

DEVELOPMENT OF A SPLIT RING RESONATOR-LOADED IMPLANTABLE ANTENNA FOR HIGHER ISM BAND HEALTHCARE COMMUNICATIONS

K. Sajith, V. Chaithra, Athulya Gopinath, N.N. Jithin Babu

Department of Electronics and Communication Engineering, Government College of Engineering, Kannur, India

Abstract

This paper presents the design and development of Coplanar Wave Guide (CPW) fed Octagonal Ring T-Slot Antenna (ORTSA) for Industrial Medical Service (ISM) band (5.72-5.87GHz) applications. The antenna size is 20mm x 20mm x 1.6mm and it is fabricated on Teflon substrate. The proposed antenna comprises an octagonal ring structure integrated with a T-shaped slot. The geometric parameters of the antenna are carefully optimized to enhance the impedance bandwidth and improve the realized gain over the desired operating frequency range. By placing Split Ring Resonator (SRR) with bio-layers the proposed antenna under measurement achieves 28dB return loss, 1.82dBi gain, 1190MHz bandwidth at 5.75GHz as a resonant frequency. The simulated and measured results demonstrate that the proposed antenna achieves an improved gain–bandwidth performance compared with existing biomedical antennas reported in the literature. Therefore, it can be considered a promising candidate for wireless biomedical applications.

Keywords:

Implantable Antenna (IMA), Antenna Gain, CPW, Specific Absorption Rate (SAR), ISM-band, SRR

1. INTRODUCTION

Biomedical systems stimulated the real-time monitoring of vital physiological parameters such as body temperature, blood pressure, and glucose levels. With the fast advancement of the Internet of Medical Things (IoMT), implantable and epidermal antennas have become important for establishing reliable wireless communication between medical devices and external monitoring systems, in that way supporting efficient healthcare monitoring and diagnosis [1]. Recently, implantable antennas are essential devices designed to communicate within the human body. These antennas are used in many medical applications such as ISM communication, early detection of disease, diagnostics and other applications. Modern implantable medical devices are designed to possess several important features, including biocompatibility, compact size, long battery life, low cost, and reliable performance. In addition, these devices must operate safely within the human body while complying with relevant medical regulations and safety standards (IEEE C95.1-2019 and IEEE C95.1-2005 standards). Therefore, implantable antennas must meet several critical design requirements, including miniaturized dimensions, multiband functionality, stable radiation characteristics, high data transmission capability, effective impedance matching, and compliance with specific absorption rate (SAR) safety regulations [2]. The main challenges faced the implantable antenna design are interference problem, power-supply issue, conformal issue, and reliability, etc. Biocompatibility is the capability of substance to react with bio-tissues without causing toxicity, inflammation, immune rejection, or other conflicting biological retorts. For IMA, the materials used must not cause any immune reactions in the body, such as

irritation, infection, or harmfulness [3]. The biocompatibility is vital role for the design of implantable antennas, confirming that they can function efficiently within the body without causing risk. In general, an implanted antenna's gain in the higher frequency bands is negative, whereas its gain in the lower frequency band is positive. In high-frequency band antennas is absorb or attenuate electromagnetic waves more quickly, therefore, the propagated wave quickly disappeared with very small spatial distance. Generally biomedical implantable wireless communications operated in the MedRad frequency bands (401-406, 413-419, 426-432, 438-444, 451- 457MHz), MICS band (402-405 MHz), and ISM band frequencies (2.4-2.5GHz and 5.72-5.87GHz) [4]-[6]. Fig.1 clearly demonstrates the location of the implantable antenna for establishing wireless biomedical communication.

Research on implantable antenna design is growing globally in various universities and institutions. A compact planar asymmetric coplanar strip (ACS)-fed patch antenna operated for 5.2/5.8 GHz WLAN and ISM applications. The ACS fed half u-shaped antenna achieves enhanced gain and directivity without employing additional parasitic elements and fabricated on an FR4 substrate with a relative permittivity of 4.4, the antenna occupies a compact size of $20 \times 9.1 \times 1.6 \text{ mm}^3$, making it fit for ISM band applications [4]. Abdenasser et.al [5], discussed a double-band IMA with a gain of -22dBi and -19dBi, used for healthcare monitoring applications. Kottouri et.al [7], discussed the IMA and designed to operate at 915MHz and 2.4GHz, this implantable antennas are frequently made of biocompatible materials like rogers or biocompatible polymers. These biocompatible materials helps the antenna won't damage any organs or tissue. A flexible full-duplex antenna operating at 5.8 GHz is designed using PET and foam substrates. The antenna incorporates two rectangular patches and a defected ground structure to achieve a 400 MHz bandwidth and high isolation performance ($S_{21} < -45 \text{ dB}$), making it suitable for wireless communication applications [9].

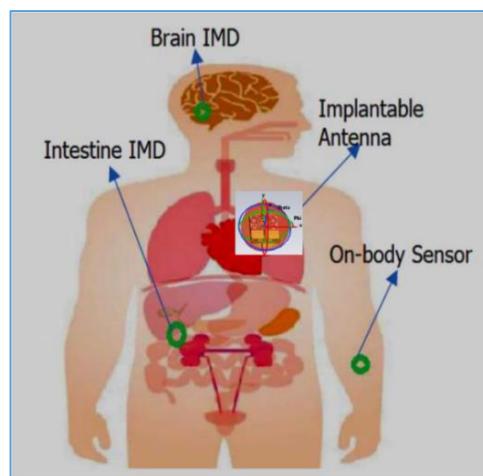


Fig.1.Location of IMA and sensors

The introduction of implantable devices and implantable antenna is covered in section 1. Section 2 provides an explanation of the ORTSA antenna design steps as well as its various parametric values. Section 3 presents simulation and experimental results, and ORTSA antenna analysis for ISM band communication. The conventional antenna is challenged by low gain and bandwidth, while the proposed antenna overcomes this problem by using CPW feed and SRR-loaded techniques, and achieved enhanced gain and bandwidth. The performance comparison between existing antenna and proposed antenna is mentioned in section 3. The concluding section of the ORTSA is provided in section 4.

2. DESIGN METHODOLOGY OF ORTSA

The bio-membrane (skin), radiating element, substrate with SRR, and additional bio-layers (fat and muscle) are clearly demonstrates in Fig.2. The CPW feedline is connected to the radiating patch and SRR structure is inspired at the backside of substrate [10]-[12]. The Teflon material is inexpensive and widely accessible, with dielectric value is 2.1, utilized as a bio-compatible substrate. The proposed antenna design methodology consists of two sequential phases: conventional antenna design in a free-space environment, followed by biomedical modeling and performance evaluation within human tissues. The proposed antenna is premeditated and simulated by CST Studio Suite, a widely used high-frequency electromagnetic simulation software coded on numerical techniques such as the Transmission Line Matrix (TLM) and Finite Element Method (FEM). The designed model is created using an iterative, parametric design process, using tetrahedral meshing with a finite element technique. The final phase of antenna structure achieves resonance within the ISM-band (5.72-5.87GHz). To preserve simplicity and conciseness, only the optimized design is shown, whereas the intermediate iterative design phases are omitted from the discussion.

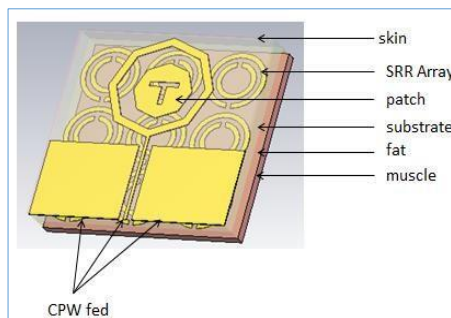


Fig.2. 3D View of proposed antenna with SRR Array

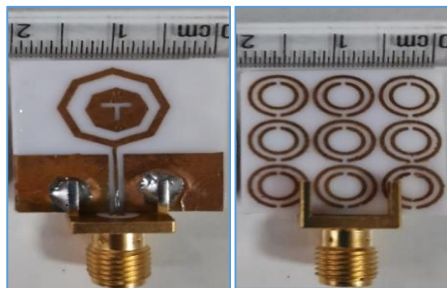


Fig.3. Fabricated antenna front and back view

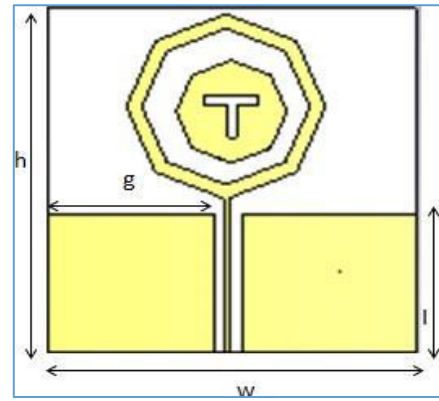


Fig.4. Dimensions of ORTSA antenna

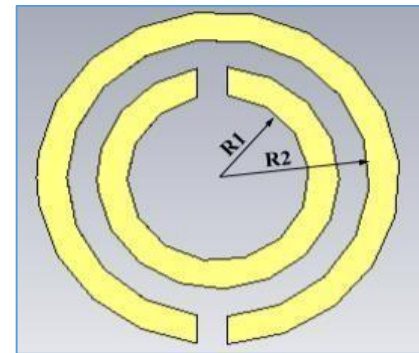


Fig.5. Dimensions of unit cell

Table.1. ORTSA specifications

Parameter	Value (mm)	Parameter	Value (mm)
h	20	w	20
I	7	g	9.1
R_1	2	R_2	3

Fig.3 shows the fabricated ORTSA implantable medical antenna (IMA) from the front and back perspectives. The antenna is fabricated on a Teflon substrate ($\epsilon_r=2.1$, $\mu_r=1$) with copper metallization for the CPW feed line and ground planes. The substrate is white in color, while the copper conducting regions appear light golden. The Fig.4 shows the sizes of the CPW Fed ORTSA antenna. The overall dimensions of the antenna are 20 mm $\times$ 20 mm. The preliminary dimensions of the ORTSA radiating element are derived from the conventional rectangular microstrip patch antenna (RMSA) design equations conforming to the desired operating frequency. Then, the antenna geometry is optimized through parametric analysis to realize the desired resonant topographies and impedance matching. A CPW feeding structure is used to excite the ORTSA antenna. The CPW ground planes have dimensions of 7mm $\times$ 9.1mm and are located symmetrically on either side of the feed line. The conducting regions, including the radiating element, feed line, and ground planes, are fabricated using copper metallization [12]. The Fig.5 shows the back-view of designed SRR unit cell. At the resonant frequency, oscillating currents flow through the rings, and this current produces a magnetic dipole moment perpendicular to the axis of the rings, which produces a negative permeability property of the SRR array, these phenomena simultaneously lead to

increased bandwidth and gain. The detailed dimensions of ORTSA antenna are summarized in Table.1.

3. PERFORMANCE ANALYSIS OF ORTSA

3.1 RETURN LOSS OF ORTS ANTENNA

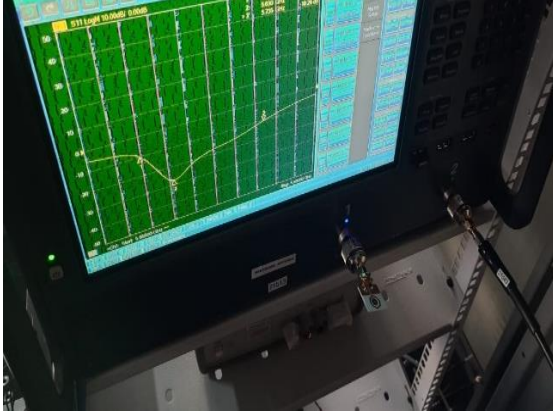


Fig.6. Measurement for $|S_{11}|$ Parameter

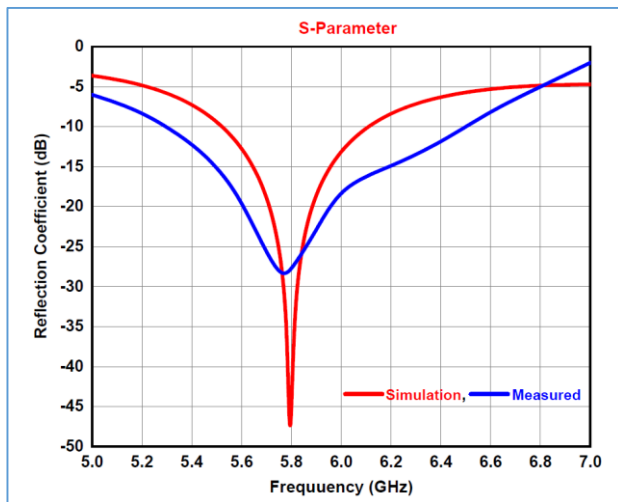


Fig.7. RL versus freq. plot of at ISM band

The Fig.6 presents the measured $|S_{11}|$ response of the ORTSA antenna, demonstrating satisfactory impedance matching and confirming the antenna's operation in the ISM band. The most important objective of this designed ORTSA prototype is enhancement of gain, bandwidth, and miniaturization, minimizing the SAR. Return loss, also known as magnitude of reflection coefficients, is the ratio of incident power to reflected power. The return loss plot of bio-tissue layers is shown in Fig.7. The SRR loaded radiator resonates at 5.79GHz, 52dB return loss and 582MHz bandwidth is observed under the simulation, similarly measurement results shows 28dB return loss and 1190MHz bandwidth is observed at resonant frequency of 5.75GHz, both case the resonant frequency response is lies in between the ISM band (5.72 to 5.82GHz). The Eq.(1) lay down the relationship between return loss and reflection coefficient [6].

$$RL = -20\log_{10}|S_{11}| \quad (1)$$

where RL is return loss and $|S_{11}|$ is reflection coefficient.

3.2 VSWR OF ORTS ANTENNA

The Fig.8 shows the VSWR versus frequency Plot of simulated and measured value of ORTSA shaped antenna. The simulated VSWR value of ORTSA shaped antenna with bio-tissue layer reaches a minimum 1.009 at 5.79GHz. whereas measured VSWR value reached a 1.082 at resonant frequency of 5.75GHz. The slit deviation between the simulation and measurement results can be attribute to fabrication tolerance and measurement uncertainties, material property variation, etc. Nevertheless, the measured response follows the similar behavior of the simulated results, this confirms the effectiveness of the impedance matching characteristics achieved in both the design and experiment validation.

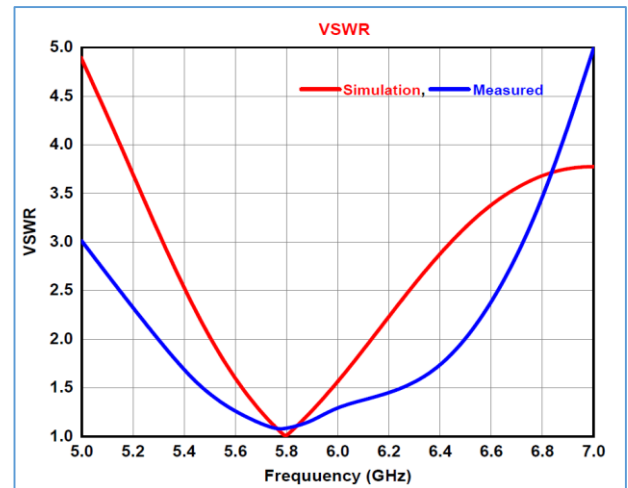


Fig.8. VSWR v/s frequency plot of ORTSA

3.3 SURFACE CURRENT OF ORTS ANTENNA

The surface current distribution of the proposed CPW-fed antenna was studied to examine its radiation behavior and to identify the main radiating regions. The simulated results shows that the maximum surface current density spreads around 366A/m, signifying the solid electromagnetic excitation within the radiating patch.

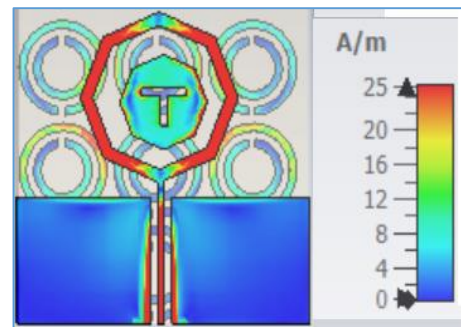


Fig.9. 2D view of surface current density

The Fig.9 shows the surface current distribution profile is demonstrated with a color scale ranging from 0 to 25A/m to augment the visualization of current flow pattern across the whole antenna surface. Such scaling is normally employed in antenna simulation software to enhance the view of current variations in antenna structure where the current density is moderately low

likened to the maximum value. It can be observed that the current is mainly concentrated around the CPW feed line and the edges of the radiating element, verifying the resourceful power transfer and excitation of the resonant modes. Therefore, the observed surface current distribution confirms the effective excitation of the proposed ORTSA shaped antenna and reveals that the CPW-fed arrangement positively supports the anticipated resonant behavior, foremost to enhanced antenna characteristics.

3.4 SAR OF ORTS ANTENNA

The SAR distribution result exposes a peak SAR point value of 0.25 W/g at a resonant frequency 5.75GHz, seen at the top of the radiating patch, whereas the nearby biological tissue shows a significantly lower SAR value of approximately 0.0001 W/g as shown in Fig.10.

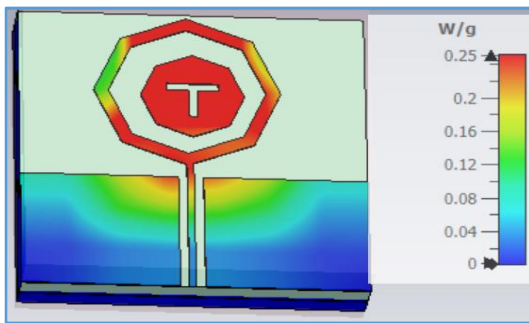


Fig.10. 2D view of SAR point value at 5.75GHz

This significant difference indicates that the absorbed useful radiated power is mainly concentrated radiating element, instead of surrounding biological tissues. Furthermore, the simulated SAR levels in the skin, fat, and muscle layer remain significantly below generally accepted safety limits, signifying that the proposed radiating structure efficaciously confines electromagnetic exposure while minimizing undesirable radiated power absorption in the surrounding tissue [1]. These results confirm the limited nature of the radio-frequency interaction and this behavior supports the suitability of the proposed design for biomedical applications requiring controlled energy deposition while minimizing exposure to surrounding biological tissues.

3.5 GAIN OF ORTS ANTENNA

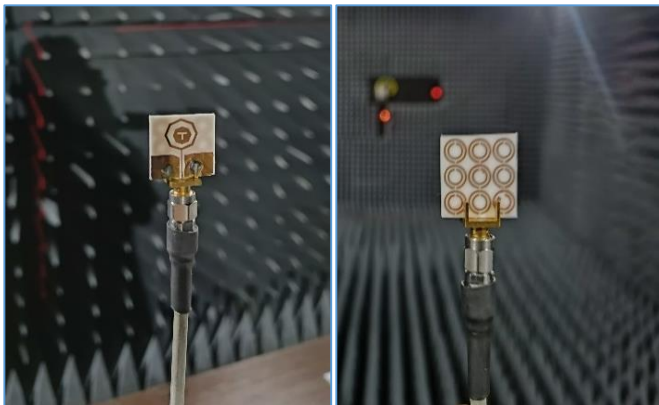


Fig.11. Antenna Gain Measurement

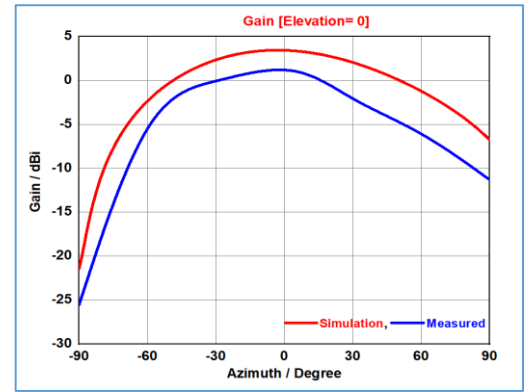


Fig.12. antenna gain vs azimuth angle.

Fig.11 shows the experimental setup used for antenna gain measurement. The measurement was carried out to confirm the radiation characteristics of the developed antenna under practical scenario. Fig.12. illustrates the azimuth radiation pattern of the proposed ORTSA antenna at an elevation angle of 0°, where the gain is plotted as a function of azimuth angle. Both simulated and measured results shows a similar gain pattern. The simulated radiation pattern achieves a peak gain of 3.82dBi at an azimuth angle of 0°, whereas the measured result shows a maximum gain of 1.82dBi at the same direction. The observed reduction in measured gain may be attributed to fabrication tolerances, dielectric property variations, conductor losses, connector losses, etc. Nevertheless, the measured pattern follows the overall behavior of the simulated response, this indicating the ORTSA-shaped antenna gain pattern performs as a predictable way under practical condition.

Finally, the proposed antenna is compared with previously reported biomedical implantable antennas in terms of gain, bandwidth, SAR value, as shown in Table.2. Compared to the cited works, the proposed antenna is smaller in size and higher in the gain-bandwidth value, and acceptable SAR levels, making it a promising prototype for biomedical implantable applications.

Table.2. Comparison of referred versus proposed work

Reference	Bandwidth (MHz)	Gain (dBi)
[1]	490	0.81
[2]	510	-20.3
[5]	310	-21.8
[8]	480	-16.5
[9]	402	-32
[13]	200	-10
This work (measured)	1190	1.8

4. CONCLUSION

The designed antenna operates in the ISM band frequency range (5.72-5.87GHz) with a resonant frequency of 5.75GHz. The SRR-inspired co-planar waveguide-fed ORTSA-shaped antenna is mainly used for healthcare monitoring applications.

The micro-size antenna measures 20mm×20mm×1.6mm. An SRR structure is integrated into the proposed ORSTA antenna to realize size reduction and performance improvement. The incorporation of the SRR-array significantly enhances the gain and bandwidth with in the (5.72-5.87GHz) ISM band. The close agreement between simulation and measurement results confirms the validity of the design process of ORSTA antenna. Therefore, the performance parameters of the proposed antenna demonstrate that it is a promising candidate for ISM-band implantable biomedical applications.

REFERENCES

- [1] O.F. Celik and A. Yazgan, "A Conformal Monopole Hair-Like Epidermal Antenna for Multitasking Implantable IoMT Applications", *IEEE Antennas and Wireless Propagation Letters*, Vol. 25, pp. 2591-2595, 2026.
- [2] A. Alshammari, M. Zada and I.B. Mabrouk, "Compact In-Band Full-Duplex Antenna for Deeply Implantable Biomedical IoT Applications", *IEEE Internet of Things Journal*, Vol. 13, pp. 22415-22424, 2026.
- [3] M.R. Soares and D. Albuquerque, "Dual-Band Patch Antenna for On-Body to In-Body Applications", *Proceedings of International Conference on Microwave Biomedical*, pp. 1-3, 2026.
- [4] S.M. Nair and M. Abraham, "ACS Fed Enhanced Gain Directive Antenna for 5.2/5.8 GHz WLAN and ISM Applications", *ICTACT Journal on Microelectronics*, Vol. 11, No. 3, pp. 2177-2182, 2025.
- [5] L. Abdenasser and S.V. Daniel, "Miniaturized Dual-Band Implantable Antenna for Implanted Biomedical Devices", *IEEE Access*, Vol. 12, pp. 15026-15036, 2024.
- [6] V.M. Harikrishnan, Aswani and K. Sajith, "Design of Co-Planar Waveguide Fed Split Ring Resonator Loaded Diamond Shaped Antenna for Industrial Scientific Medical Radio Communication", *Proceedings of International Conference on Advanced Power, Communication and Intelligent Systems*, pp. 1-4, 2024.
- [7] A. Kiourti and A.M. Abbosh, "Next-Generation Healthcare: Enabling Technologies for Emerging Bio-Electromagnetics Applications", *IEEE Open Journal of Antennas and Propagation*, Vol. 3, pp. 363-390, 2022.
- [8] A. Iqbal and M. Yousaf, "Ultra Miniaturized Antenna for Deeply Implanted Biomedical Devices", *IEEE Access*, Vol. 10, pp. 54563-54571, 2022.
- [9] R. Hossain and A.A. Mertvy, "A High Gain Flexible Antenna for Full Duplex System at 5.8 GHz with Defected Ground Structure", *Proceedings of IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting*, pp. 1040-1041, 2022.
- [10] T.J. Sweety, K. Sajith and T.R. Arun, "CB-CPW Fed Double Sided Figure of Eight Shape Implantable Antenna for WBAN Applications", *Proceedings of International Conference on Intelligent Computing, Instrumentation and Control Technologies*, pp. 1284-1287, 2022.
- [11] A. Rithika and K. Sajith, "CPW Fed SRR Inspired Decagon-Trident Slotted Shape Antenna for On-Body Communication", *Proceedings of International Conference on Microwave, Antennas and Propagation*, pp. 707-710, 2022.
- [12] T.J. Sweety, K. Sajith and T.R. Arun, "A Micro-Size CB-CPW Fed Implantable Antenna for High Frequency ISM Band Applications", *Proceedings of International Conference on VLSI Systems, Architecture, Technology and Applications*, pp. 1-4, 2022.
- [13] H. Liu, X. Xiao, "Flexible CPW-Fed Fishtail-Shaped Antenna for Dual Band Applications", *IEEE Access*, Vol. 13, pp. 54578-54689, 2014.