Novel Implantable Disk DRA for Bio-Telemetry Applications at 2.4 GHz ISM Band

(Article begins on next page)

Novel Implantable Disk DRA for Bio-Telemetry Applications at 2.4 GHz ISM Band

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***Abstract*—In this paper, a novel circular disk implantable Dielectric Resonator Antenna (DRA) working at 2.4 GHz ISM band for bio-telemetry applications is proposed. DRAs have advantages of no metallic losses and high efficiency in comparison to their counterparts patch antenna which is a significant benefit in implantable antenna. Metallic implants pose serious problems due to various reasons such as induced current, heating, and resistance in MRI, X-Ray, ECG. Proposed DRA is made up high dielectric constant material (TiO_2) and excited by a unique circular L-shaped feedline with defected ground structure (DGS). Simulated impedance bandwidth of proposed antenna covers the entire 2.4 GHz ISM Band (2.40 GHz-2.4832 GHz). A flexible, thermally stable, bio-compatible layer of Polydimethylsiloxane (PDMS) is allowed on the surface of the whole structure. Antenna performance is observed under 20 mm depth in male right arm phantom in EM simulator HFSS. Maximum Antenna gain in broadside direction measured is -18 dBi inside the phantom and radiations are within permissible SAR limits. The proposed antenna is a suitable candidate for bio-telemetry applications in the ISM band.**

I. Introduction

Early diagnosis of life-threatening diseases continues to be a major healthcare challenge. Implantable antennas have shown promise for wireless bio-telemetry applications, yet they remain in the developmental phase prior to large-scale clinical adoption. Various metallic implantable antennas [1]–[14] have been reported in the literature; however, dielectric resonator antennas (DRAs) present distinct advantages due to their absence of metallic components. Since the human body is composed of tissues with varying dielectric properties, as summarized in Table I, DRAs exhibit superior electromagnetic compatibility compared to conventional metallic patch antennas. Metallic antennas suffer from practical drawbacks including interference with MRI and X-ray imaging, as well as localized heating, which may compromise patient safety.

The Federal Communications Commission (FCC) has allocated specific frequency ranges for implantable medical devices, including the Medical Implant Communication Services (MICS, 402–405 MHz) and the Industrial, Scientific, and Medical (ISM, 902–928 MHz and 2400–2483.5 MHz) bands. In our previous work [15], we developed a theoretical framework for the design of DRA-based implantable antennas. Building upon this foundation, this paper presents the design and analysis of a novel circular disk DRA optimized for operation in the 2.4 GHz ISM band. Presence of a dielectric disk in proposed configurations strongly reduces the metallic content of the antenna and minimises the repercussions of metallic parts in bio-telemetry.

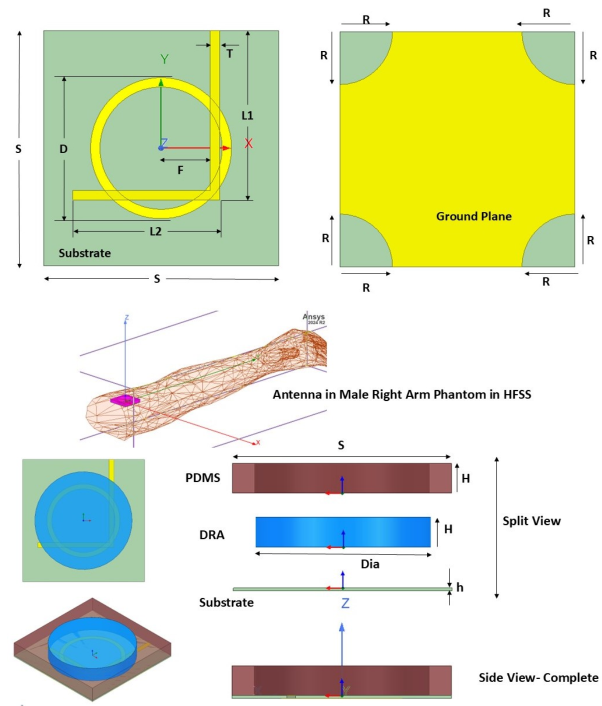

Fig. 1. Geometry of the Antenna (All dimensions are in mm)

TABLE I
Dielectric Properties of Human Tissues at 2.45 GHz [16]

Human Tissue	Dielectric constant (ϵ_r)	Conductivity (σ (S/m))	Loss Tangent ($\tan\delta$)
Skin	38.06	1.4410	0.2835
Muscle	52.79	1.705	0.2419
Fat	5.285	0.1023	0.1450
Cortical Bone	11.38	0.3943	0.2542

II. Design of Antenna

The proposed antenna employs TiO_2 ($\epsilon_r = 79$) as the high-permittivity dielectric resonator material shaped in a disk with dimensions 32 mm in diameter and 5.5 mm in height. Excitation is achieved through a circular L-shaped microstrip feedline integrated with a defected ground structure (DGS) on Roger 5880 0.5 mm thick substrate, to enhance impedance matching and radiation performance. To ensure biocompatibility and thermal stability, the antenna is encapsulated in a conformal layer of polydimethylsiloxane (PDMS), which provides electrical isolation from surrounding body fluids while maintaining mechanical flexibility. The geometric configuration of the antenna is illustrated in Fig. 1, with

TABLE II
DESIGN PARAMETERS

Parameter	in mm	Parameter	in mm
L1	28.8	L2	25
T	1.6	S	40
D	24	F	8.4
H	5.5	R	9
h	0.5	Dia	32

detailed design parameters listed in Table II.

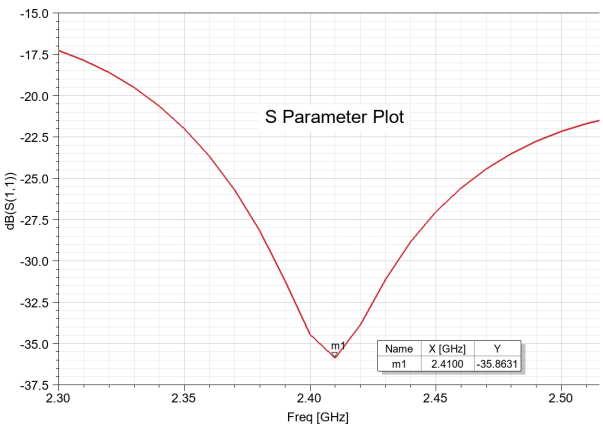

Fig. 2. Simulated S_{11} parameter of proposed Antenna

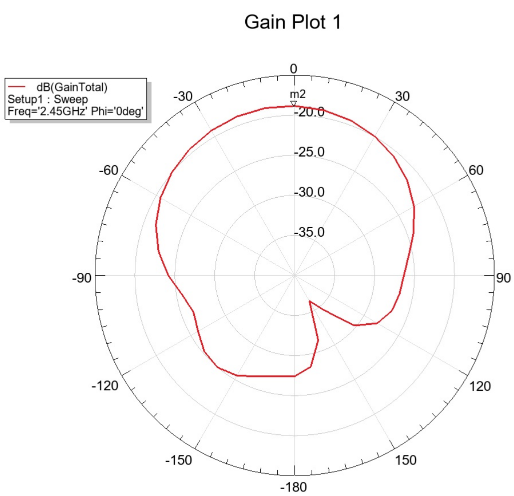

Fig. 3. Simulated Gain of proposed Antenna

III. RESULTS AND DISCUSSION

The antenna was evaluated using Ansys HFSS EM Simulator within a male right-arm tissue-equivalent phantom model at a depth of 20 mm. The simulated results indicate a maximum broadside gain of –18 dBi, with radiation levels remaining within permissible specific absorption rate (SAR) limits, thereby satisfying international safety guidelines [17]–[19]. The simulated impedance bandwidth spans the entire 2.4 GHz ISM range (2.400–2.4832 GHz), ensuring reliable operation across the allocated spectrum as shown in Fig.2.

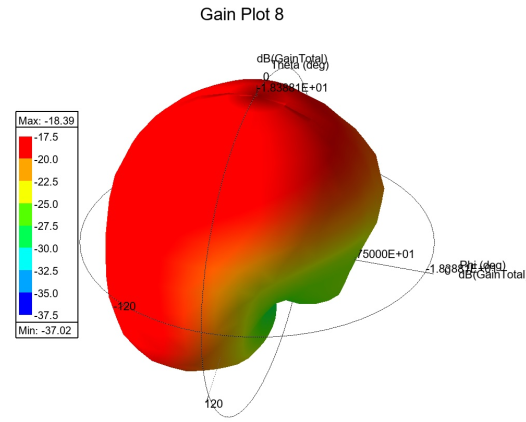

Fig. 4. Trimetric view of radiation pattern

The radiation performance is further demonstrated in Fig. 3, which depicts the broadside gain characteristics, and Fig. 4, which presents the three-dimensional trimetric radiation pattern. The results confirm symmetric and isometric radiation distribution around the broadside axis, verifying the antenna's stable operation within biological environments. These findings establish the proposed DRA as a strong candidate for bio-telemetry applications in the ISM band.

ACKNOWLEDGEMENT

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REFERENCES

[1] M. K. Magill, G. A. Conway and W. G. Scanlon, "Tissue-Independent Implantable Antenna for In-Body Communications at 2.36-2.5 GHz," in IEEE Transactions on Antennas and Propagation, vol. 65, no. 9, pp. 4406-4417, Sept. 2017, doi: 10.1109/TAP.2017.2708119.

[2] J. M. Felício, 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.

[3] I. Gani and H. Yoo, "Multi-Band Antenna System for Skin Implant," in IEEE Microwave and Wireless Components Letters, vol. 26, no. 4, pp. 294-296, April 2016, doi: 10.1109/LMWC.2016.2538470.

[4] M. K. Magill, G. A. Conway and W. G. Scanlon, "Circularly Polarized Dual-Mode Wearable Implant Repeater Antenna With Enhanced Into-Body Gain," in IEEE Transactions on Antennas and Propagation, vol. 68, no. 5, pp. 3515-3524, May 2020, doi: 10.1109/TAP.2020.2972335.

[5] F. Merli, L. Bolomey, J. Zurcher, G. Corradini, E. Meurville and A. K. Skrivervik, "Design, Realization and Measurements of a Miniature Antenna for Implantable Wireless Communication Systems," in IEEE Transactions on Antennas and Propagation, vol. 59, no. 10, pp. 3544-3555, Oct. 2011, doi: 10.1109/TAP.2011.2163763.

[6] W. Xia, K. Saito, M. Takahashi and K. Ito, "Performances of an Implanted Cavity Slot Antenna Embedded in the Human Arm," in IEEE Transactions on Antennas and Propagation, vol. 57, no. 4, pp. 894-899, April 2009, doi: 10.1109/TAP.2009.2014579.

[7] L. Matekovits, Y. Su and I. Peter, "On the radiation mechanism of implanted antennas with large conformal ground plane" IET Microw. Antennas Propag., Vol. 11 pp. 1765-1769, 2017. https://doi.org/10.1049/iet-map.2017.0280

[8] L. Matekovits, J. Huang, I. Peter and K. P. Esselle, ”Mutual Coupling Reduction Between Implanted Microstrip Antennas on a Cylindrical Bio-Metallic Ground Plane,” in IEEE Access, vol. 5, pp. 8804-8811, 2017, doi: 10.1109/ACCESS.2017.2703872.
[9] J. Kim and Y. Rahmat-Samii, ”Implanted antennas inside a human body: simulations, designs, and characterizations,” in IEEE Transactions on Microwave Theory and Techniques, vol. 52, no. 8, pp. 1934-1943, Aug. 2004, doi: 10.1109/TMTT.2004.832018.
[10] A. Kiourti and K. S. Nikita, ”A Review of Implantable Patch Antennas for Biomedical Telemetry: Challenges and Solutions [Wireless Corner],” in IEEE Antennas and Propagation Magazine, vol. 54, no. 3, pp. 210-228, June 2012, doi: 10.1109/MAP.2012.6293992.
[11] A. Kiourti and K. S. Nikita, ”Miniature Scalp-Implantable Antennas for Telemetry in the MICS and ISM Bands: Design, Safety Considerations and Link Budget Analysis,” in IEEE Transactions on Antennas and Propagation, vol. 60, no. 8, pp. 3568-3575, Aug. 2012, doi: 10.1109/TAP.2012.2201078.
[12] A. Kiourti, J. R. Costa, C. A. Fernandes and K. S. Nikita, ”A Broadband Implantable and a Dual-Band On-Body Repeater Antenna: Design and Transmission Performance,” in IEEE Transactions on Antennas and Propagation, vol. 62, no. 6, pp. 2899-2908, June 2014, doi: 10.1109/TAP.2014.2310749.
[13] A. Kiourti and K. S. Nikita, ”Implantable Antennas: A Tutorial on Design, Fabrication, and In VitroIn Vivo Testing,” in IEEE Microwave Magazine, vol. 15, no. 4, pp. 77-91, June 2014, doi: 10.1109/MMM.2014.2308765.
[14] A. Kiourti and K. S. Nikita, ”A Review of In-Body Biotelemetry Devices: Implantables, Ingestibles, and Injectables,” in IEEE Transactions on Biomedical Engineering, vol. 64, no. 7, pp. 1422-1430, July 2017, doi: 10.1109/TBME.2017.2668612.
[15] S. S. Singhwal, L. Matekovits, I. Peter and B. K. Kanaujia, ”A Study on Application of Dielectric Resonator Antenna in Implantable Medical Devices,” in IEEE Access, vol. 10, pp. 11846-11857, 2022, doi: 10.1109/ACCESS.2022.3144664.
[16] S. Gabriel, R. W. Lau, and C. Gabriel, ”The dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz”, Phys. Med. Biol., vol. 41, no. 11, p. 2251, 1996. [Online]. Available: http://niremf.ifac.cnr.it/tissprop/
[17] IEEE Standard for Safety Levels With Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 KHz to 300 GHz, IEEE Standard C95.1-1991, 1999.
[18] IEEE Standard for Safety Levels With Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 KHz to 300 GHz, IEEE Standard C95.1-2005, 2005.
[19] IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz, IEEE Std C95.1-2019.