Compact Implantable Antenna Design for Leadless Cardiac Pacemaker System

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***Abstract*—This paper details an implantable antenna for leadless cardiac pacemaker (LCP) applications operating in the Industrial Scientific Medical (ISM) frequency band (2.4–2.48GHz). The antenna uses a shorting pin to achieve an improved simulated 10dB fractional bandwidth of 20%, compared to similar literature designs. It implements a spiral-shaped meander pattern in an ultra-compact 3x3x0.5 mm^3 footprint. The calculated maximum specific absorption rate (SAR) values comply with IEEE C95.1-2005 and C95.1-1999 safety guidelines.**

I. Introduction

LCPs attempt to reduce complications and infections caused by conventional wired pacemakers. An important aspect of LCPs is biotelemetry which allows for control of the device and patient monitoring. This wireless communication requires an implantable antenna. The limited space inside implantable medical devices (IMDs) necessitates miniaturisation of implantable antennas. The important parameters for an antenna design include impedance matching, bandwidth, compactness, polarization matching, SAR, and radiation efficiency. Many miniaturisation methods have been developed including meandering, ground slots, shorting pins, implementing a superstrate and the use of high-dielectric constant materials. A 7x6.5x0.375 mm^3 multiband design employed a hooked open-end ground slot to lengthen the current path, without increasing the size of the antenna [1]. The slot allowed for tuning the antenna to the desired frequencies while improving resonance depth. This design also employed a superstrate to reduce the operating frequency, allowing for a smaller current path for the desired frequencies. The design used a high dielectric constant material. In [2], a thicker superstrate (0.25 mm) than [1] was used to shorten the effective wavelength further and reduce antenna losses. [3] used ground slots in a 3x3x0.5 mm^3 antenna with a folded meander. 5 open-end ground slots were able to increase radiation efficiency to achieve a similar gain to [2]. [4] illustrates the use of shorting pins to create a multiband resonance by altering the current path. An open-ended slot was used to tune the antenna to the desired frequencies. Etched ground slots were also used to improve impedance matching. [5] presents a large conformal spiral-shaped antenna that makes use of a shorting pin to achieve the desired frequency.

In this paper, a novel ultra-compact single-frequency implantable antenna for LCPs is proposed using a shorting pin to achieve a greater simulated fractional bandwidth than similar literature designs [3] [2]. In addition, tuning is achieved by optimising the position of the via instead of with ground slots.

II. Antenna Design and Simulation Results

A key property of implantable antennas is they must be biocompatible. This antenna would need to be coated in a thin film of ceramic aluminium oxide, as the dielectric used is not biocompatible [6]. The antenna design is presented in fig. 1.

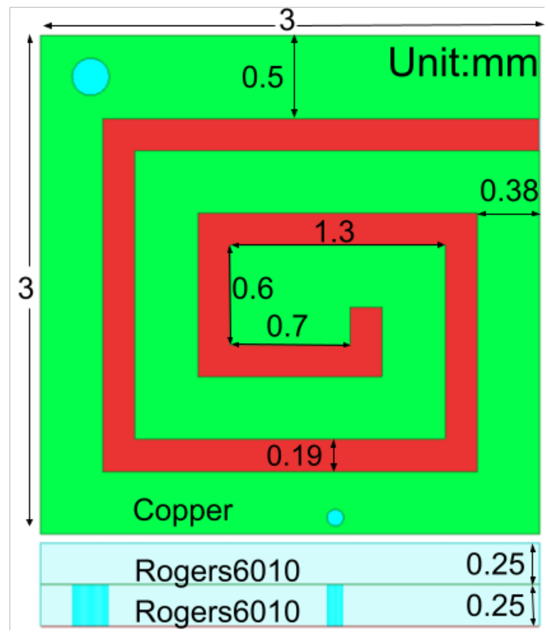

Fig. 1. Suggested antenna structure

The centre of the 50 Ω coaxial feed and shorting pin are (0.3 mm, 2.75 mm) and (1.75 mm, 0.1 mm) respectively. The design includes a substrate and superstrate of dielectric material. Rogers6010 was selected due to its high dielectric constant r = 10.2. It has a tangent loss of 0.0023. The antenna was modelled and optimised at the centre of a homogeneous heart phantom 60x60x150 mm^3, as used in [3]. A conductivity of 2.215 S/m and dielectric permittivity of 54.918 were used to model heart tissue at 2.45 GHz [7]. The antenna was designed and simulated in Ansys HFSS. Fig. 2 shows the S11 of the antenna.

Fig. 3 illustrates the low gain of the design. This is due to the shorting pin reducing the current path, illustrated in the current distribution in fig. 4. Table I compares key parameters to literature.

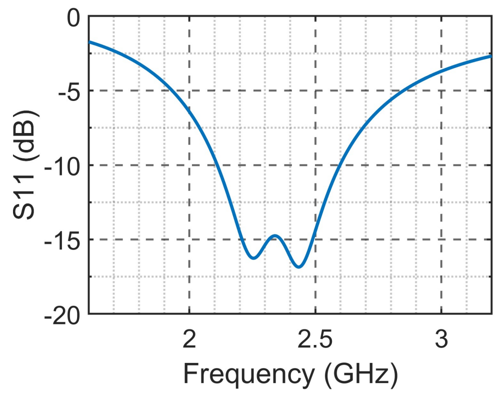

Fig. 2. Simulated reflection coefficient

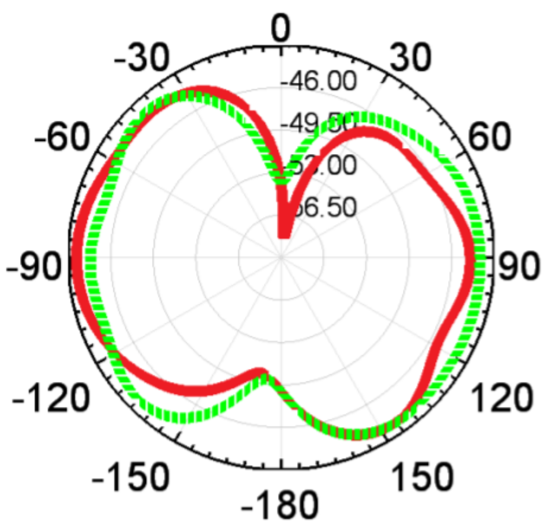

Fig. 3. Radiation pattern at 2.45 GHz. Red: E-plane. Green: H-plane

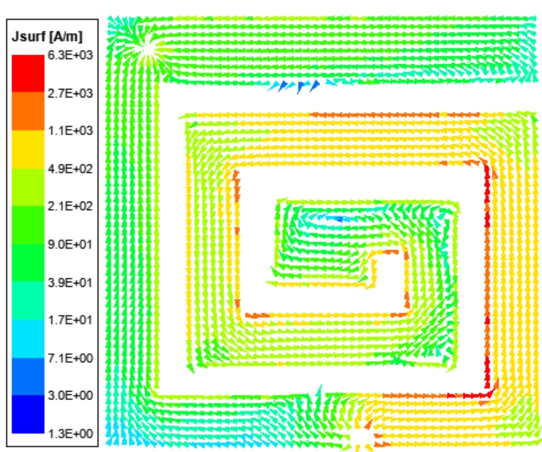

Fig. 4. Current distribution at 2.45 GHz

III. Conclusion

This paper introduces a compact, implantable antenna design for LCPs operating at 2.45 GHz. The discussed antenna uses a shorting pin to achieve a fractional bandwidth of 20% in simulation. This is improved compared to current antennas of similar dimensions at the cost of antenna gain as summarised in table I. It complies with SAR guidelines (IEEE C95.1-2005). The discussed antenna has an ultra-compact structure at 3x3x0.5 mm^2 [3]. Further research could include implementing ground slots and fabricating the antenna design to observe whether the improved simulated bandwidth carries over to real testing.

Acknowledgement

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 872172 (TESTBED2 project: www.testbed2.org).

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TABLE I
Comparison to Existing Literature (simulated 10dB fractional bandwidths were estimated from figures in cited literature)

Ref.	Size (mm^3)	Freq. (GHz)	Simulated fractional 10dB BW (%)	Measured 10dB BW (%)	Peak Gain (dBi)	Phantom Size (mm^3)
[2]	3×4×0.5	2.4	6.5	21.8	-25.9	80×60×120
[3]	3×3×0.5	2.45	7.0	22	-24.9	60×60×150
-This Work	3×3×0.5	2.45	20	—	-42.7	60×60×150