An Implantable Antenna for Wireless Body Area Network Application

Uisheon Kim · Jaehoon Choi

Abstract

In this paper, an implantable planar inverted-F antenna (PIFA) for an artificial cardiac pacemaker is proposed. The antenna has a simple structure with a low profile and is placed on the top side of the pacemaker. The dimensions of the pacemaker system, including the antenna element, are 42×43.6×11 mm. When the antenna is embedded in pig tissue, its S_{11} value is -10.94 dB at 403 MHz and the -10 dB impedance bandwidth of the antenna is 6 MHz (399～406 MHz). The proposed PIFA in tissue has a peak gain of -20.19 dBi and a radiation efficiency of 1.12 % at 403 MHz. When the proposed antenna is placed in a flat phantom, its specific absorption ratio (SAR) value is 0.038 W/kg (1 g tissue). Performances of the proposed PIFA is sufficient to operate at the MICS band (402 ~ 405 MHz).

Key words : WBAN, Implantable Antenna, Pacemaker, MICS, PIFA

Ⅰ. Introduction

Application of the wireless body area network (WBAN) has been expanding to medical services, national defenses, and wearable computing. Among these areas, the Medical Implant Communication Service (MICS) has been investigated with great interest [1～5]. The MICS is a system that can transmit vital information from an implanted antenna embedded in a human body to external equipment through use of a wireless communication link. This system is able to reduce the time required to obtain a diagnosis in patients and ease patients physical or mental burdens. 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 are 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 antennas for an implanted application due to the reduced antenna efficiency, impact of the environment on the antenna, need to reduce antenna size, and strong effect of multipath losses at the 400 MHz band. Several types of antennas have previously been 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, 5]. Since antennas were located on the front face of the pacemakers used in these studies, antenna thicknesses were increased. The antennas employed also had low gain and radiation efficiency.

In this paper, we propose an implantable antenna for an artificial cardiac pacemaker. To maintain the low profile of a pacemaker and enhance radiation performance, a simple PIFA placed on the top side of the pacemaker is used. The performance of the antenna in human body tissues with regard to S_{11} characteristics, radiation patterns and specific absorption ratio (SAR) are analyzed through simulation and measurement.

Ⅱ. Antenna Design

Fig. 1 shows 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(a), the radiating element, which has dimensions of 37×8.5×6.4 mm, is located on the top side of the pacemaker. The radiator is fed near the center of the top edge and shorted at 4 mm away from the feeding point, as shown in Fig. 1(b). In Fig. 1(c), the radiator has an L-shaped split to control the resonance frequency. Taconic CER-10 with a relative permittivity of 10.0 is used for the substrate and superstrate. As shown in Fig. 1(b), they have thicknesses of 6.4 mm and 1.6 mm, respectively. The superstrate reduces the effect of high conductive body tissue on the antenna. The dimensions of the pacemaker body are 40×30×9 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 dimensions of the pacemaker system, including the antenna element, are 42×43.6×11 mm. This antenna structure is designed and

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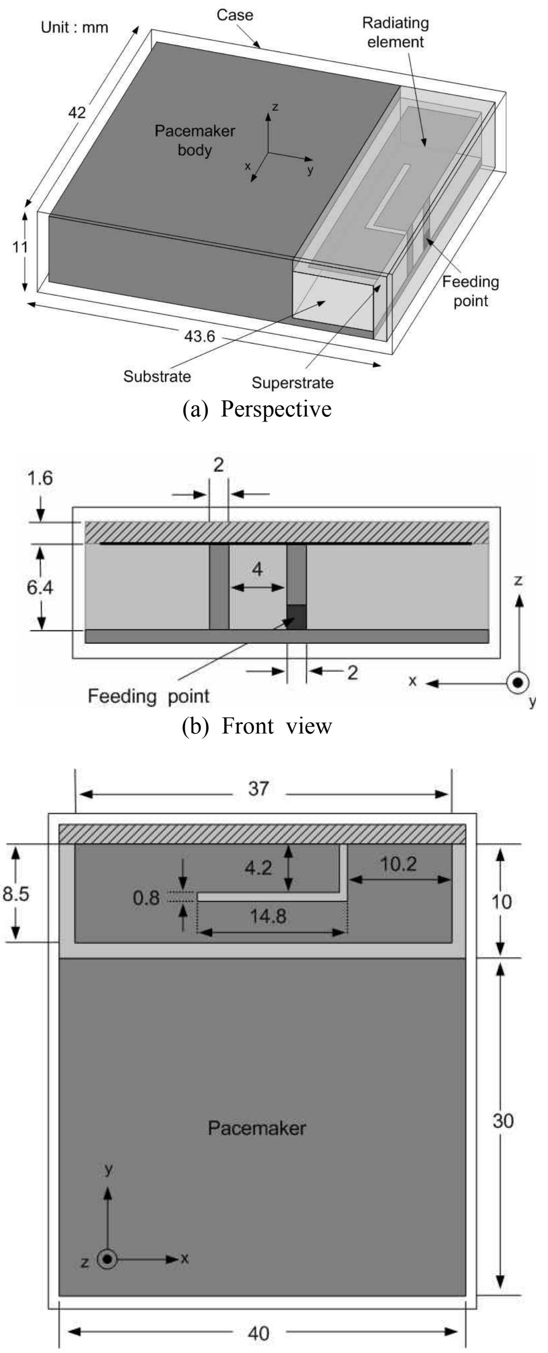


(a) Perspective

(b) Front view

(c) Top view

Fig. 1. Configuration of the proposed antenna on an artificial cardiac pacemaker.

analyzed using the SEMCAD X 3D EM field simulation tool [6].

In order to analyze the antenna performance in the human body, simulations were carried out after placing the proposed antenna in models of the human body. Human body models used in this study are as shown in Table 1. Models 1 and 2 are simplified flat phantoms for fast simulation. To more accurately account for the effect

Table 1. Human body models.

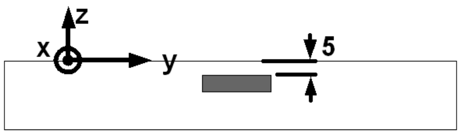
Model No.	Shape/size [mm]	Material properties	
1	Flat body tissue 200×200×50	ε_r=56.7, σ=0.94 S/m, tan δ=0.74	
2	Flat body tissue 200×200×45	Skin (2 mm)	ε_r=46.71, σ=0.69 S/m, tan δ=0.66
		Fat (3 mm)	ε_r=5.58, σ=0.04 S/m, tan δ=0.33
		Muscle (30 mm)	ε_r=57.1, σ=0.8 S/m, tan δ=0.62
		Bone (10 mm)	ε_r=22.42, σ=0.24 S/m, tan δ=0.47
3	Virtual voxel model Height: 1.6 m Weight: 58 kg	ε_r=56.7, σ=0.94 S/m, tan δ=0.74	
4		Includes the electrical properties of each human tissue	

of human body, models 3 and 4 are used. Models 3 and 4 are virtual voxel models, with a height of 1.6 m and a weight of 58 kg (human model software of IT'IS Foundation (Information Technologies in Society) [9]. Models 1 and 3 are one material layer, which has equivalent electrical properties to whole human body [7]. Model 2 has four material layers : skin, fat, muscle, and bone [8]. Model 4 includes the electrical properties of each human tissue.

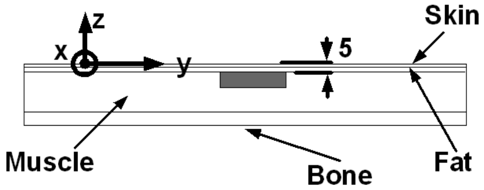
Fig. 2 shows various simulation models for evaluating the effect of human body. The pacemaker system is embedded 5 mm beneath the outer face in model 1. In model 2, the proposed antenna is placed between the fat layer and the muscle layer. In models 3 and 4, the proposed antenna is located in the muscle tissue on the left side of the chest.

Fig. 3 illustrates simulated S_{11} characteristics of the proposed antenna for various body models. The S_{11} characteristics of the proposed antenna in models 1 and 3 are nearly identical, and those of models 2 and 4 are similar. The resonance frequencies of models 2 and 4 become higher than those of models 1 and 3 due to the lower dielectric constants of skin and fat layers used in models 2 and 4. Therefore, one can conclude that the resonance frequency depends on the electrical properties of the body model rather than the size of the respective models.

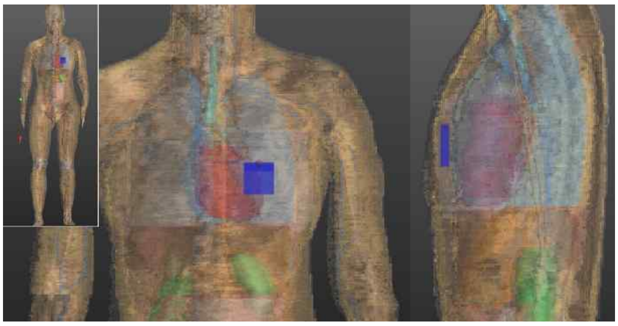
Fig. 4 shows simulated radiation patterns for various body models. The simulated peak gains are −21.17, −20.95, −21.8, and −22.9 dBi, respectively. In models 3 and 4, the back radiation on yz-plane is reduced by the height of voxel model. In model 2, the back radiation on yz-plane increases by the long penetration depth in each layer of model 2. Thus, the radiation pattern of



(a) Model 1



(b) Model 2



(c) Models 3 and 4

Fig. 2. Antenna positions in human body models.

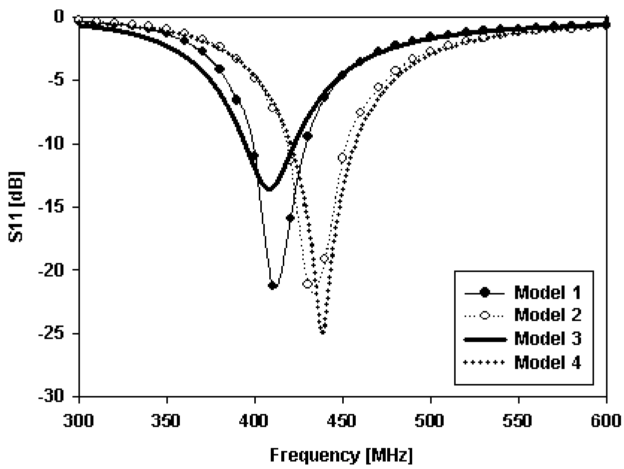
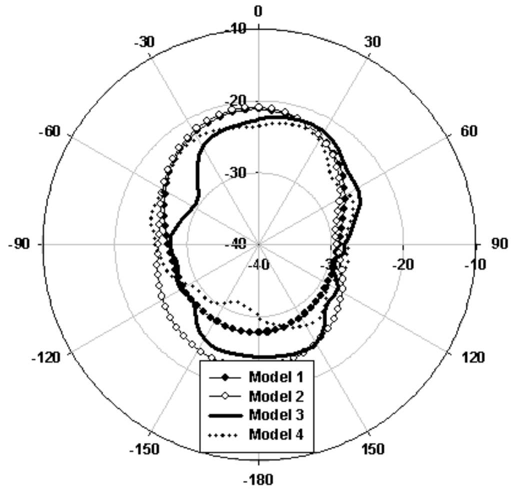


Fig. 3. Simulated S_{11} characteristics for various body models.

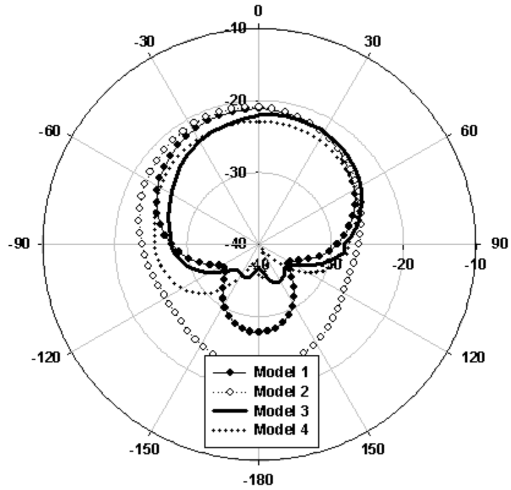
the implant antenna depends on both electrical properties and dimensions of the human model.

Table 2 compares the performances of the three antennas. The proposed antenna has low profile and higher gain than those of existing implantable antennas.

Fig. 5 shows the simulated SAR distributions of the proposed antenna in models 3 and 4. In the simulation, the input power is normalized as 1 W. Peak values of average 1 g SAR are 6.31 mW/kg and 6.56 mW/kg, respectively. Peak value of SAR in model 3, which has one material layer, is similar to that in model 4. The SAR distribution in model 3 is omnidirectional. On the other hand, the SAR distribution in model 4 shows directional property.



(a) xz-plane



(b) yz-plane

Fig. 4. Simulated radiation patterns for various body models at 403 MHz.

Table. 2. Comparison with existing design scheme.

	Size [mm]	Body model	Peak gain [dBi]
Ref. [1]	30×39×12 (without case)	ε_r=38.9, σ=0.53 S/m	−28
Ref. [5]	29.4×19.6×6 (without pacemaker and case)	ε_r=42.807, σ=0.65 S/m	−35
Proposed	42×43.6×11 (with pacemaker and case)	ε_r=56.7, σ=0.94 S/m	−21.17

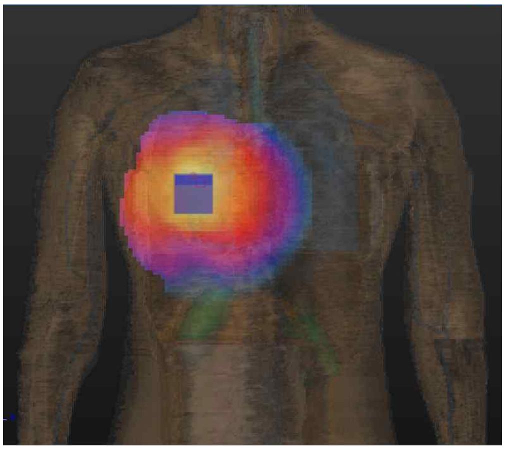
Ⅲ. Experimental Results

3-1 Antenna Performances

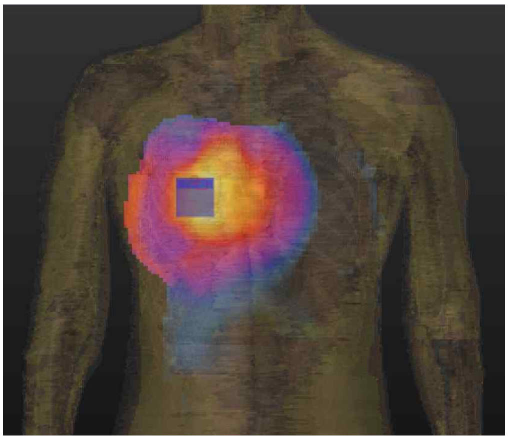
The fabricated antenna is shown in Fig. 6. Porcine tissue with dimensions of 280×210×80 mm is used to measure the S_{11} characteristics and radiation patterns, as shown in Fig. 6. The pig tissue consists of three layers: skin, fat, and muscle. The thicknesses of each layer are approximately 2, 10, and 68 mm, respectively. The *S*-parameters of the proposed antenna were measured using the network analyzer.

Fig. 7 shows the measured S_{11} characteristics of the proposed antenna. When the antenna is embedded in tissue, the S_{11} values of the proposed antenna is -10.94 dB at 403 MHz. The -10 dB impedance bandwidth of the antenna is 6 MHz (399～406 MHz).

The measured radiation patterns of the proposed antenna in the xz- and yz- planes are plotted in Fig. 8. Those are measured in a 10 m anechoic chamber. The PIFA in tissue has a peak gain of -20.19 dBi and a radiation efficiency of 1.12 % at 403 MHz. The difference between the simulated (in model 2) and measured radiation pattern is caused by a thick fat layer and the absence of bone layer of pig tissue.



(a) Model 3



(b) Model 4

Fig. 5. Simulated SAR distributions for models 3 and 4 at 403.5 MHz.

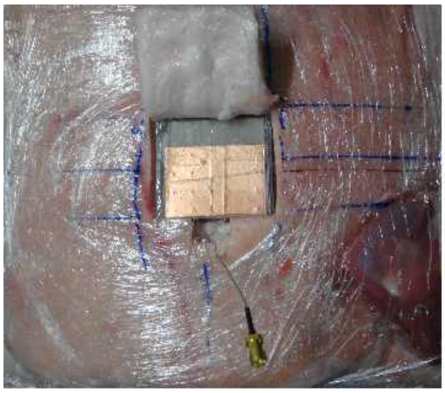


Fig. 6. Measurement set-up for the S_{11} and radiation patterns.

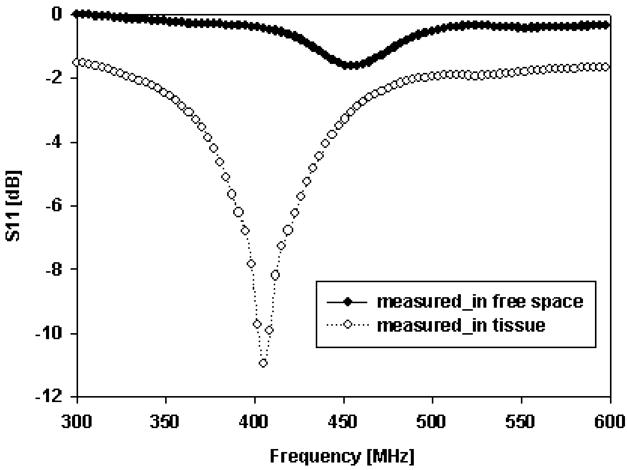


Fig. 7. Measured S_{11} characteristics.

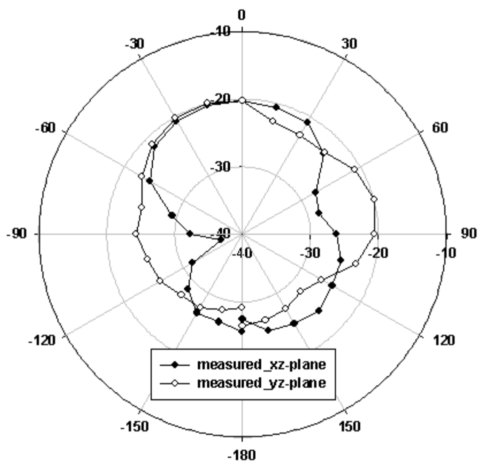


Fig. 8. Measured radiation patterns at 403 MHz.

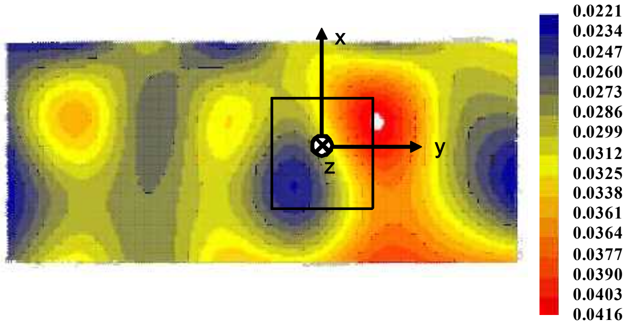


Fig. 9. Measured SAR distributions at 403 MHz.

In the sickroom, the distance between the transmitter and the receiver is 6.0 m and the bit rate is assumed to be 7 kbps in consideration of the transmitting vital signal. The required implanted antenna gain should be greater than −35.0 dBi [1]. The measured peak gain of the proposed antenna is sufficient to operate in [1].

3-2 SAR Evaluation

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 using ESSAY system [10]. The proposed antenna is excited by the spectrum analyzer. Fig. 9 shows the measured SAR distributions of the proposed antenna located on bottom inside a flat phantom which has a dimension of 300×200×200 mm. It is filled with an equivalent liquid to body tissue at 450 MHz [7]. Since the effective isotopically radiated power (EIRP) from the implantable device is limited to 25 μW [2], the input power of 1 mW is used to measure SAR at 403 MHz. The FCC of United State requires that the input power should be below 1.6 watts per kilogram (W/kg) over a volume of 1 gram of tissue to evaluate SAR [7]. When the proposed antenna is placed in a flat phantom, the SAR value of the proposed antenna is 0.038 W/kg (1 g tissue).

Ⅳ. Conclusion

In this paper, we propose an implantable PIFA for an artificial cardiac pacemaker. To maintain the low profile of a pacemaker and enhance radiation performance, the antenna is placed on the top side of the pacemaker. The total dimension of the pacemaker system, including the antenna element, is 42×43.6×11 mm. Performance of the antenna in human body tissues with regard to S_{11} characteristics, radiation patterns, and SAR are analyzed through simulation for various human body models. When the antenna is embedded in a pig tissue, the S_{11} value of the proposed antenna is −10.94 dB at 403 MHz and the −10 dB impedance bandwidth of the antenna is 6 MHz (399~406 MHz). The proposed PIFA in tissue has a peak gain of −20.19 dBi and the radiation efficiency of 1.12 % at 403 MHz. When the antenna is placed in a flat phantom, the SAR value is 0.038 W/kg (1 g tissue). The proposed PIFA can be used for an implantable device at the MICS band (402~405 MHz) due to low profile and high gain that are comparable to those for existing implantable antenna.

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