Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

Starch Nanoparticle Encapsulated Biocompatible Implantable Antenna Design for Smart and Safe Patient Monitoring at 2.45 GHz

Sanjana Chatterjee, Pratik Das, Piyali Basak
School of Bioscience and Engineering (Biomedical Engineering)
Jadavpur University
Kolkata – 700032, India

Soham Ghosh, Bhaskar Gupta
Electronics and Telecommunication Engineering
Jadavpur University
Kolkata 700032, India

Abstract— **Smart patient monitoring enhances requirement of implantable antenna for transferring the sensed health parameters wirelessly to external monitoring devices. Use of Starch-nanoparticle (St-NP) as a biocompatible encapsulation of implantable antenna instead of previously used materials (Teflon, MACOR etc.) provides several advantages like better biocompatibility and facility of drug delivery along with provision of wireless communication. In this work, St-NP layer is developed to encapsulate a 22X8 mm2 meander-line implantable antenna operating at 2.45 GHz ISM band. St-NP is produced by mixing Corn starch powder in de-ionized water along with using some techniques like ultrasonication, stirring and centrifugation. The characterization results show that the average size of the St-NP is less than 100 nm. A six-meanderline implantable antenna is designed within a homogeneous human body phantom which has return loss and realized gain of 15.87 dB and -23.7 dBi respectively. It is fabricated and encapsulated within gelatinized St-NP. The encapsulated antenna is measured within homogeneous body phantom developed utilizing DI water, DGME and NaCl. The fabricated antenna has return loss of 14.53 dB and realized gain of -25.69 dBi at 2.43 GHz. The use of St-NP as a biocompatible encapsulation of implantable antenna is the novel approach of this work.**

Keywords— **Starch nanoparticle, biocompatible, implantable antenna, Patient monitoring, TEM**

I. INTRODUCTION

According to the latest statistical analysis, about 30% of urban people and about 20% of rural people in India are suffering from chronic diseases such as cardiovascular disease, diabetes, hyper tension, etc. [1, 2]. In the modern era of health science, safe and continuous patient monitoring is one of the prime focus of engineers as well as doctors. The use of implantable antenna can increase the quality of smart patient monitoring. Implantable antenna embedded in Implantable Medical Device (IMD) can provide a facility of transferring sensed parameters (blood pressure, sugar content, hormonal imbalance etc.) wirelessly to the external monitoring devices [3-5]. The significant factors required for crafting implantable antenna are miniaturization of antenna, high lossy tissue layers, low input power restriction, Specific Absorption Rate (SAR) etc. [4-6]. Implantable antennas can be implemented in different medical applications such as glucose monitoring [4], intracranial pressure monitoring [7-8], cardiac telemetry [9] etc. In previous works, there are many investigations on shape, bandwidth, size, operation frequency, gain etc. as a novelty in the research regarding implantable antenna [10]. However, there are very limited works available related to the importance of biocompatibility for implantable antenna design, which is very important for patient's safety.

Biocompatibility of implantable antenna is important for preserving patient's safety and preventing the rejection of implants [11]. Tissue layers of human body are conductive in nature. As the patch element and ground plane of antenna are also conductors, there may be a possibility of short circuit condition between human tissue and the implantable antenna while direct contact will happen. It can hamper as well as cause death to the patient [12]. Extensively used biocompatible materials for implantable antenna design are alumina (ceramic), Teflon (polymer), MACOR (machinable glass-ceramic), zirconia (ceramic), biomedical-grade base elastomer (polymer) etc. [9, 13-14]. In this work, a novel approach of biocompatible encapsulation of the implantable antenna using starch nanoparticle (St-NP) is proposed. Starch is a biocompatible, biodegradable, eco-friendly biopolymer with large number of glucose units connected with glycosidic bonds. Starch mainly contains amylopectin and amylase. It is highly compatible with human tissues due to similar biochemical components as the extra cellular matrix of human body [15]. Starch is widely used in different industrial applications such as drug delivery, pharmaceuticals etc. Nanoparticle takes leading role in drug delivery.

In this manuscript, a starch nanoparticle based encapsulated implantable antenna operated at 2.45 GHz Industrial, Scientific and Medical band has been designed. St-NP is chosen here as a biocompatible encapsulation not only to ensure biocompatibility but also to provide a facility of controlled drug delivery to the patient and sensing continuous health parameters such as blood sugar, pressure level etc. Nanomaterial composes of atoms or molecules, whose size ranges from 1-100 nm [16]. Performing Dynamic light scattering (DLS), the average size of the starch solution is obtained as 62.36 nm which is within the range of being

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

nanoparticle. Transmission Electron Microscope (TEM) is also carried out to verify the size as well as the distribution of nanoparticles. Then a meander line implantable antenna is designed and fabricated. It is placed into gelatinized St-NP and is kept at 10ºC for 2 days to solidify. The encapsulated antenna is measured within human body phantom.

II. ST-NP GENERATION AND CHARACTERIZATION

A. Materials

Cornstarch powder is obtained from Foodfrillz, De-ionized (DI) water is from IC centre, Jadavpur University, and 90% Ethanol obtained from Merck India Pvt Ltd.

B. Synthesis of Corn Starch Nanoparticle

Corn Starch powder (5% w/v) is mixed with DI water. It is gelatinized at 85 ºC, 800 rpm for 30 minutes with Remi 2MLH magnetic stirrer. Gelatinized starch paste is ultrasonicated using Labman Probe sonicator for 5 to 25 minutes and lastly starch nanoparticle (St-NP) is produced under constant stirring within 90% ethanol at 1:1 ratio. An aliquot of colloidal suspension is diluted with distilled water after thorough mixing for characterization.

C. Characterization

1) Dynamic Light Scattering (DLS): Dynamic Light Scattering (DLS) is performed using Malvern Zetasizer Nano-ZS, Malvern Instruments, Life Science and Biotechnology Department, Jadavpur University to estimate average hydrodynamic diameters and polydispersity index (PDI) of the 1 mL obtained 5% w/v from St-NPs stock solution at 25º C. The intensity (%) vs size (nm) of this sample is illustrated in Fig. 1. From this plot, it is observed that the average particle size is 62.36 nm which is justifying this sample as a Nanomaterial. The PDI value obtained from this measurement is 0.281 which is sufficiently low. As the PDI is nearly 0, it is concluded that the sample is monodispersed.

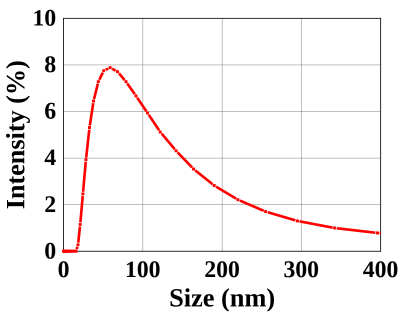

Fig. 1: DLS particle size for St-NP

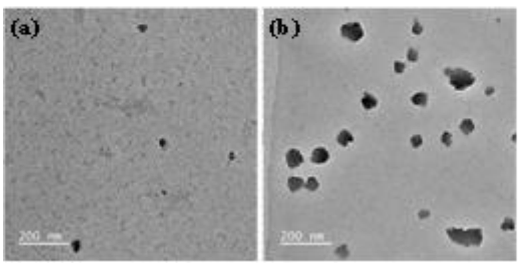

Fig. 2: TEM images indicating size and distribution of St-NP

2)Transmission Electron Microscope: The Transmission Electron Microscope (TEM) is performed to understand the shape, morphology and size of St-NP. It is performed in Central Facility of Jadavpur University, India. Diluted St-NP solution is casted on copper-grid. Next, the grid is dried for 48 h before recording TEM image. The TEM snapshots (Fig. 2) suggest that the St-NP sizes are between 13.41–59.69 nm. As DLS indicates the hydrodynamic size of St-NP, therefore the size of St-NP obtained in DLS is larger than TEM. The distribution of the NPs is also observed from Fig. 2 (a) and (b).

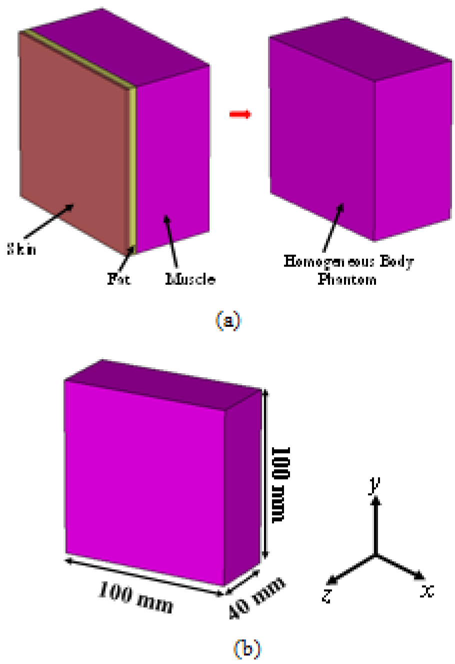

Fig. 3: (a) Equivalent human body model design and (b) its dimensions

III. IMPLANTABLE ANTENNA DESIGN

A. Human Body Model

Human body has multiple numbers of layers. It is very difficult to replicate the multilayer human body model practically for in-vitro measurement of implantable antenna due to possible formation of air gaps between two layers, chemical reactions between two layers etc. while placing one layer on other. Therefore, it is recommended to use homogeneous human body model for testing [17].

Therefore, it is very important to choose the dielectric properties of homogeneous equivalent human body model because the impedance and radiation characteristics of the antenna are highly dependent on the dielectric properties in terms of relative permittivity and conductivity of its environment. According to some standard guidelines [18-22], the relative permittivity, i.e., ε_{rt}, and conductivity, i.e. σ_t, are taken as 52.7 and 1.95 S/m at 2.45 GHz ISM band. The schematic view of human body model utilized to simulate a biocompatible St-NP encapsulated meander-line implantable antenna in CST Microwave Studio 2021 is shown in Fig. 3.

Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

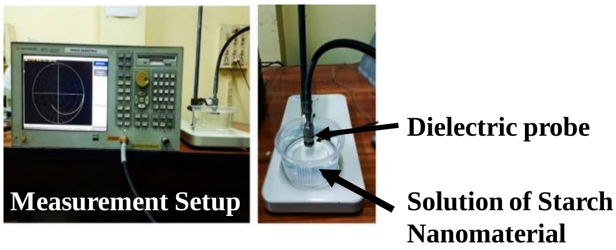

Fig. 4: Dielectric Measurement of the solution containing St-NP

B. Biocompatible St-NP layer Modeling

To design an encapsulation in St-NP of the implantable antenna, it is important to test its dielectric properties practically. Therefore, the dielectric properties of the solution containing St-NPs are measured using 85070E dielectric measurement kit (based on open ended coaxial probe technique) as shown in Fig. 4. The measured relative permittivity and conductivity of starch solution are 2.74 and 0.051 S/m. Then, the starch solution is magnetically rotated at 30°C for 1.5 hr to make a gel-like structure.

C. Implantable Antenna Modeling

A meander-line implantable antenna is designed here to operate at 2.45 GHz as shown in Fig. 5. Here a low loss dielectric substrate, Arlon AD 430 (relative permittivity of 4.3, loss tangent of 0.003 and thickness of 30 mil), is used for antenna designing. Fig. 5 (a) and (b) are showing the top and bottom views of the antenna respectively and corresponding design parameters are tabulated in Table I. The antenna is encapsulated by 1 mm thick biocompatible St-NP layer as shown in Fig. 5 (c).

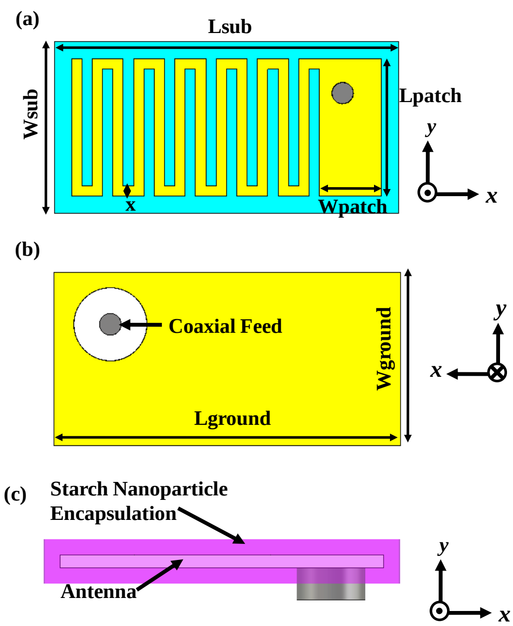

Fig. 5: (a) Top view, (b) Bottom view and (c) side view of the antenna

TABLE I. ANTENNA DESIGN PARAMETERS

Parameters	Values (mm)	Parameters	Values (mm)
Ground Length (Lground)	22	Ground Width (Wground)	8
Substrate Length (Lsubstrate)	22	Substrate Width (Wsubstrate)	8
Patch Length (Lpatch)	8.5	Patch Width (Wpatch)	3.5
Location of the feed point	(7.2, 2.2)	Thickness of Meander- Line stub (x)	0.5

D. Design Evolution of Antenna Part

Use of meander-line concept to design miniaturized antenna is a popular practice. As per previous discussion, the size of the implantable antenna should be very small for proper placement within patient's body. Therefore, a meander-line implantable antenna is designed here as shown in Fig. 5. The design evolution is discussed here. From rigorous literature survey [23-25], it is observed that the typical foot-print area of implantable antennas is less than 200 mm^2. Here 22 mm X 8 mm antenna is designed with area of 176 mm^2. A simple patch with 8.5 mm X 3.5 mm (Fig. 6(a)) is considered first including St-NP layer within homogeneous human body model where no cuts are present. From the return loss plot of 'Step 1' in Fig. 6(b), it is clear that this antenna is not radiating at 2.45 GHz.

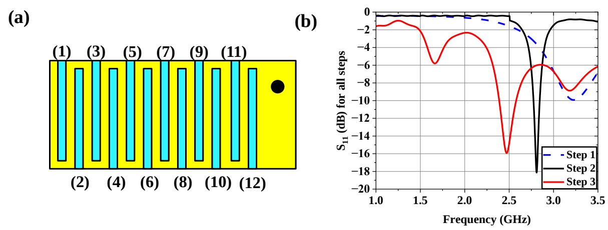

Fig. 6: (a) Design evolution and (b) corresponding return loss plots

In the next step (Step 2), two cuts (cut no. 1 and 2) are incorporated in patch to make one meander structure. Corresponding return loss plot is plotted in 'Step 2' of Fig. 6(b). The S_{11} of this antenna is -18.32 dB at 2.77 GHz. The addition of more meanders on the patch can increase the effective current path length and effective wavelength which leads to decrease the operating frequency of the antenna. In this context, 12 cuts are incorporated to design 6 meanders on patch as depicted in Fig. 6 (a). The return loss plot of this structure symbolized as 'Step 3' in Fig. 6 (b) is shown that this antenna is operating at 2.44 GHz with 15.87 dB return loss value. This frequency is within 2.45 GHz ISM band (2.4-2.48 GHz). Therefore, this St-NP encapsulated antenna is finalized to propose as novel St-NP encapsulated implantable antenna.

The encapsulated final antenna has fractional bandwidth of 6.75 % with -23.5 dBi realized gain. Based on std. guidelines [26-27], Specific Absorption Rate (SAR), safety measure of implantable antenna, should be <1.6 and <2 Watt/Kg respectively for 1g and 10g cubical body model. 345 Watt/Kg and 62.58 Watt/Kg simulated peak SARs are obtained for 1W RF input power respectively for 1g and 10g. The simulated Co- and Cross- Polar radiation plots are shown in Fig. 7. The simulated 3-D SAR distributions of implantable antenna are illustrated in Fig. 8.

Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

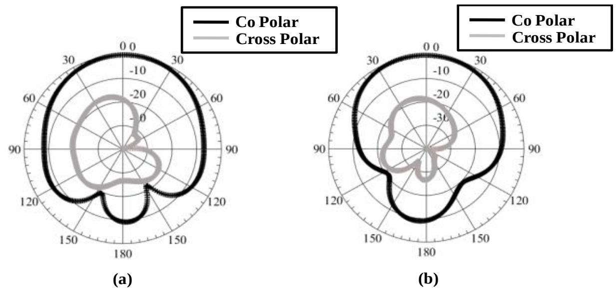

Fig. 7: Co- and Cross-polar simulated radiation configurations of St-NP encapsulated antenna at 2.44 GHz for (a) E and (b) H-planes

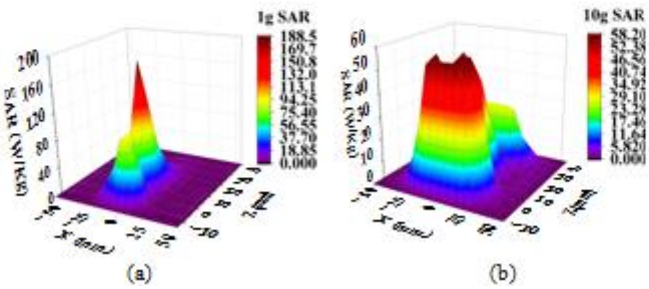

Fig. 8: Simulated SAR distribution for (a) 1g and (b) 10g model at 2.45 GHz for 1W applied power

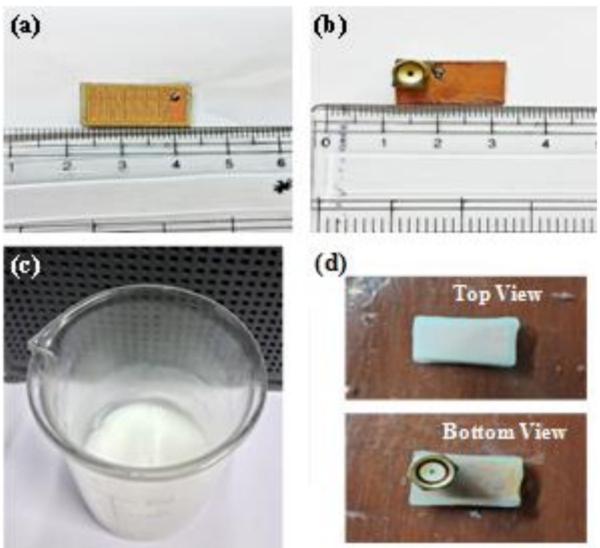

Fig. 9: (a) Top view and (b) bottom view of the fabricated antenna, (c) gelatinized St-NP and (d) Top and bottom views of St-NP encapsulated Implantable antenna

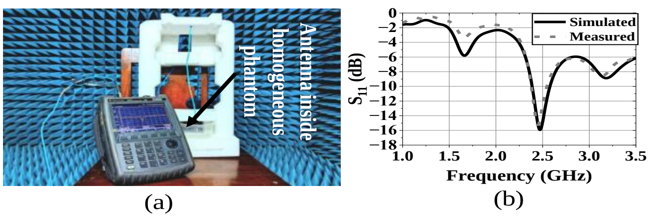

Fig. 10: (a) In-Vitro measurement of St-NP encapsulated implantable antenna within homogeneous equivalent human body model, (b) return loss plots from simulation and measurement

IV. FABRICATION AND MEASUREMENT

Finalized implantable antenna has been practically fabricated and encapsulated within gelatinized St-NP. The simulated architecture is practically fabricated using photo-lithography technology. Fabricated prototype of the antenna is shown in Fig. 9 (a-b). The fabricated antenna is then placed within gelatinized St-NP solution (refer to Fig. 9 (c)) prepared in Section II (B). Then the antenna engulfed St-NP gelatinized model, is kept at15ºC for 3 days to make it solid. The different views of encapsulated antenna are shown in Fig. 9 (d).

For practical in-vitro measurement of simulated antenna responses, homogeneous body equivalent model is fabricated by mixing 71% DI water, 29% DGME and 0.58 g NaCl. The measured respective relative permittivity and conductivity values are observed as 52.48 and 1.92 S/m respectively. Final antenna is placed within this equivalent body model as shown in Fig. 10 (a). The measured return loss plot is presented and compared with simulated response in Fig. 10 (b). From this plot, it is shown that the measured antenna 14.53 dB at 2.43 GHz which is almost similar to the simulated return loss plot. The measured realized gain of the antenna is -25.69 dBi at 2.43 GHz.

V. NOVELTY OF THIS WORK

Biocompatibility is one of the main design considerations for implantable antenna for ensuring patient's safety, avoiding radiation to nearby tissues, isolating the human tissues from conductors of the antenna to overcome short circuit possibility between them. Several biocompatible materials were used previously [9, 13-14, 28-29] such as Teflon, zirconica, MACOR, alumina etc. There is no reported work where nanomaterial based encapsulation is used having facility of drug loading for controlled drug delivery along with the facility of sensing and transfer of sensed health parameters of the patient for smart patient monitoring. The designed St-NP based implantable antenna provides many advantages over previously reported antennas such as - (i) biocompatible encapsulation, (ii) controlled drug delivery, (iii) patient's health parameters sensing and wirelessly transfer the sensed data to external monitoring devices etc. The designed antenna also has novelty over some reported works which is discussed in Table II.

TABLE II. COMPARISON WITH PREVIOUSLY REPORTED WORKS

Ref. of work	Realized Gain (dBi)	1g 1W Max SAR (W/Kg)	10g 1W Max SAR (W/Kg)
[30]	-22.8	807.34	102.04
[31]	-22.37	759.72	87.24
[32]	-46	338	-
This design	**-23.5**	**345**	**62.58**

VI. CONCLUSION

A meanderline implantable antenna encapsulated by corn starch based nanomaterial layer is designed in this work to operate at 2.45 GHz ISM band. Starch is a well-known biocompatible material. The St-NP is synthesized here by using Corn starch powder, DI water and 90% Ethanol. Several processes like ultrasonication and centrifugation are performed to develop solution containing St-NP; DLS and TEM are used

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

to characterize the solution of St-NP in terms of size, PDI, distribution of particles etc. According to DLS and TEM, it is observed that the particle size of this solution is below 100 nm which concludes it as nanoparticles. The dielectric properties of St-NP are measured in terms of relative permittivity and conductivity using 85070E dielectric measurement kit. A meander-line implantable antenna is designed and fabricated. It is placed within gelatinized St-NP solution and kept in refrigerator for solidification. Finally, St-NP encapsulated antenna is measured within a homogeneous human body phantom produced by mixing DI water, DGME and NaCl. The simulated antenna has S_{11} and realized gain of -15.87 dB and -23.5 dBi respectively at 2.44 GHz. The measured respective S_{11} and realized gain of biocompatible St-NP encapsulated antenna within developed phantom are -14.53 dB and -25.69 dBi at 2.43 GHz (measured operating frequency). The use of Starch nanoparticles as biocompatible encapsulation of implantable antenna is the novel approach of this work for Electronic Drug Delivery by sensing the target place to deliver through implantable antenna.

REFERENCES

[1] A. Jana and A. Chattapadhyay, "Prevalence and potential determinants of chronic disease among elderly in India: Rural-urban perspectives," PubMed Central, vol. 17, no. 3, March 2022, doi : 10.1371/journal.pone.0264937.

[2] V. Patel, S. Chatterji, D. Chisholm, S. Ebrahim, G. Gopalakrishna, C. Mathers, V. Mohan, D. Prabhakaran, R. D. Ravindran and K.S. Reddy, "Chronic diseases and injuries in India," The Lancet, vol. 377, no. 9763, pp. 413-428, February 2011, doi : 10.1016/S0140-6736(10)61188-9.

[3] J. R. Nagel, C. M. Furse, D. A. Christensen and C. A. Durney, "Basic Introduction to Bioelectromagnnetics," CRC Press, Taylor & Francis Group, 2019.

[4] T. Karacolak, A. Z. Hood and E. Topsakal, "Design of a Dual – Band Implantable Antenna and Development of Skin Mimicking Gels for Continuous Glucose Monitoring," IEEE Transactions on Microwave theory and Techniques, vol. 56, no. 4, April 2008.

[5] T. Yilmaz, T. Karacolak and E. Topsakal, "Characterization and Testing of a Skin Mimicking Material for Implantable Antennas Operating at ISM Band (2.4 GHz – 2.48 GHz),"IEEE Antennas and Wireless Propagation Letters, vol. 7, pp. 418 – 420, June 2008.

[6] S. Ghosh, A. Kundu and B. Gupta, "Slot based Miniaturized Human Body Implantable Antenna Design at 2.45 GHz ISM Band," 2022 IEEE Wireless Antenna and Microwave Symposium (WAMS), Rourkela, India, 2022, pp. 1-5.

[7] R. Warty, M. R. Tofighi, U. Kawoos, and A. Rosen, "Characterization of Implantable Antennas for Intracranial Pressure Monitoring: Reflection by and Transmission Through a Scalp Phantom,", IEEE Transactions on Microwave Theory and Techniques, vol. 56, pp. 2366-2376, 2008.

[8] A. Kiourti, K. A. Psathas, J. R. Costa, C. A. Fernandes, and K. S. Nikita, "Dual-Band Implantable Antennas for Medical Telemetry: A Fast Design Methodology and Validation for Intra-Cranial Pressure Monitoring," Progress in Electromagnetics Research, vol. 141, pp. 161-183, 2013.

[9] P. Soontornpipit, C. M. Furse, and C. You Chung, "Design of implantable microstrip antenna for communication with medical implants," IEEE Transactions on Microwave Theory and Techniques, vol. 52, pp. 1944-1951, 2004.

[10] K. A. Psathas, A. Kiourti and K. S. Nikita, "Biocompatibility of implantable antennas: Design and performance considerations," The 8th European Conference on Antennas and Propagation (EuCAP 2014), The Hague, Netherlands, 2014, pp. 1566-1570, doi: 10.1109/EuCAP.2014.6902083.

[11] A. Kiourti and K. S. Nikita, "A Review of Implantable Patch Antennas for Biomedical Telemetry: Challenges and Solutions [Wireless Corner]," IEEE Antennas and Propagation Magazine, vol. 54, pp. 210- 228, 2012.

[12] T. Karacolak, R. Cooper, J. Butler, S. Fisher and E. Topsakal, "In Vivo Verification of Implantable Antennas Using Rats as Model Animals," IEEE Antennas and Wireless Propagation Letters, vol. 9, pp. 334-337, 2010, doi: 10.1109/LAWP.2010.2048693.

[13] R. Warty, M. R Tofi ghi, U. Kawoos, and A. Rosen, "Characterization of Implantable Antennas for Intracranial Pressure Monitoring: Refl ection By and Transmission Through a Scalp Phantom," IEEE Transactions on Microwave Theory and Techniques, 56, 10, October 2008, pp. 2366-2376.

[14] A. K. Skrivervik and F. Merli, "Design Strategies for Implantable Antennas," Proceedings of the Antennas and Propagation Conference, Loughborough, UK, November 2011.

[15] N.B. Shelke, R. James, C.T. Laurencin and S.G. Kumbar, "Polysaccharide biomaterials for drug delivery and regenerative engineering," Polymers Advanced Technology, vol. 25, pp. 448-460, 2014.

[16] V. Lisovskiy, S. Dudin, A. Minenkov, S. Bogatyrenko and P. Platonov, "Formation of Nanoparticles and Polymer Films in RF Gas-Discharge Plasma in Acetylene," 2021 IEEE 11th International Conference Nanomaterials: Applications & Properties (NAP), Odessa, Ukraine, 2021, pp. 1-5.

[17] V. Kaim, B. K. Kanaujia, S. Kumar, H. C. Choi, K. W. Kim, and K. Rambabu, "Ultra-Miniature Circularly Polarized CPW-Fed Implantable Antenna Design and its Validation for Biotelemetry Applications," Scientific Reports, April 2020.

[18] https://itis.swiss/virtual-population/tissue-properties/database/dielec tric-properties/

[19] http://niremf.ifac.cnr.it/tissprop/htmlclie/htmlclie.php

[20] F. Gozasht and A. S. Mohan, "Miniaturized Slot PIFA Antenna for Triple band Implantable Biomedical Applications," 2013 IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-BIO), March2014.

[21] ICNIRP, "Guidelines for limiting exposure to electromagnetic fields (100 KHz to 300 GHz)," Health Phys., vol. 118, no. 5, pp. 483-524, March 2020.

[22] R. F. Cleveland, Jr., D. M. Sylvar, and J. L. Ulcek, "Evaluating compliance with FCC guidelines for human exposure to radiofrequency electromagnetic fields," FCC OET Bulletin, vol. 65, Edition 97-01, Washington D.C., November 1997.

[23] F-J. Huang, C-M. Lee, C-L. Chang, L-K. Chen, T-C. Yo and C-H. Luo, "Rectenna Application of Miniaturized Implantable Antenna Design for Triple-Band Biotelemetry Communication," IEEE Transactions on Antennas and Propagation, vol. 59, no. 7, pp. 2646 – 2653, July 2011.

[24] C. Liu, Y-X. Guo and S. Xiao, "A Hybrid Patch/Slot Implantable Antenna for Biotelemetry Devices,")," IEEE Antennas and Wireless Propagation Letters, vol. 11, pp. 1646 – 1649, 2012.

[25] L-J. Xu, Y-X. Guo and W. Wu, "Miniaturised slot antenna for biomedical applications," Electronics Letters, vol. 49, no. 17, pp. 1060 – 1061, August 2013.

[26] ICNIRP, "Guidelines for limiting exposure to electromagnetic fields (100 KHz to 300 GHz)," Health Phys., vol. 118, no. 5, pp. 483-524, March 2020.

[27] R. F. Cleveland, Jr., D. M. Sylvar, and J. L. Ulcek, "Evaluating compliance with FCC guidelines for human exposure to radiofrequency electromagnetic fields," FCC OET Bulletin, vol. 65, Edition 97-01, Washington D.C., November 1997.

[28] R. Warty, M. R. Tofighi, U. Kawoos, and A. Rosen, "Characterization of Implantable Antennas for Intracranial Pressure Monitoring: Reflection by and Transmission Through a Scalp Phantom," IEEE Transactions on Microwave Theory and Techniques, vol. 56, pp. 2366-2376, 2008.

[29] F. Merli, B. Fuchs, J. R. Mosig, and A. K. Skriverviky, "The Effect of Insulating Layers on the Performance of Implanted Antennas," IEEE Transactions on Antennas and Propagation, vol. 59, pp. 21-31, 2011.

[30] S. A. A. Shah and H. Yoo, "Scalp-implantable antenna systems for intracranial pressure monitoring," IEEE Transactions of Antennas Propagations. vol. 66, no. 4, pp. 2170-2173 (2018).

[31] I. Gani and H. Yoo, "Multi-Band Antenna System for Skin Implant," IEEE Microwave and Wireless Components Letters, vol. 26, no. 4, 2016.

[32] M. Usluer, B. Centindere and S. C. Basaran, "Compact implantable antenna design for MICS and ISM band biotelemetry applications," Microwave and Optical Technology Letters, Vol. 62, no. 4, 2020.