A Multiband Implantable Antenna for Pacemaker

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Abstract.

A quad band microstrip patch antenna is presented in this paper designed for bio implant application specifically for pacemaker. The antenna's dimensions are $5\times5\times0.578mm^3$, and it was made of Rogers RT/Duroid6010, which has a thickness of 0.254mm. The antenna utilizes a meandering technique with a simple design structure to achieve miniaturization and multiband operation. The antenna has an impressive S11 magnitude of -24.79dB at 2.44GHz, -20.74dB at 3.53GHz, -22.13dB at 4.10GHz and -14.58dB at 5.79GHz making it operational in ISM and 5G sub 6 frequency bands. Simulated antenna gains at 2.44GHz, 3.5GHz, 4.10GHz, and5.79 GHz are -33.99dB, -15.49dB, -29.49dB and -20.8dB respectively. To ensure human safety SAR is analyzed in human heart model and the maximum allowable input power is 4.4mW which comply with FCC SAR limitations of 1.6W/Kg for 1 gm of tissues.

Keywords. Implantable antenna, multiband, pacemaker,5G

1. INTRODUCTION

Energy Pacemakers and implantable medical devices rely on implantable antennas for wireless communication, enhancing functions like monitoring and telemetry. Recent advancements focus on improving antenna performance, size, and multiband operation. Notable developments include J. Wang introduced a conformal antenna for endoscopy systems involving wireless capsule [1], while Zada developed a miniaturized implantable antenna with three bands for biotelemetry [2]. Shah et al. designed a spiral-shaped slotted implant antenna with four bands for scalp and leadless pacemakers [3]. Zhang et al. improved medical telemetry with a compact multiband antenna [4], and J. B. O'Connell et al. tested a multiband antenna for implanted devices [5]. Parker and K. E. Fisher optimized a dual-band antenna for leadless pacemakers [6].Recent advancements include a 5G MIMO antenna for cardiac pacemakers by Deepti Sharma et al. [7], a conformal implantable antenna for endoscopy by Jingchen Wang et al. [8], and a MIMO quad terminal triple-band antenna for deep tissue applications by Syed Manaf Ali Shah et al. [9]. These innovations enhance connectivity and efficiency in modern healthcare.

2. Antenna Design

The structure of proposed compact implantable antenna incorporates two symmetric meandered spiral arms modified with defected ground structure(DGS) making the design simple and compact as displayed in Figure 2.1. Geometry started with slotted arms and full ground and then meandering coupled with DGS to achieve multiple bands as in Figure 2.1.1. Antenna is designed to print on dual sided substrate and a superstrate is used to cover the radiating patch. Antenna has a planar square dimension of side 5 mm and height 0.578 mm, suitable for medical devices which has to be implanted smaller body parts. Rogers 6010 laminate act as substrate and top superstrate, having reduced dielectric loss with high permittivity. Meandering and defected ground improved antenna performance for desired bands with miniaturization. This laminate enhances microstrip antenna properties and miniaturization. Patch antenna equation(1&2) with multiple dielectric is used for calculating dimensions whose optimized dimensions are Listed in TABLE I.

Length $L=\lambda/(2\sqrt{\varepsilon eqv})$ (1)

Width W=λ/(2√εeqv) (2)

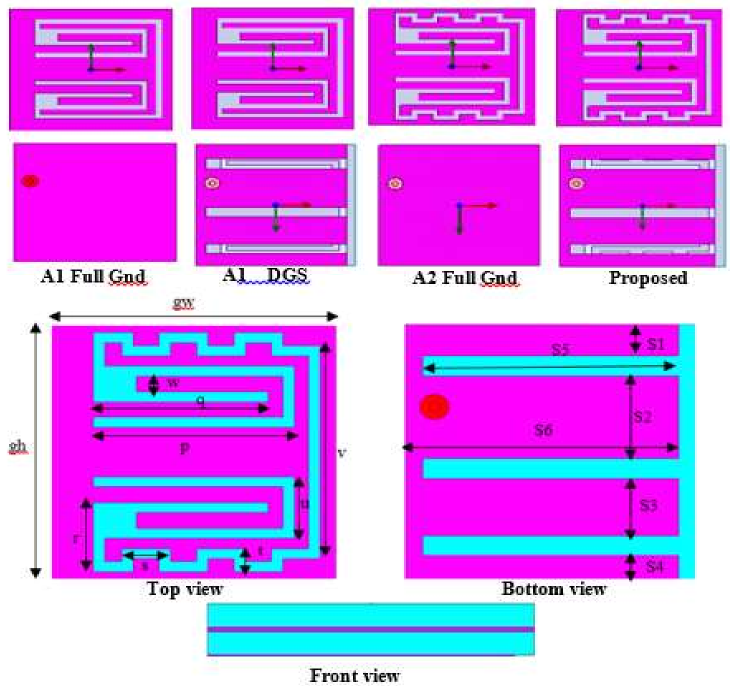

Figure 2.1. Geometry of Proposed Implantable Antenna with evolution

Table 1. Antenna Parameter

Antenna Parameter	gh	gw	p	q	r	s	t	u	v	w	S1	S2	S3	S4	S5	S6
Value (mm)	5	5	3.5	3.05	1.35	0.7	0.45	1.2	4.15	0.3	0.6	1.6	1.1	0.5	4.4	4.7

2.1. Results and Performance Discussion

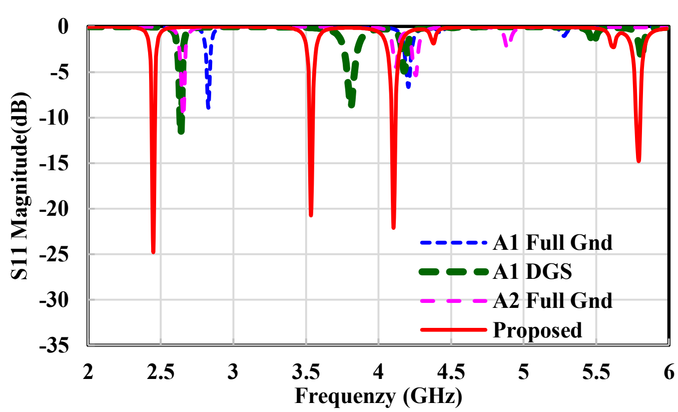

Figure 2.1.1 Return loss of designed antennas

This project simulations are done using HFSS software to evaluate the reflection and radiation performance with normal radiation open boundary condition at lower frequency of 2.45GHz. Slotted antenna (A1 Full gnd) is dual band with S_{11} >-10dB. When modified ground as DGS with multiple slots improved one band. Meandering with DGS provided multiband performance. Heart model of the software is utilized to study the real time bio implant application of pacemaker. The design has been carefully refined, showcasing remarkable impedance matching with return loss of 24.79dB at 2.44GHz, 20.74dB at 3.53GHz, 22.13dB at 4.10GHz and 14.58dB at 5.79GHz frequency as depicted in Figure 2.1.1. Multiple frequency bands of the antenna make the pacemaker efficient and operational in 5G application with faster data transmission rate. Bandwidth offered by the antenna is 25MHz for the first two lower frequency band s and 30MHz for the two higher frequency bands. The radiation field patterns of the antenna is displayed in Figure 2.1.2, demonstrates how the radiated power changes with angular position for both Phi = 0° and 90° at operational frequencies of 2.44GHz, 3.53GHz, 4.1GHz and 5.79GHz. Stable and dependable radiative performance is confirmed by the observed symmetry and shape of patterns of radiation. Figure 2.1.3 shows the antenna's gain plot, offers a thorough examination of the antenna's radiation capabilities throughout its working frequency spectrum. The antenna exhibits gain of -33.99 dB at 2.44 GHz, -15.49 dB at 3.5GHz, 29.49 dB at 4.10 GHz and -20.80db at 5.79GHz reflecting reliable performance across the specified frequency ranges. There is a trade off between antenna size and gain.

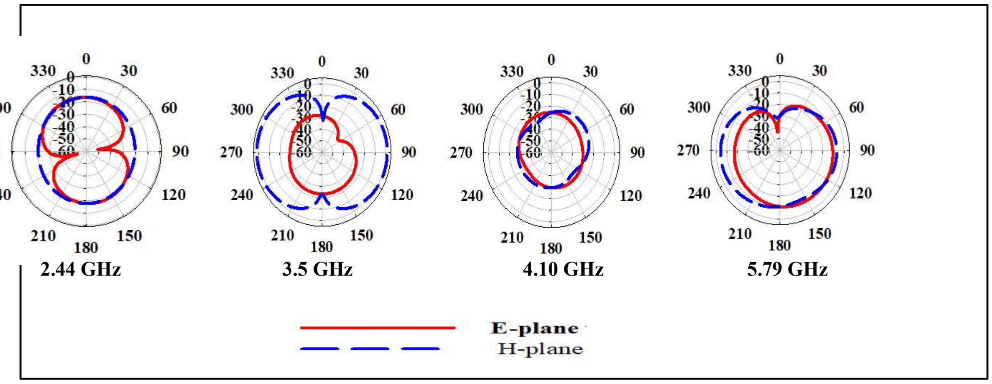

Figure 2.1.2. Radiation patterns of suggested Antenna

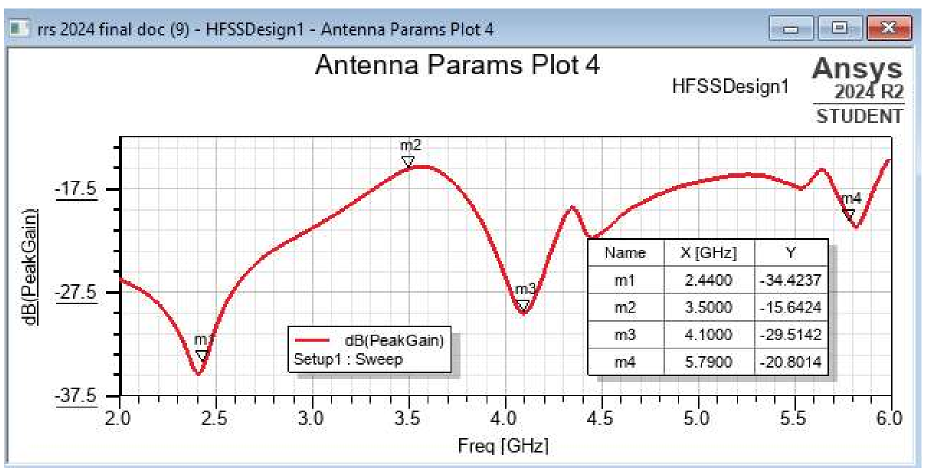

Figure 2.1.3. Gain of proposed antenna

2.2. SAR results

The rate at which electromagnetic energy is absorbed by bodily tissues in response to radio-frequency electromagnetic fields is measured by the SAR. To enable a safer transmission system in the body, the body's capacity to absorb radiation per unit mass of 1gm of tissue needs to be examined. The simulated antenna SAR on heart model at various frequency band are shown in Figure 2.2.1. We reproduce the 1-g averaged specific absorption rate (SAR) at 2.45GHz with varying input power levels to guarantee patient safety. Within the simulation, the antenna was carefully positioned in a model of heart tissue. Maximum SAR values obtained for 1W input power is 71.28W/Kg, 362.44W/kg, 421W/kg and 139.9W/kg for 2.4GHz, 3.53GHz, 4.1GHz and 5.79GHz respectively and the maximum input power allowable for FCC regulation limited SAR of 1.6W/Kg is 3.8mW.

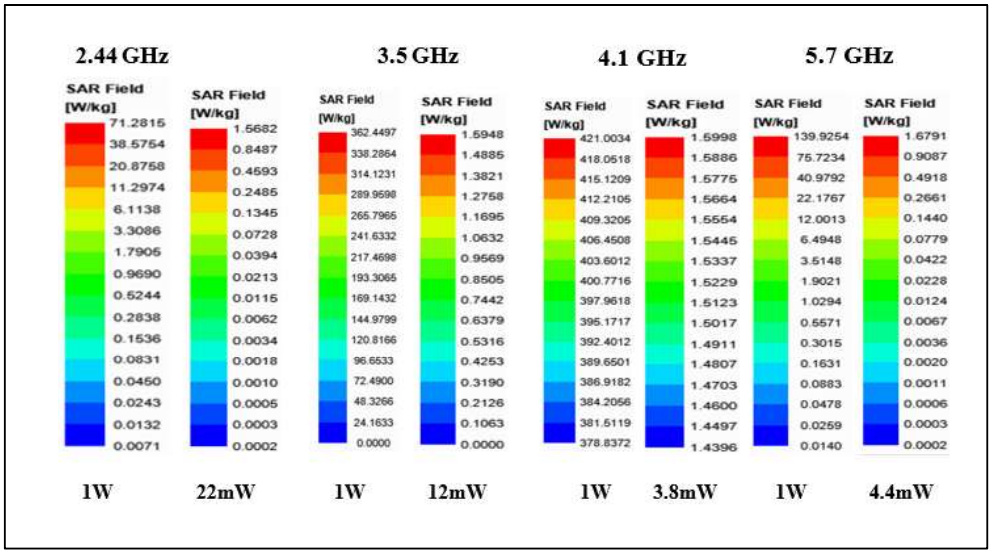

Figure 2.2.1. SAR results of the suggested antenna at various frequencies

Table 2. Comparison of Antenna Parameter with Literature

Reference	Frequency (GHz)	Bandwidth (MHz)	Dimension (mm^3)	Gain(dB)	SAR(W/Kg)	Max Input Power (mW)	Material
[1]	2.45 and 5.8	280 and 110	15x 15x 0.79	-31.6 and -- 28.66	403 and 361	1.7	Rogers 5870
[2]	1.95 and 2.45	65 and 60	7x 6x 0.5	-26.4 and -23	380, 358 and 363	4.4	Roger RT/Duroid 6010
[7]	2.45 and 5.8	44 and 40	3.4x 6.6x 0.254	-31.6 and - 21.4	263.3 and 107.45	6.3 and 11	Roger 3010
[8]	2.45	55	15x 15x 0.79	-27.5	913	1.6	Rogers 5870
[9]	0.9, 1.7 and 2.45	90, 129 and 200	7.5x 10.5x 0.127	-37.3, -30.3 and -20.9	251, 211 and 261	20	Roger RT/Duroid 6010
Proposed Antenna	2.44, 3.53 4.10 and 5.79	25,25,30 and 30	5 x5 x0.578	-33.99, -15.49, -29.49 and -20.8	71.28, 362.4, 421 and 139.92	22,12,3.8 and 4.4	Rogers 6010

3. Conclusion

The design and development of a small, rectangular antenna for novel biomedical uses specifically, real-time cardiac monitoring—was discussed in this study. With S11 magnitudes of -24.79 dB at 2.44GHz, -20.74 dB at 3.53GHz, -22.13 dB at 4.10GHz, and -14.58 dB at 5.79GHz, the proposed antenna operates in quad bands. The antenna's integration of the 5G frequency alongside the ISM band is an advantage. In future antenna will be experimentally validated for pacemaker and other biomedical applications such as endoscopy and ICP. The antenna is appropriate for cardiac pacemaker applications due to its acceptable gain and decreased SAR value.

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References

1. 1. J. Wang, "An Implantable and Conformal Antenna for Wireless Capsule Endoscopy", IEEE Antennas and Wireless Prop. Lett, vol. 17, Pp. 1568-1571, 2018.
2. M. Zada, "A Miniaturized Triple-Band Implantable Antenna System for Biotelemetry Applications", IEEE TAP., vol. 16, No. 12, pp. 3851-3860, 2018.doi: 10.1109/TAP.2018.2874681
3. IA. Shah, M. Zada and H. Yoo, "Design and Analysis of a Compact-Sized Multiband Spiral Shaped Implantable Antenna for Scalp Implantable and Leadless Pacemaker Systems", IEEE TAP, vol. 67, no. 6, pp. 4230-4234, 2019. doi: 10.1109/TAP.2019.2908252.
4. L. R. Zhang, Y. K. Tan, And H. T. Nguyen, "Design Of A Compact Multiband Implantable Antenna For Medical Telemetry Applications," IEEE Trans on Biomedical Engg, vol. 66, No. 5, Pp. 1245-1254, May 2019.
5. J. B. O'Connell, J. K. Lee, and M. M. Krueger, "Development and Testing of a Compact Multiband Antenna for Implanted Medical Devices," IEEE Transactions on Microwave Theory and Techniques, vol. 68, no. 1, pp. 231-240, Jan. 2020.
6. R. V. W. Z. B. Parker and K. E. Fisher, "A Compact Dual-Band I Implantable Antenna for Leadless Pacemakers: Design, Simulation, and Testing," IEEE Antennas and Wireless Propagation Letters, vol. 18, no. 1, pp. 99-106, Jan. 2019.
7. Deepti Sharma1 , Binod Kumar Kanaujia1,2, Sachin Kumar3 , Karumudi Rambabu4 & Ladislau Matekovits5,6,7 "Low-loss MIMO antenna wireless communication system for 5G cardiac pacemakers " 2023
8. Jingchen Wang, Mark Leach, Eng Gee Lim, Zhao Wang, Rui Pei and Yi Huang "An Implantable and Conformal Antenna for Wireless Capsule Endoscopy ": DOI 10.1109/LAWP.2018.283639
9. Syed Manaf Ali Shah, Muhammad Zada , Member, IEEE, Jamal Nasir , Owais Owais, and Hyoungsuk Yoo , Senior Member, IEEE "Four-Port Triple-Band Implantable MIMO Antenna for Reliable Data Telemetry in Wireless Capsule Endoscopy and Deep Tissue Applications" Ieee Transactions On Antennas And Propagation, VOL. 72, NO. 8, AUGUST 2024