a) and 2(b) represent the proposed antenna with and without fat for analyzing their performance.

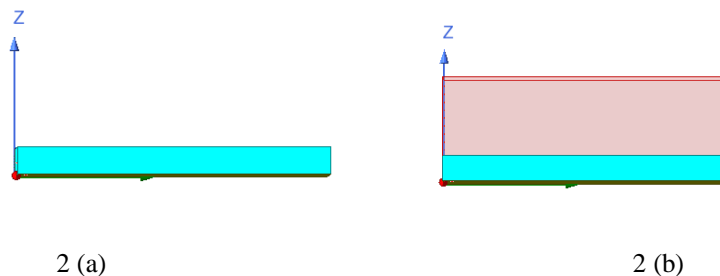
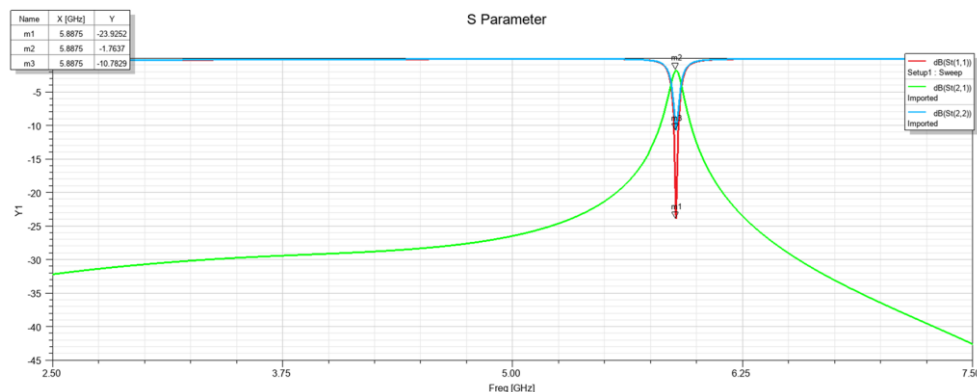
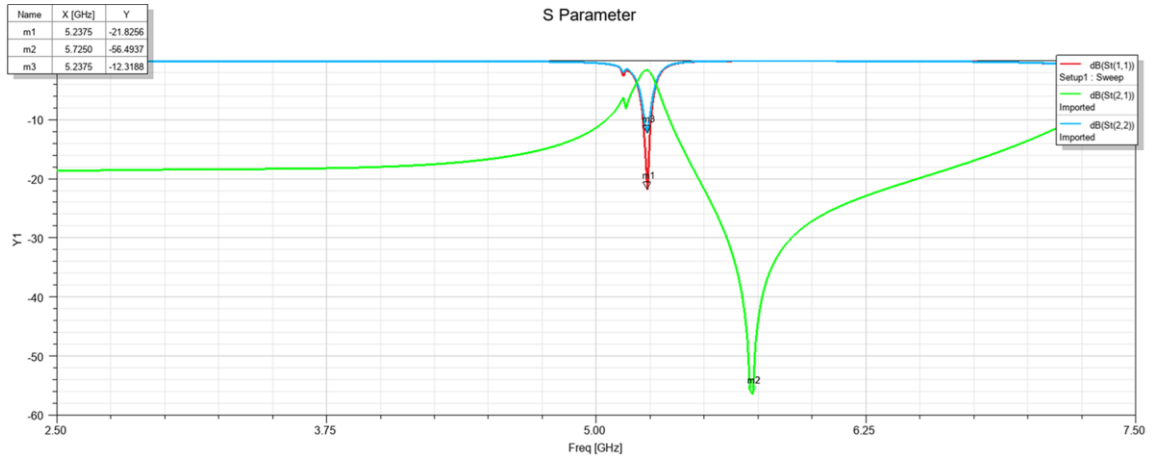


Figure 2(a): Antenna without fat material, 2(b): Antenna with fat material

Without the fat-equivalent substrate, the antenna exhibits a return loss of -1.76 dB at 5.88 GHz for S12 & S21 and -10.78 dB for S22, while achieving strong port isolation of -23.92 dB for S11. The corresponding VSWR values confirm good impedance matching of 1.1 dB. In the absence of the fat substrate, the antenna achieves a return loss of -23.92 dB at 5.88 GHz with acceptable VSWR characteristics. With the fat-equivalent substrate, the antenna exhibits a return loss of -12.31 dB at 5.23 GHz for S22 and -21.82 dB for S11, while achieving strong port isolation of -56.49 dB for S12 & S21. The corresponding VSWR values confirm good impedance matching of 1.41 dB. In the presence of the fat substrate, the antenna achieves a return loss of -56.49 dB at 5.72 GHz with acceptable VSWR characteristics.

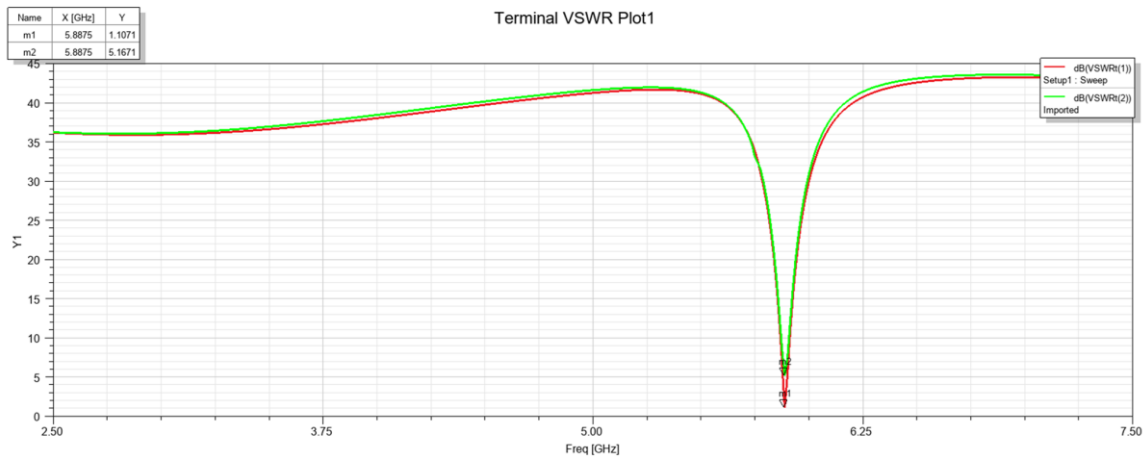


3 (a)

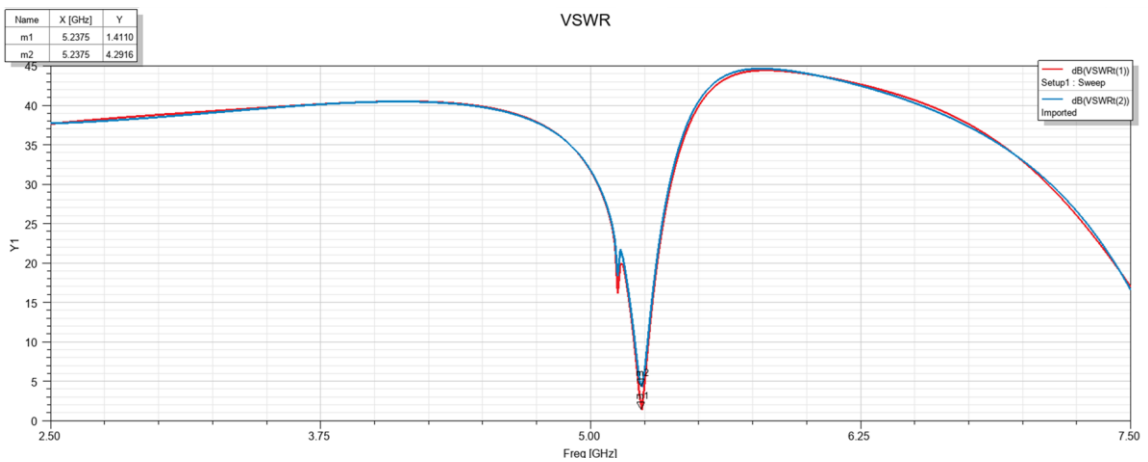


3 (b)

Figure 3 (a): Return loss of antenna without fat, 3 (b): Return loss of antenna with fat



4 (a)



4(b)

Figure 4 (a): VSWR of antenna without fat, 4 (b): VSWR of antenna with fat



Table 1: Performance analysis of return loss of proposed antenna with and without fat

S Parameter	Without Fat		With Fat	
	Return Loss (dB)	Frequency (GHz)	Return Loss (dB)	Frequency (GHz)
S11	-23.92	5.88	-21.82	5.23
S12 & S21	-1.76	5.88	-56.49	5.72
S22	-10.78	5.88	-12.31	5.23

Table 2: Performance analysis of VSWR of proposed antenna with and without fat

VSWR	Without Fat		With Fat	
	Value (dB)	Frequency (GHz)	Value (dB)	Frequency (GHz)
S11	1.1	5.88	1.41	5.23
S22	5.88	5.88	4.29	5.23

These results demonstrate that the proposed design provides efficient tri-band operation, strong isolation, and stable radiation behavior under varying tissue conditions.

V. CONCLUSION

A compact dual-port tri-band UWB implantable antenna employing a seamless circular geometric pattern has been presented. The proposed design achieves good impedance matching, high port isolation, and stable performance in both fat and non-fat tissue environments. The incorporation of the geometric pattern enhances bandwidth and radiation efficiency while maintaining a compact form factor. The obtained results confirm that the antenna is well suited for biomedical telemetry and WBAN applications, making it a promising candidate for next-generation implantable medical devices.

REFERENCE

- [1] S. N. Shah, M. Zada, J. Nasir, S. M. A. Shah, E. Arnieri and H. Yoo, "Dual-Band Two-Port MIMO Antenna for Biomedical Deep Tissue Communication: Design, Characterization, and Performance Analysis," in *IEEE Access*, vol. 11, pp. 104622-104632, 2023, doi: 10.1109/ACCESS.2023.3319216.
- [2] S. Ding, S. Koulouridis and L. Pichon, "Implantable Wireless Transmission Rectenna System for Biomedical Wireless Applications," in *IEEE Access*, vol. 8, pp. 195551-195558, 2020, doi: 10.1109/ACCESS.2020.3032848.
- [3] N. A. Malik, P. Sant, T. Ajmal and M. Ur-Rehman, "Implantable Antennas for Bio-Medical Applications," in *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, vol. 5, no. 1, pp. 84-96, March 2021, doi: 10.1109/JERM.2020.3026588.
- [4] C. He, Y. Liu, T. P. Ketterl, G. E. Arrobo and R. D. Gitlin, "Performance evaluation for MIMO in vivo WBAN systems," 2014 *IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-Bio2014)*, London, UK, 2014, pp. 1-3, doi: 10.1109/IMWS-BIO.2014.7032380.
- [5] J. M. Felicio, J. R. Costa and C. A. Fernandes, "Dual-Band Skin-Adhesive Repeater Antenna for Continuous Body Signals Monitoring," in *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, vol. 2, no. 1, pp. 25-32, March 2018, doi: 10.1109/JERM.2018.2806186.
- [6] A. J. Alazemi and A. Iqbal, "A High Data Rate Implantable MIMO Antenna for Deep Implanted Biomedical Devices," in *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 2, pp. 998-1007, Feb. 2022, doi: 10.1109/TAP.2021.3111186.
- [7] S. Ahlawat et al., "Design and Performance Measurement of Implantable Differential Integrated Antenna for Wireless Biomedical Instrumentation Applications," in *IEEE Transactions on Instrumentation and Measurement*, vol. 71, pp. 1-10, 2022, Art no. 5502110, doi: 10.1109/TIM.2022.3185622.
- [8] S. Ishraq, M. A. Imran, K. Alam and M. M. Khan, "Implantable UWB Microstrip Patch Antenna for Biomedical Applications," 2024 *International Conference on Sustainable Communication Networks and Application (ICSCNA)*, Theni, India, 2024, pp. 327-332, doi: 10.1109/ICSCNA63714.2024.10864098.



- [9] S. Chakraborty, A. J. Islam, M. Mehedi Farhad, M. Mahmudul Hasan, M. Siddat Bin Nesar and M. A. Rahaman, "Performance Studies of UWB Microstrip Antenna for Multipurpose Biotelemetry Applications," 2018 International Conference on Innovations in Science, Engineering and Technology (ICISSET), Chittagong, Bangladesh, 2018, pp.322-327, doi:10.1109/ICISSET.2018.8745572.
- [10] H. M. A. Rahman, S. Ishraq, S. Yeamin, T. N. Khan and M. M. Khan, "Implantable Ultra Wideband (UWB) Antenna for Wireless Body Centric Network Based Medical Applications," 2024 IEEE International Conference on Biomedical Engineering, Computer and Information Technology for Health (BECITHCON), Dhaka, Bangladesh, 2024, pp. 181-186, doi: 10.1109/BECITHCON64160.2024.10962617.
- [11] K. Albaden, S. Ahmad, G. Elzwawi and T. A. Denidni, "Compact and Wideband Implantable Antenna for Biomedical Applications," 2025 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting (AP-S/CNC-USNC-URSI), Ottawa, ON, Canada, 2025, pp. 2580-2583, doi: 10.1109/AP-S/CNC-USNC-URSI55537.2025.11266578.
- [12] K. Yekeh Yazdandoost, "UWB antenna for body implanted applications," 2012 42nd European Microwave Conference, Amsterdam, Netherlands, 2012, pp. 932-935, doi: 10.23919/EuMC.2012.6459433.
- [13] M. Ghafari, P. Brennan and M. Ghavami, "UWB power propagation for bio-medical implanted devices," 2015 17th International Conference on E-health Networking, Application & Services (HealthCom), Boston, MA, USA, 2015, pp. 483-487, doi: 10.1109/HealthCom.2015.7454551.
- [14] F. Faisal, M. Zada, A. Ejaz, Y. Amin, S. Ullah and H. Yoo, "A Miniaturized Dual-Band Implantable Antenna System for Medical Applications," in IEEE Transactions on Antennas and Propagation, vol. 68, no. 2, pp. 1161-1165, Feb. 2020, doi: 10.1109/TAP.2019.2938591.
- [15] A. Lamkaddem, A. El Yousfi, Y. Huang, V. González Posadas and D. Segovia-Vargas, "Miniaturized Wireless Power Transfer System With a Dual-Band Implantable Antenna for Multifunctional Biomedical Devices," in IEEE Sensors Journal, vol. 25, no. 16, pp. 31473-31488, 15 Aug.15, 2025, doi: 10.1109/JSEN.2025.3587334.
- [16] R. N. Tiwari, D. Sharma, P. Singh and P. Kumar, "Design of Dual-Band 4-Port Flexible MIMO Antenna for mm-Wave Technologies and Wearable Electronics," in IEEE Access, vol. 12, pp. 96649-96659, 2024, doi: 10.1109/ACCESS.2024.3412712.
- [17] C.Nagarajan and M.Madheswaran - 'Stability Analysis of Series Parallel Resonant Converter with Fuzzy Logic Controller Using State Space Techniques'- Taylor & Francis, Electric Power Components and Systems, Vol.39 (8), pp.780-793, May 2011. DOI: 10.1080/15325008.2010.541746
- [18] C.Nagarajan and M.Madheswaran - 'Experimental verification and stability state space analysis of CLL-T Series Parallel Resonant Converter' - Journal of Electrical Engineering, Vol.63 (6), pp.365-372, Dec.2012. DOI: 10.2478/v10187-012-0054-2
- [19] C.Nagarajan and M.Madheswaran - 'Performance Analysis of LCL-T Resonant Converter with Fuzzy/PID Using State Space Analysis'- Springer, Electrical Engineering, Vol.93 (3), pp.167-178, September 2011. DOI 10.1007/s00202-011-0203-9
- [20] S.Tamilselvi, R.Prakash, C.Nagarajan, "Solar System Integrated Smart Grid Utilizing Hybrid Coot-Genetic Algorithm Optimized ANN Controller" Iranian Journal Of Science And Technology-Transactions Of Electrical Engineering, DOI10.1007/s40998-025-00917-z,2025
- [21] S.Tamilselvi, R.Prakash, C.Nagarajan, " Adaptive sliding mode control of multilevel grid-connected inverters using reinforcement learning for enhanced LVRT performance" Electric Power Systems Research 253 (2026) 112428, doi.org/10.1016/j.epr.2025.112428
- [22] S.Thirunavukkarasu, C. Nagarajan, 2024, "Performance Investigation on OCF and SCF study in BLDC machine using FTANN Controller," Journal of Electrical Engineering And Technology, Volume 20, pages 2675–2688, (2025), doi.org/10.1007/s42835-024-02126-w
- [23] C. Nagarajan, M.Madheswaran and D.Ramasubramanian- 'Development of DSP based Robust Control Method for General Resonant Converter Topologies using Transfer Function Model'- Acta Electrotechnica et Informatica Journal , Vol.13 (2), pp.18-31, April-June.2013, DOI: 10.2478/aei-2013-0025.
- [24] C.Nagarajan and M.Madheswaran - 'DSP Based Fuzzy Controller for Series Parallel Resonant converter'- Springer, Frontiers of Electrical and Electronic Engineering, Vol. 7(4), pp. 438-446, Dec.12. DOI 10.1007/s11460-012-0212-0.
- [25] C.Nagarajan and M.Madheswaran - 'Experimental Study and steady state stability analysis of CLL-T Series Parallel Resonant Converter with Fuzzy controller using State Space Analysis'- Iranian Journal of Electrical & Electronic Engineering, Vol.8 (3), pp.259-267, September 2012.
- [26] Mathew, A. (2021). Edge Computing and its convergence with blockchain in 6G: Security challenges. Int. J. Comput. Sci. Mob. Comput, 10(8), 8-14.



- [27] Gopinathan, V. R. (2025). AI-Powered Kubernetes Orchestration for Complex Cloud-Native Workloads. *International Journal of Research Publications in Engineering, Technology and Management (IRPETM)*, 8(6), 13215-13225.
- [28] Mathew, A. (2023). Learning Metaverse Powered by Artificial Intelligence. *Recent Progress in Science and Technology* Vol. 4, 4, 134-141.
- [29] C.Nagarajan and M.Madheswaran, "Analysis and Simulation of LCL Series Resonant Full Bridge Converter Using PWM Technique with Load Independent Operation" has been presented in ICTES'08, a IEEE / IET International Conference organized by M.G.R.University, Chennai.Vol.no.1, pp.190-195, Dec.2007
- [30] Suganthi Mullainathan, Ramesh Natarajan, "An SPSS and CNN modelling based quality assessment using ceramic materials and membrane filtration techniques", *Revista Materia (Rio J.)* Vol. 30, 2025, DOI: <https://doi.org/10.1590/1517-7076-RMAT-2024-0721>
- [31] M Suganthi, N Ramesh, "Treatment of water using natural zeolite as membrane filter", *Journal of Environmental Protection and Ecology*, Volume 23, Issue 2, pp: 520-530,2022
- [32] A. Iqbal, M. Al-Hasan, I. B. Mabrouk and T. A. Denidni, "Deep-Implanted MIMO Antenna Sensor for Implantable Medical Devices," in *IEEE Sensors Journal*, vol. 23, no. 3, pp. 2105-2112, 1 Feb.1, 2023, doi: 10.1109/JSEN.2022.3232727.
- [33] U. Musa et al., "Design and Analysis of a Compact Dual-Band Wearable Antenna for WBAN Applications," in *IEEE Access*, vol. 11, pp. 30996-31009, 2023, doi: 10.1109/ACCESS.2023.3262298.
- [34] S. Modak, V. Kaim, T. Khan, B. K. Kanaujia, L. Matekovits and K. Rambabu, "Design and Performance Measurement of Worn-on-Body Instrumental Ultra-Miniaturized UWB Wearable Patch for e-Health Monitoring," in *IEEE Access*, vol. 12, pp. 25719-25730, 2024, doi: 10.1109/ACCESS.2024.3365938.
- [35] J. Chu et al., "An Ultrawideband Implantable Antenna With Hybrid Polarization for Human Health Monitoring," in *IEEE Antennas and Wireless Propagation Letters*, vol. 24, no. 9, pp. 2859-2863, Sept. 2025, doi: 10.1109/LAWP.2025.3575448.
- [36] A. J. Islam, S. Pranta, S. Salehin, N. Das, M. R. Ahmed Shawon and S. S. Alam, "Performance Analysis of Human Tissue-Embedded Antennas for Enhanced Wireless Power Transfer in Medical Implants," 2024 6th International Conference on Electrical Engineering and Information & Communication Technology (ICEEICT), Dhaka, Bangladesh, 2024, pp. 01-06, doi: 10.1109/ICEEICT62016.2024.10534512.