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Design of an implanted compact antenna for an artificial cardiac pacemaker system

Soonyong Lee[1], **Wonbum Seo**[1], **Koichi Ito**[2], **and Jaehoon Choi**[1a)]

[1] *Department of Electrical and Computer Engineering, Hanyang University*
222 Wangsimni-ro, Seongdong-gu, Seoul, 133–791, Republic of Korea
[2] *Graduate School of Engineering, Chiba University, Japan*
1–33, Yayoi-cho, Inage-ku, Chiba-shi, Chiba, 263–8522, Japan
a) *choijh@hanyang.ac.kr*

Abstract: An implanted compact antenna for an artificial cardiac pacemaker is proposed. The dimension of the pacemaker system, including the antenna element, is 30 mm × 35 mm × 7 mm. When the antenna is embedded in a semi-solid flat phantom with equivalent electrical properties as the human body, S_{11} value is −19.2 dB at 403.5 MHz and the −10 dB impedance bandwidth of the antenna is 10 MHz (399∼409 MHz). The proposed antenna in the phantom has a peak gain of −24.61 dBi at 403.5 MHz. The measured specific absorption ratio (SAR) value of the proposed antenna is 0.0079 W/Kg (1 g tissue). Moreover, to estimate the communication performance of the proposed antenna operated in the real environment, a link budget analysis is performed.

Keywords: implanted antenna, pacemaker, medical devices, PIFA
Classification: Wireless communication hardware

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1 Introduction

Recently, Medical Implant Communication Service (MICS) has been investigated with great interest due to the increasing concern about health problems [1, 2, 3, 4]. The MICS is a system that can transmit vital information from an antenna embedded in a human body to external equipment through use of a wireless communication link. Such a system can reduce the time required to obtain a diagnosis in patients and ease patients' physical or psychological stress. In addition, it can communicate without a wire piercing the skin, and is therefore not a risk for causing infection [1].

The antennas for implantable medical devices have been designed to operate in the 402∼405 MHz band recommended by the Federal Communication Commission (FCC) [2] and the European Telecommunications Standards Institute (ETSI) [3]. It is difficult to design implanted antennas due to the reduced antenna efficiency, effects of an environment surrounding the antenna, need to reduce antenna size, and strong effects of multipath losses at the 400 MHz band. Several types of antennas have been previously used or proposed for various implantable wireless communication applications (loop antenna, monopole antenna, meander line antenna, and so forth). Planar inverted-F (or shorted patch) antennas (PIFAs) have often been used for implantable systems [1, 4]. Since antennas were located on the front face of the pacemakers used in these studies, the overall thicknesses were increased. The antennas employed also had low gain and high power consumption to create links.

In this paper, an implanted compact antenna for an artificial cardiac pacemaker is proposed. To maintain the low profile of a pacemaker and enhance the radiation performance, a simple PIFA placed on the top side of the pacemaker is used. The performances of the antenna in human body tissue including S_{11} characteristics, radiation patterns and specific absorption ratio (SAR) are analyzed through simulation and measurement utilizing a semi-solid flat phantom with equivalent electrical properties to whole human body.

2 Antenna design

Fig. 1 (a), (b), and (c) show the configuration of the proposed antenna for an artificial cardiac pacemaker. The antenna structure is based on a PIFA often used for mobile handsets. In Fig. 1 (b), the radiating element which has dimension of 35 mm × 6.86 mm is located on the top side of the pacemaker. The radiator is fed by a coplanar waveguide (CPW) having a wide impedance bandwidth characteristic and shorted at 1 mm away from the feeding strip. The CPW fed antenna has an advantage of easy integration with other integrated circuits. The CPW feeding structure is implemented on a FR-4 substrate with $\varepsilon_r = 4.4$ and thickness of 1 mm. In Fig. 1 (c), the radiator has an L-shaped split to control the resonance frequency. Taconic CER-10 with a relative permittivity of 10 is used for the substrate and two superstrates. As shown in Fig. 1 (c), they have thicknesses of 4.36 mm and 1.6 mm, respec-

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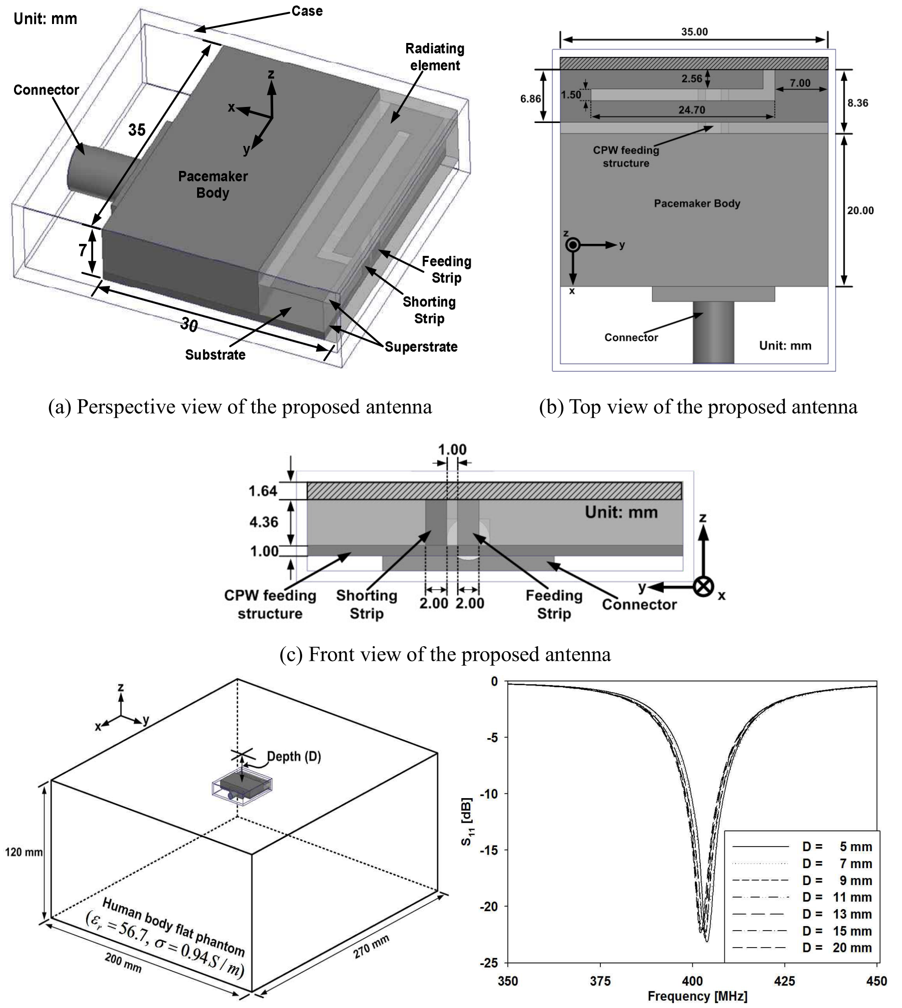

(a) Perspective view of the proposed antenna (b) Top view of the proposed antenna

(c) Front view of the proposed antenna

(d) Numerical analysis flat phantom model (e) Simulated S_{11} characteristics for various depths

Fig. 1. Configuration and simulated S_{11} characteristics of the proposed antenna

tively. The superstrate reduces the effect of high conductive body tissue on the antenna. The dimension of the pacemaker body is 35 mm × 20 mm × 6 mm. In order to reduce the electrical loss, the pacemaker system is covered with a case in acrylic with a dielectric constant of 2.6 and thickness of 1 mm. The whole dimension of the pacemaker system including the antenna element is 35 mm × 30 mm × 7 mm. This antenna structure is designed and analyzed using the HFSS Ver. 13 of ANSYS Inc. In order to analyze the antenna performance in a human body, simulations were carried out after placing the proposed antenna in a human body model which has equivalent electrical properties ($\varepsilon_r = 56.7$, $\sigma = 0.94$ S/m, $\tan\delta = 0.74$) to whole human body and the size of 200 mm × 270 mm × 120 mm as shown in Fig. 1 (d) [5].

In general, since fat thickness differs by individual body type and gender, a depth (D) from phantom surface to pacemaker is changed to evaluate the effect of thickness for the fat. Fig. 1 (e) shows the S_{11} performance of the proposed antenna for various depths (D). When the depth (D) from phantom surface to the proposed antenna is changed from 5 mm to 20 mm, the resonant frequencies of the proposed antenna are slightly shifted and the −10 dB

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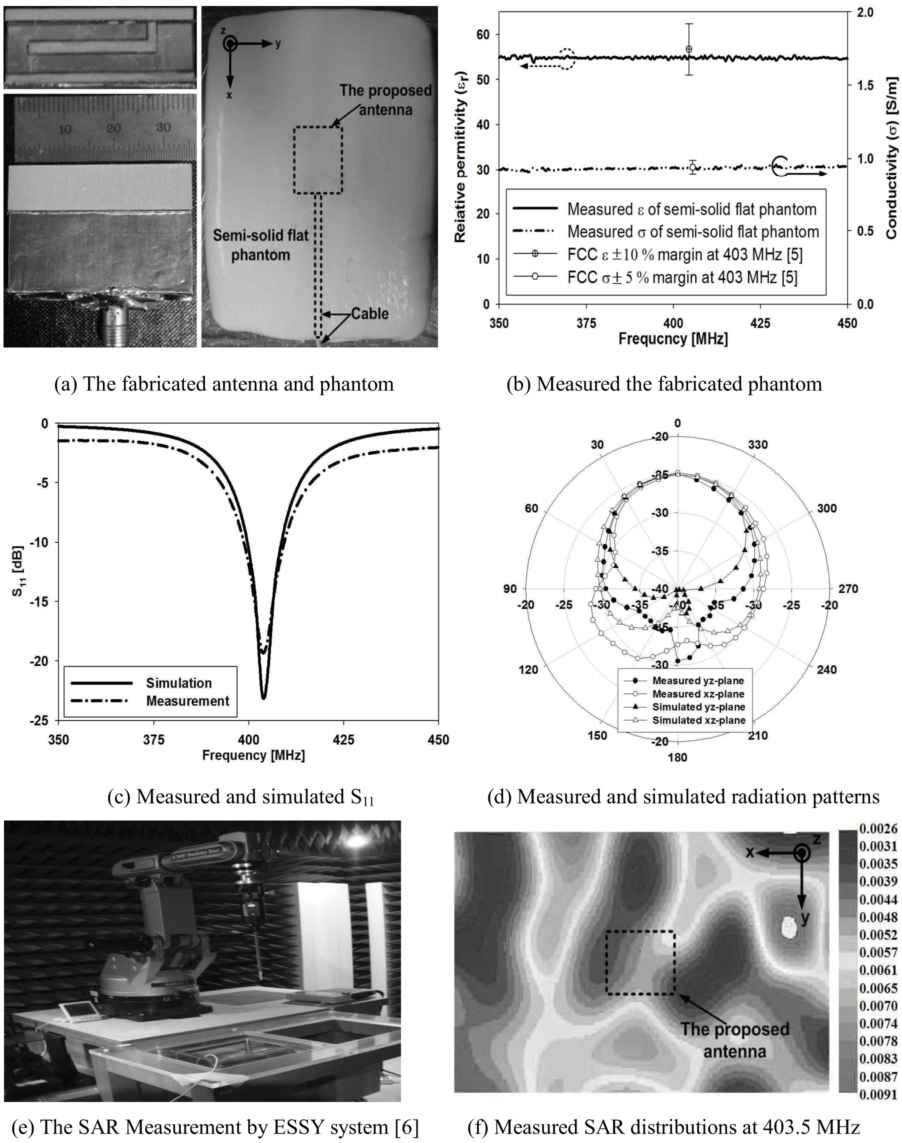
impedance bandwidth at MICS band is satisfied for various depths due to the usage of the two superstrates with high permittivity ($\varepsilon_r = 10$).

3 Experimental results

The fabricated antenna and semi-solid flat phantom are shown in Fig. 2 (a). Also, measured relative dielectric constant and conductivity of the phantom using an Agilent 85070E dielectric probe kit and 8719ES network analyzer together are shown in Fig. 2 (b). The semi-solid flat phantom with a dimension of 200 mm × 270 mm × 120 mm is used to measure the S_{11} characteristics and radiation patterns, as shown in Fig. 2 (c) and (d). Fig. 2 (c) shows the measured S_{11} characteristics of the proposed antenna. When the antenna is embedded at 5 mm from the semi-solid phantom surface, the S_{11} value of the proposed antenna is −19.2 dB at 403.5 MHz. The −10 dB impedance bandwidth of the antenna is 10 MHz (399 MHz∼409 MHz). The simulated and



(a) The fabricated antenna and phantom

(b) Measured the fabricated phantom

(c) Measured and simulated S_{11}

(d) Measured and simulated radiation patterns

(e) The SAR Measurement by ESSY system [6]

(f) Measured SAR distributions at 403.5 MHz

Fig. 2. The fabricated antenna and the measured performance

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measured results show very good agreement in Fig. 2 (c). The measured radiation patterns of the proposed antenna in the xz- and yz- planes are plotted in Fig. 2 (d). Those are measured in a 10 m anechoic chamber. The antenna in the phantom has a peak gain of −24.61 dBi at 403.5 MHz.

The SAR is an essential factor to evaluate when the antenna is operated on or inside the human body. The SAR was measured at the Radio Research Agency of Korea using ESSAY system [6]. The proposed antenna is excited by the signal generator. Fig. 2 (e) shows the measured SAR distributions of the proposed antenna located at 5 mm away from the bottom inside a liquid flat phantom which has a dimension of 300 mm × 200 mm × 200 mm. It is filled with an equivalent liquid to body tissue ($\varepsilon_r = 56.7$, $\sigma = 0.94$ S/m, $\tan\delta = 0.74$) at 403 MHz. Since the Effective Isotopically Radiated Power (EIRP) from the implantable device is limited to 25 μW [2], the input power of 7.26 mW which is the maximum input power for the proposed antenna is used to measure SAR at 403.5 MHz. The FCC of United States requires that the SAR value should be below 1.6 watts per kilogram (W/kg) over a volume of 1 gram of tissue to evaluate SAR [5]. When the proposed antenna is placed in a liquid flat phantom, the SAR value of the proposed antenna is 0.0079 W/kg (1 g tissue).

4 Link budget analysis at MICS band

The implanted antennas are used to create link for delivering the vital information such as temperature, blood pressure, cardiac beat, and so on in the medical/health-care applications. Therefore, link budget analysis for wireless communication between the implanted antenna and an external receiver are essential. Table I shows a link budget between the proposed antenna and the external receiver.

Table I. Link budget calculation for the proposed antenna

The proposed antenna (Tx)		Propagation in air and body	
Frequency [MHz]	403.5	Distance between Tx and Rx [m]	10
Input power [dBm]	-31	Distance between Tx and body surface [mm]	5
Max. Antenna gain [dBi]	-24.61	Free space loss [dB]	44.59
EIRP [dBi]	-85.61	In-body loss [dB]	14.5
External receiver (Rx)		**Signal Quality**	
Antenna gain [dBi]	2	Bit rate [Kbps]	7
Receiver-NF [dB]	4	Bit error rate	1×10^{-5}
Noise power density [dB/Hz]	-199.07	E_b/N_o (ideal FSK) [dB]	12
Ambient temperature [K]	299	Fixing deterioration [dB]	2.5
Link C/N_0 [dB/Hz]		56.37	
Required C/N_0 [dB/Hz]		54.95	
Margin [dB]		1.42	

The operating frequency is fixed to 403.5 MHz (MICS band). Modulation and bit rate are assumed to be FSK and 7 kbps, respectively. In this analysis, we assume that a patient with a cardiac pacemaker is inside a hospital room so that the maximum distance between the implanted antenna and the external

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receiver is set to be 10 m. If the link C/N_0 which defines the availability of the communication exceeds the required C/N_0, the wireless communication is possible.

From the Table I, one can observe that the link C/N_0 exceeds the required C/N_0 when the input power of the proposed antenna is higher than −30.97 dBm. Since the measured peak gain of the proposed antenna is relatively high, input power required to provide good communication link can be lower than those for existing antennas for artificial cardiac pacemaker.

5 Conclusion

In this paper, an implanted antenna for an artificial cardiac pacemaker is proposed. The total dimension of the pacemaker system, including the antenna element, is 35 mm × 30 mm × 7 mm. To estimate a communication in the real environment a link budget calculation is presented. As a result, the proposed antenna operation at the MICS band is sufficient to create a communication link of MICS with external equipment located within 10 m distance. The proposed antenna can be used for an artificial cardiac pacemaker at the MICS band (402 MHz∼405 MHz) due to low profile, high gain, low input power requirement that are comparable to those for existing implantable antenna.

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