Conference Paper

A Miniaturized Wide Band Implantable Antenna for Biomedical Application

Bashir, Z., Zahid, M., Abbas, N., Yousaf, M., Shoaib, S., Asghar, M.A., Amin, Y

This is a paper presented at the UK/ China Emerging Technologies (UCET), Glasgow, United Kingdom, 2019

A Miniaturized Wide Band Implantable Antenna for Biomedical Application

Zubair Bashir[1], Muhammad Zahid[1], Naeem Abbas[1], Muhammad Yousaf[1], Sultan Shoaib[2], Muhammad Adeel Asghar[1], and Yasar Amin[1]

[1]Department of Telecommunication Engineering, University of Engineering and Technology, Taxila, 47050 Pakistan.
[2]School of Applied Science, Computing & Engineering, Glyndwr University Wales, UK.
{zubairbashir9293@gmail.com, zahidnazir11760@gmail.com, naeem.hsn.1@gmail.com, myousafalamgir@yahoo.com, sultan.shoaib@glyndwr.ac.uk, adeel_asghar21@yahoo.com, and yasar.amin@uettaxila.edu.pk}

***Abstract*—In this paper, a miniaturized high gain antenna was designed for biomedical applications. The designed antenna operates on the industrial, medical, and scientific (2.40 - 2.4835) GHz band. The proposed antenna consists of the radiating element having rectangular, and circular slots, and a ground plane with rectangular slots. The total volume of the designed antenna is (7×7×0.2) mm^3, and the thickness of the superstrate and substrate is 0.1 mm. The Rogers ULTRALAM (ε_r = 2.9, tanδ = 0.0025) material is used for substrate and superstrate. The proposed antenna is placed inside the different phantoms of the human body. The maximum gain achieved by the simulations of the proposed antenna is -12 dBi at 2.45 GHz. The designed antenna has better results than the antennas discussed in the literature in term of size, gain, and bandwidth.**

***Index Terms*—Reflection coefficient, biomedical application, ground plane, implantable antenna, ISM band.**

I. Introduction

In the field of biomedical, implantable medical devices (IMDs) have attracted the attention of the researchers due to their applications for the betterment and continuous monitoring of human health. The biomedical devices are used to monitor and diagnose the diseases [1]. In biotelemetry, the primary function of the implanted antennas/devices is that to communicate with the external unit/device for continuous monitoring and sharing of the monitored information such as temperature, and blood pressure [2]. The IMDs face the challenges of the compact size, specific absorption rate (SAR), more significant operating frequency, and flexibility for the safety of the patient [3]. With the advancement of biomedical devices, human health care will be a reality soon. The implantable medical devices use the different bands like (401-406 MHz) band for medical implant communication and the biomedical application. But the usage of industrial, scientific, and medical (ISM) bands vary from country to country [4]. Due to large size, small bandwidth, resolution of the images and low data rate in MedRadio band, ISM bands (2.4–2.4835 GHz and 902–928 MHz) are used for specific IMDs [5].

The size of the implantable antenna should be small for the proper placement inside the human body. For miniaturization of the implantable antenna, the different techniques have proposed by the researchers. A flexible dipole slot antenna operating at ISM band is designed for the biomedical application. The size of the flexible dipole antenna is (25.9×18.5×5) mm^3, and the gain achieved by antenna designed in [6] is -23.98 dB. The L-shaped dipole antenna for the MedRadio band has designed for the biomedical applications. The L-shaped dipole antenna has a large size with the volume of 18.1 mm^3, and the highest achieved gain by [7] is -29.4 dB. A meta-material (MTM) technique is introduced to reduce the size of the implantable antenna and to enhance the gain of the antenna for biomedical implants [8], and the size of antenna is reduced upto (10×10×0.4) mm^3, and the total gain achieved by this design is -9 dBi. In [9], a circularly polarized implantable antenna has been designed, and the dimension of the truncated patch is (8.6×8.6) mm^2. A dual-band flowered shaped antenna is introduced in [10], to reduce the size of the antenna for the medical implants and to enhance the gain of the antenna for biotelemetry. The volume of this flowered shaped antenna is (7×7.2×0.2) mm^3. The maximum gain achieved by this antenna design is -28.44 dB for 928 MHz and -25.65 dB for 2.45 GHz band. There are many patients, they are facing some type of sickness as well as abnormalities. To facilitate the patients, we are making antenna for in body applications, and some researcher also done in [16] - [19].

In this paper, a novel circular shaped single band antenna has designed. This proposed antenna is achieved by getting the idea from [9]. The designed antenna has the compact size of (7×7×0.2) mm^3, this antenna having a small size as compared to other antennas. The proposed antenna implanted in the homogeneous phantom of the human body at 2.45 GHz band and the dimension of the skin box is 50 $mm\times$ 50 $mm\times$ 50 mm. The latest version of HFSS 19.2 is used for the simulations. The maximum gain by the simulation is -12 dB and the achieved bandwidth after the simulation is 483 MHz. This proposed antenna design has some prominent features having small volume than that of other proposed antennas [6] - [10]. At the end, a comparison with previous work has made. The article is divided in the following sections. Section I consist of an introduction and literature review. In section II, the methodology has discussed, and in section III, results have carried out.

II. Methodology

The implanted antenna should have a small size for the better placement of the antenna inside the human body. The primary purpose of this paper is to design a miniaturized antenna that covers the ISM band. The effective antenna demands that the antenna should have a small size, biocompatible, and better radiation performance.

A. Antenna design

The configuration of the proposed antenna design shown in Fig. 1 (a–d). The Fig. 1 shows the top, back, side, and

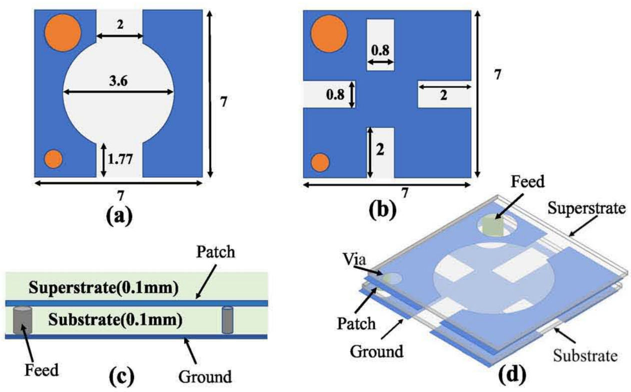


Fig. 1. (a) Patch view. (b) Ground. (c) Side view. (d) Exploded view.

the exploded views of the rectangular-shaped antenna. The proposed antenna consists on the ground plane, substrate, patch or radiating element, and the superstrate. The ground plane has rectangular slots, and the patch consists of the circular and rectangular slots. The radiating element backed by a substrate having a thickness of 0.1 mm. The change in the thickness of the substrate has some effects on the permittivity of the substrate [11]. The ULTRALAM polymer is used as a substrate and superstrate in the designed antenna. The Rogers ULTRALAM is a liquid crystalline polymer (LCP) which is suitable for the biomedical applications. The total volume of the proposed antenna design is (7 × 7 × 0.2) mm^3. A feed with a radius of 0.5 mm used as the excitation port for the antenna. The radiating part of the proposed antenna consists of the rectangular slots and circular slot. These slots have a great effect on the resonant frequency. A shorting pin called via used in the antenna with a diameter of 0.6 mm. A rectangular slotted ground plane is placed behind the substrate. The current distribution on the ground element of the antenna has a great effect on the performance of the antenna. The rectangular slots in the ground plane are used to increase the capacitance, and this capacitance used to move the resonance frequency to the lower frequency band.

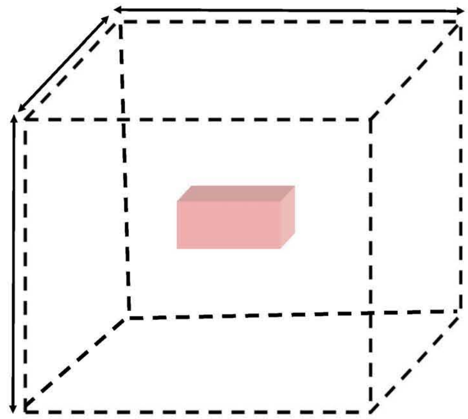
B. Simulation Environment

The proposed antenna designed for the biomedical applications, so the proposed antenna is simulated in HFSS using the human body phantoms. The relative permittivity and electrical conductivity of the different human body phantom are given in Table. I. To simulate the antenna system, the proposed antenna is placed at the center of the skin box having the dimension of 25 mm × 25 mm × 25 mm as shown in Fig. 2.

TABLE I

PARAMETERS OF HUMAN BODY PHANTOMS AT 2.45 GHZ.

Phantom	**Skin**	**Stomach**	**Large Intestine**	**Small Intestine**
Relative permittivity (ε_r)	38	62.2	53.9	54.4
Electrical Conductivity (*S/m*)	1.46	2.21	2.04	3.17



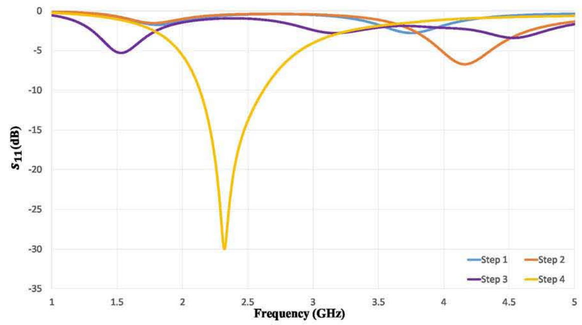


Fig. 4. Comparison of the reflection coefficients of design steps (S_{11}).

C. Parametric Analysis

This section of presents the effect of change in the parameters of the patch and the ground plane, and the proposed antenna with the same dimension is placed in the human body phantom.

1) Variations in the Width of the Patch Rectangular Slot: In the first step, the width of the rectangular slot in the patch is 1 mm, and at this width, the resonant frequency moves towards the lower rate and the ISM band is not covered by the achieved band. Now by changing the width up to 2 mm of the rectangular slot in the patch, the resonant frequency goes to the upper-frequency band, and it covers the ISM band.

2) Change in Radius of slot in the Patch: The circular slot in the radiating element of the antenna has some significant effects of the frequency band. If the radius of the circular slot increased, the resonant frequency goes to the lower frequency band and if the radius of the circular slot is decreased the resonant frequency increases to the upper-frequency band.

III. Results

In this section, the results achieved by the simulation in various human body phantoms has been discussed. By placing the antenna in different human body phantoms, such as skin, small intestine, large intestine, and stomach, the performance parameters like bandwidth and gain of the antenna are varied, and the bandwidth achieved by simulating the antenna in different phantoms, as shown in Fig. 5.

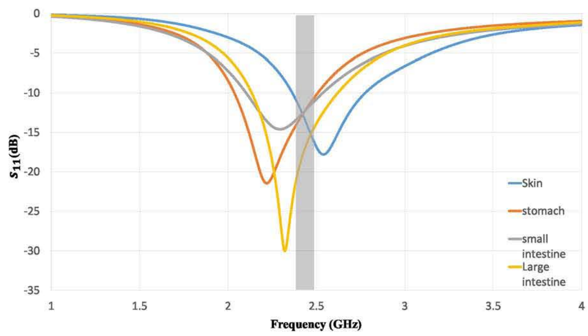


Fig. 5. Change in bandwidth by simulating antenna in different phantoms.

The proposed antenna cover the ISM (2.4 - 2.835) MHz band, by simulating the antenna in the large intestine of the human body and different tissues. The maximum gain achieved by simulating the antenna in the human body phantom shown in Fig. 6. The maximum gain achieved by simulating the

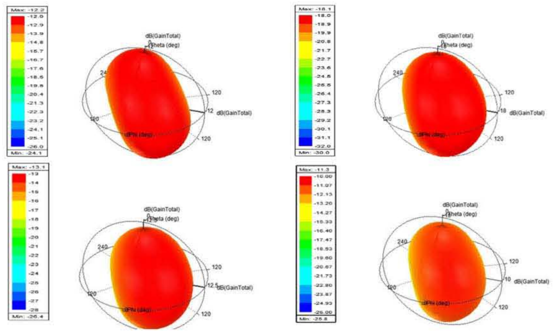


TABLE II
COMPARISON WITH PUBLISHED WORKS

References	Frequency (GHz)	Bandwidth (MHz)	Gain (dBi)	Dielectric Material	Antenna Shape	Volume (mm^3)
[2]	2.4	80	-10.3	Rogers TM 13	Zig Zag	66.41
[9]	2.45	73	-20.47	Rogers RT/duroid 6010	Zig Zag	21
[13]	2.45	300	-17	Rogers 3210	Circular	91.75
[14]	2.45	246	-21.2	Rogers RT/duroid 6010	Spiral	31.5
[15]	2.45	105	-22.3	Rogers RT/duroid 6010	Zig Zag	52.5
This Work	2.45	483	-12	Rogers Ultralam	Circular	9.8

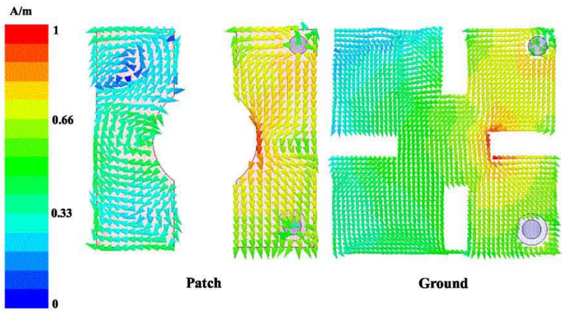


Fig. 8. Current distribution on the patch and ground plane.

IV. CONCLUSION

A miniaturized wide band antenna with high gain has been designed for the biomedical applications. The ground plane consists of a square sheet having rectangular slots and radiating element consist on a square sheet having the rectangular and the circular slots. These rectangular slots are used for the miniaturization or to reduce the size of the antenna for the better placement inside the human body. The proposed antenna is simulated in different tissues of the human body such as skin, large intestine, small intestine, and stomach. The total volume of the designed antenna is $(7 \times 7 \times 0.2)$ mm^3, and this antenna is operated at the ISM band. The achieved maximum gain is -12dB, and the achieved bandwidth is 483 MHz. This proposed antenna design has small size as compared to the previously published designed antennas. The antenna can be used for skin implantation, and biomedical applications to monitor the health of the human body.

REFERENCES

[1] 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, no. 3, pp. 210-228, 2012.

[2] S. M. Huang, M. R. Tofighi, and A. Rosen, "Considerations for the design and placement of implantable annular slot antennas for intracranial pressure monitoring devices, " *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 1514-1517, 2014.

[3] M. Zada, and H. Yoo, "A Miniaturized Triple-Band Implantable Antenna System for Bio-Telemetry Applications, " *IEEE Transactions on Antennas and Propagation*, vol. 66 no. 12, pp. 7378-7382, 2018.

[4] I. A. Shah, M. Zada, and H. Yoo, "Design and Analysis of a Compact-Sized Multi-band Spiral-Shaped Implantable Antenna for Scalp Implantable and Lead-less Pacemaker Systems, " *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 6, pp. 4230-4234, 2019.

[5] A. Kiourti, K. A. Psathas, and K. S. Nikita, "Implantable and ingestible medical devices with wireless telemetry functionalities: A review of current status and challenges, " *Bioelectromagnetics*, vol. 35 no. 1, pp.1-15, 2014.

[6] M. L. Scarpello, D. Kurup, H. Rogier, D. V. Ginste, F. Axisa, J. Vanfleteren, and G. Vermeeren, "Design of an implantable slot dipole conformal flexible antenna for biomedical applications, " *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 10, pp. 3556-3564, 2011.

[7] S. Bakogianni, and S. Koulouridis, "An implantable planar dipole antenna for wireless medradio-band bio-telemetry devices, " *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 234-237, 2015.

[8] S. Das, and D. Mitra, "A Compact Wide-band Flexible Implantable Slot Antenna Design With Enhanced Gain, " *IEEE Transactions on Antennas and Propagation*, vol. 66, no.8, pp. 4309-4314, 2018.

[9] Z. J. Yang, L. Zhu, and S. Xiao, "An implantable circularly polarized patch antenna design for pacemaker monitoring based on quality factor analysis, " *IEEE Transactions on Antennas and Propagation*, vol. 66 no. 10, pp. 5180-5192, 2018.

[10] F. Faisal, and H. Yoo, "A Miniaturized Novel-Shape Dual-Band Antenna for Implantable Applications, " *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 2, pp. 774-783, 2018.

[11] E. C. Culbertson, "A new laminate material for high performance PCBs: Liquid crystal polymer copper clad film," *45th IEEE Electronic Components and Technology Conference*, pp. 520-523, May, 1995.

[12] S. A. A. Shah, M. F. Khan, S. Ullah, , A. Basir, U. Ali, and U. Naeem, "Design and measurement of planar monopole antennas for multi-band wireless applications, " *IETE Journal of Research*, vol. 63, no.2, pp. 194-204, 2017.

[13] X. Y. Liu, Z. T. Wu,Y. Fan, and E. M. Tentzeris, "A miniaturized CSRR loaded wide-beamwidth circularly polarized implantable antenna for subcutaneous real-time glucose monitoring," *IEEE Antennas and Wireless Propagation Letters*, 16, vol. 577-580, 2016.

[14] Z. Xia, and H. Li, "Miniaturized Dual-Band Implantable Antenna," *IEEE International Conference on Microwave and Millimeter Wave Technology*, pp. 1-3. ,May, 2018.

[15] I. Gani, and H. Yoo, "Multi-band antenna system for skin implant," *IEEE Microwave and Wireless Components Letters*, vol. 26, no.4, pp. 294-296, 2016.

[16] X. Yang, S. A. Shah, A. Ren, N. Zhao, Z. Zhang, D. Fan, J. Zhao, W. Wang, and M. Ur-Rehman, "Freezing of Gait Detection Considering Leaky Wave Cable," in *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 1, pp. 554–561, 2019.

[17] B. Dong, A. Ren, S. A. Shah, F. Hu, N. Zhao, X. Yang, D. Haider, Z. Zhang, W. Zhao, Q. H. Abbasi, "Monitoring of a topic dermatitis using leaky coaxial cable," *Healthcare Technology Letters*, vol. 4, no. 6, pp. 244–248, 2017.

[18] X. Yang, S. A. Shah, A. Ren, N. Zhao, J. Zhao, F. Hu, Z. Zhang, W. Zhao, M. Ur-Rehman, and A. Alomainy, "Monitoring of Patients Suffering From REM Sleep Behavior Disorder," *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, vol. 2, no. 2, pp. 138–143, 2018.

[19] X. Yang, S. A. Shah, A. Ren, D. Fan, N. Zhao, S. Zheng, W. Zhao, W. Wang, P. J. Soh, and Q. H. Abbasi, "S-Band Sensing-Based Motion Assessment Framework for Cerebellar Dysfunction Patients," *IEEE Sensor Journal*, p.1, 2019.