A Deeply Implantable Conformal Antenna for Leadless Pacing Applications

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***Abstract*—Finite battery life and complications caused by leads of conventional pacemakers are key issues in pacemaker technology. In this paper, we propose a deeply implantable antenna which can be conformed on a commercially available leadless pacemaker and has the potential capability of receiving and harvesting radio frequency (RF) energy to achieve cardiac pacing. More specifically, a deeply implantable conformal antenna at 2.45 GHz has been designed in ANSYS HFSS and then manufactured and integrated with a 3D printed mock pacemaker. The antenna performance was measured in tissue simulating liquid (TSL) and good agreement was achieved with the simulation results. Moreover, it was concluded that the proposed conformal antenna design on a commercially available pacemaker has the potential to be integrated with a rectifier for leadless pacing.**

I. Introduction

Modern Cardiac Resynchronization Therapy devices such as pacemakers do not only stimulate the myocardium of the heart to correct its rhythm but also performs other important functions such as implementation of algorithms, obtaining measurements of diagnostic data and other sensors [1]. These devices have the ability to improve the wellbeing of the patients and the potential to increase the life expectancy. However, conventional pacemakers face two serious issues; (a) infection in the veins due to their leads, and (b) longevity due to its finite battery life which requires device replacement surgery and results in pain and healthcare cost.

To achieve leadless pacing, various wireless power transfer methods have been investigated, e.g., magnetic resonance, inductive coupling, ultrasonic, radio frequency, and solar power [2]. Unlike other methods, the use of rectennas, to harvest RF energy, for leadless pacing applications is fairly new and was demonstrated in an ovine model [3,4]. However, the electrode introduced in [3,4] is only a proof of concept and its relatively large size makes it unable to deliver using a catheter, which is a less invasive and state-of-the-art method. The work presented in this paper is an advancement in the electrode design for RF energy harvesting and an effort to design a conformal antenna that was successfully conformed on a mock electrode similar to the Micra TPS, a commercially available pacemaker by Medtronic [5].

For demonstration of the conformal antenna on the pacemaker electrode, a microstrip antenna at 2.45 GHz was designed and then optimized to achieve good impedance matching and radiation characteristics in tissue simulating liquid (TSL) [6]. The antenna was then conformed on a modeled pacemaker electrode and inserted in the TSL in HFSS to emulate the human body characteristics. The conformal structure of the antenna and its integration with the modeled pacemaker electrode is shown in Fig. 1 (a) and (b). However, Fig. 1 (c) shows the prototype of the manufactured 3D printed mock pacemaker electrode with the conformal antenna design. The manufactured prototype was inserted in the TSL provided by SPEAG [6] for the measurement of $|S_{11}|$ (dB). Overall, a good

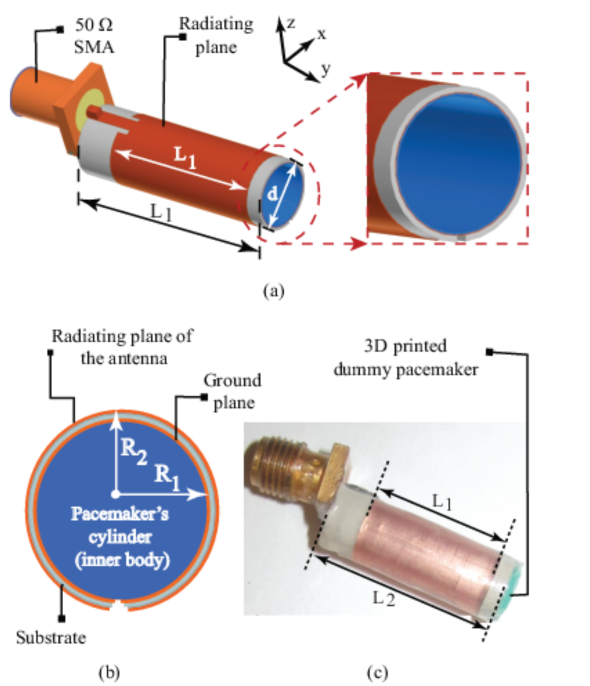


Fig. 1. (a) A 3D design of the conformal antenna modeled in HFSS with pacemaker electrode. (b) A different orientation of the antenna showing detailed view of different layers wrapped on the modeled electrode. (c) Picture of the manufactured prototype. (Dimensions are (in mm): $L_1=15$, $L_2=20$, $d=6.5$, $R_1=3$, $R_2=3.28$).

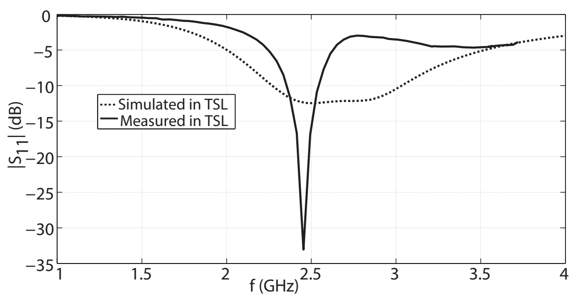
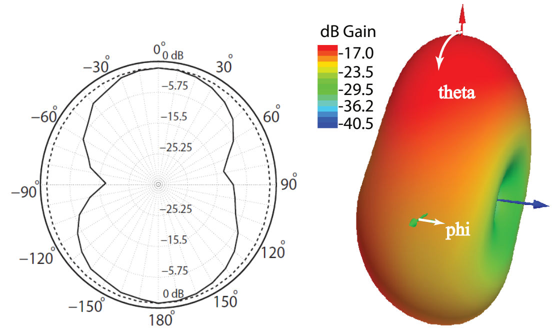


Fig. 2. Comparison of the simulated and measured reflection coefficients ($|S_{11}|$ in dB).



(a) (b)

Fig. 3. Radiation Pattern of the conformal implantable antenna. (a) E-(xy) plane (solid line) and H-plane (xz) plane (dotted line) of radiation pattern. (b) A simulated 3D radiation plot showing the total gain.

agreement was observed between simulation and measurement results.

II. Design Procedure and Prototype Fabrication

Initially, a planar microstrip antenna on a 10 mil thick Rogers 6010LM substrate (ϵ_r=10.2 and tanδ=0.0023) at 2.45 GHz in free space was designed in HFSS and a good impedance match was achieved. This substrate was selected due to its flexibility and high permittivity value, which helped in achieving a compact size. Then, to observe the performance of a planar antenna in the human body, it was first simulated and optimized in a finite boundary with properties of the body TSL [7]. This was followed by creating a model of a leadless pacemaker and then conforming the proposed antenna on its body. The wrapping of the conformal antenna on the modeled electrode in shown in Fig. 1 (a). A detailed geometry with the dimensions of the implantable antenna and pacemaker is shown in Fig. 1 (a-c). It was observed that when the antenna was wrapped around the circumference of the cylinder, the total diameter d of the model increased from 6 mm to 6.578 mm. The resultant changes in the resonance frequency, introduced due to the wrapping of the antenna on leadless pacemaker's model, were compensated by further optimization in HFSS.

Following the design optimization and simulations of the proposed deeply implantable conformal antenna, simulation results are validated by fabricating the antenna, 3D printing a pacemaker electrode, and manufacturing a conformal prototype. The manufactured prototype with a 50 Ω connector is shown in Fig. 1 (c).

III. Simulations and Measurement Results

To emulate the depth of a heart from the surface of the chest, the manufactured prototype antenna was inserted 6 cm deep inside the TSL and its performance was measured using a fully calibrated Vector Network Analyser (E5071C). The comparison of reflection coefficients shown in Fig. 2 shows a good agreement between the simulated and measured results. The bandwidth mismatch is attributed due to the fabrication imperfections. Moreover, the simulated radiation pattern of the implantable antenna is plotted in Fig. 3.

IV. Conclusion

A deeply implantable conformal antenna is designed, manufactured and tested in tissue simulating liquid. It was observed that the implanatable antenna has good impedance matching characteristics with the same radiation pattern plot as that of a planar microstrip antenna in free space. It was also concluded that the proposed embodiment has a lower gain upto -17.5 dB because of the highly lossy tissue. Furthermore, the miniature implanatable antenna integrated with the model of a commercially available pacemaker demonstrated the potential of this antenna for future integration with a rectifier circuit to achieve leadless pacing.

Acknowledgements

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