

Design and Simulation of Implantable PIFA in Presence of ANSYS Human Body Model for Biomedical Telemetry Using ANSYS HFSS

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Abstract_ In this white paper, a small implantable Planar Inverted F Antenna (PIFA) is presented for Medical Implant Communications Service (MICS) band (402-405MHz). Design modification and tuning of antenna performance are studied when the implantable antenna is placed inside the skin tissue of ANSYS human body model. The resonance, radiation, and Specific Absorption Rate (SAR) of implantable PIFA are evaluated. Simulations are performed by ANSYS HFSS (High-Frequency Structural Simulator) which is based on Finite Element Method (FEM).

I. Introduction

In recent years, with rapid development of wireless communication technology, Wireless Body Area Networks (WBAN) have drawn a great attention. WBAN technology links electronic devices on and in the human body with exterior monitoring or controlling equipment. The common applications for WBAN technology are biomedical devices, sport and fitness monitoring, body sensors, mobile devices, and so on. All of these applications have been categorized in two main areas, namely medical and non-medical, by IEEE 802.15.6 standard [1]. For medical applications, the wireless telemetric links are needed to transmit the diagnostic, therapy, and vital information to the outside of human body [2], [3]. The wide and fast growing application of wireless devices yields to a lot of concerns about their safety standards related to electromagnetic radiation effects on human body. Interaction between human body tissues and Radio Frequency (RF) fields are important. Many researches have been done to investigate the effects of electromagnetic radiation on human body [4]-[7]. The SAR, which measures the electromagnetic power density absorbed by the human body tissue, is considered as an index by standards to regulate the amount of exposure of the human body to electromagnetic radiation [8], [9].

The implantable antennas are used for communication purposes in medical devices. Designing antennas for implanted devices is an extremely challenging task. The antennas require to be small, low profile, and multiband. Additionally, antennas need to operate in complex environments. Factors such as small size, low power requirement, and impedance matching play significant role in the design procedure. Although several antennas have been proposed for implantable medical devices [10]-[14], the accurate full human body model has been rarely included in the simulations. In this white paper, an implantable PIFA is proposed based on the design in [15] for communication between implanted medical devices in human body and outside medical equipment. Since the MICS band of 402-405 MHz is a common wireless telemetry for implantable medical devices [16], the proposed PIFA is designed for MICS band in this paper. The main aim of this work is to optimize the proposed implanted antenna inside the skin tissue of ANSYS

human body model and characterize the electromagnetic radiation effects on human body tissues as well as the SAR distribution. Simulations have been performed using ANSYS HFSS along with ANSYS Optimetrics and High-Performance Computing (HPC) features.

This white paper is organized as follows. In section II, ANSYS human body model is presented. Section III describes the antenna design. The simulation results such as reflection coefficient, SAR, near-field and far-field are illustrated in Section IV. Finally, the conclusion is remarked in Section V.

II. ANSYS Human Body Model

ANSYS offers the adult-male and adult-female body models in several geometrical accuracy in millimeter scale [17]. Fig. 1 shows a general view of the models. ANSYS human body model contains over 300 muscles, organs, tissues, and bones. The objects of the model have geometrical accuracy of 1-2 mm. The human body materials are Frequency-dependent from 10 Hz to 10 GHz. Frequency-dependent material properties are included in the ANSYS material Library. The data of material properties are based on the research performed by [18]. The model can be modified by users for the specific applications and parts, and model objects can simply be removed if not needed. For high frequencies, the body model can be electrically large, resulting in huge number of meshes which makes the simulation very time-consuming and computationally complex. The ANSYS HPC technology enables parallel processing, such that one has the ability to model and simulate very large size and detailed geometries with complex physics.

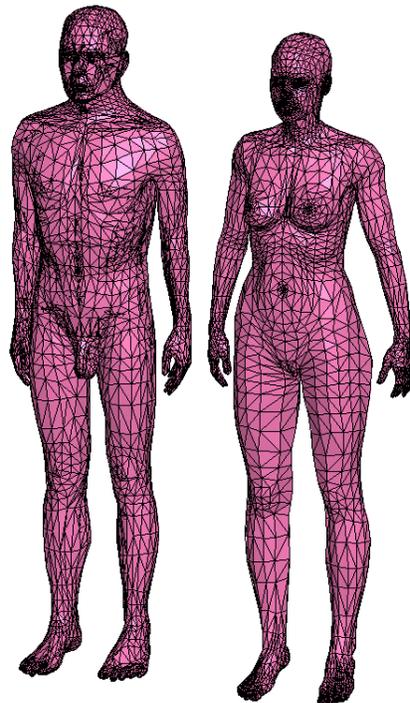


Fig. 1 ANSYS Human Body Models [17]

In presented work, the implantable antenna is placed inside the skin tissue of the left upper chest where most pacemakers and implanted cardiac defibrillators are located [3]. Incorporating ANSYS Optimetrics and HPC features, optimization iterations can be performed in an efficient manner to simulate the implantable antenna inside the human body model.

III. Antenna Design

The general shape of proposed PIFA is based on the presented work in [15]. The antenna is simulated in the ANSYS HFSS which is a FEM electromagnetic solver. In the simulations, Rogers RO3210 ($\epsilon_r=10.2$ and $\tan\delta=0.003$) is used as the substrate and superstrate material. Top and side view of proposed PIFA is illustrated in Fig. 2. The origin of the coordinate system is located in the center of the Antenna's ground plane. The thickness of dielectric layer of both substrate and superstrate is 1.28 mm. The length and width of the substrate and superstrate are $L_{sub}=20\text{mm}$ and $W_{sub}=24\text{mm}$, respectively. The width of each radiating strip is $W_{strip}=3.8\text{mm}$. The other parameters of antenna are considered to be changed within the solution space in order to improve PIFA performance at 402 MHz center frequency. HFSS Optimetrics, an integrated tool in HFSS for parametric sweeps and optimizations, is used for tuning and improving the antenna characteristics at the MICS bands inside the ANSYS human body model. A grounding pin is used at the end of the radiating strip to achieve smaller antenna size. The location of the feed can be optimized along x- and y-axis to match the antenna to 50Ω over MISC band. The strip lengths (L_{strip1} and L_{strip4}) are also included in optimizations to provide more degrees of freedom for improving the PIFA performance at the desired frequency band (402-405 MHz). The 3D view of the implantable PIFA is demonstrated in Fig. 3.

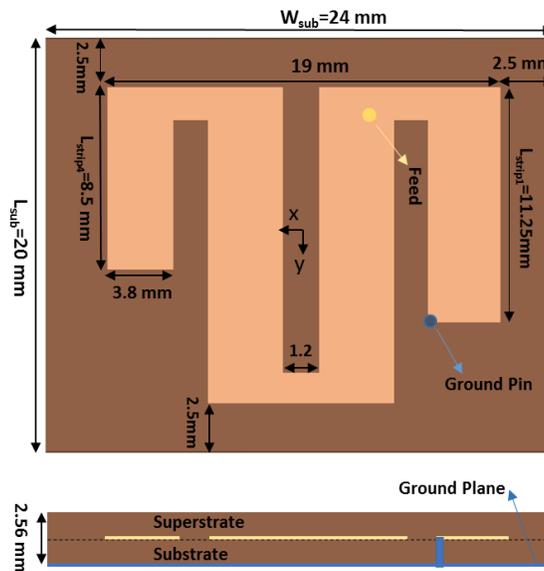


Fig. 2 Top and side view of PIFA

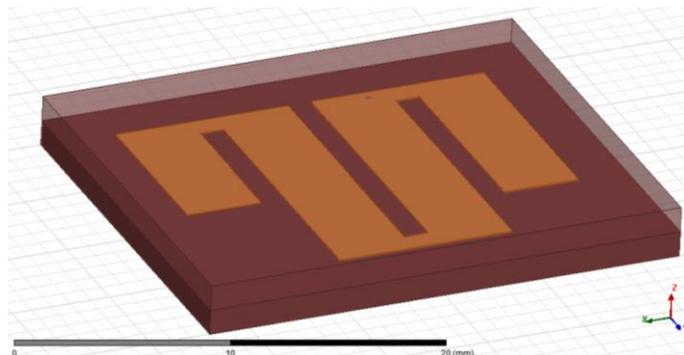


Fig. 3 3D view of PIFA geometry in HFSS

The antenna is designed and simulated while implanted inside the skin tissue of the left upper chest of the detailed male body model, as shown in Fig. 4.

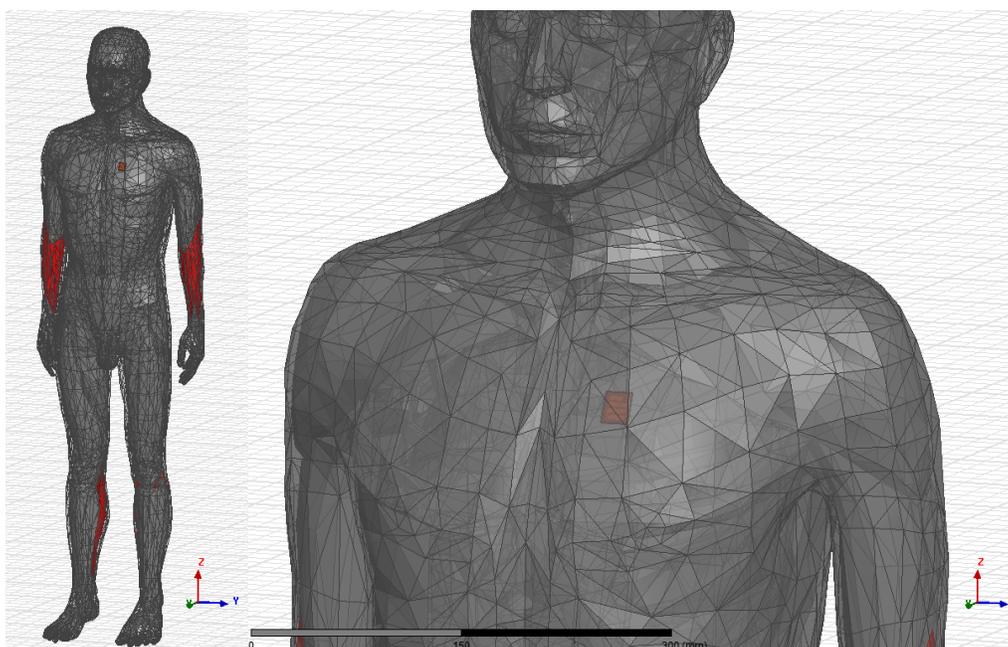


Fig. 4 Implanted antenna in ANSYS male human body model

IV. Results and Analysis

The reflection coefficient (S_{11}) frequency response of the implanted PIFA is presented in Fig. 5. The antenna resonates at 402 MHz with -28 dB reflection coefficient and provides 36 MHz bandwidth covering the MICS band. The simulated input impedance (Z_{in}) frequency response is shown in Fig. 6. As can be seen, the proposed PIFA is matched at 402 MHz.

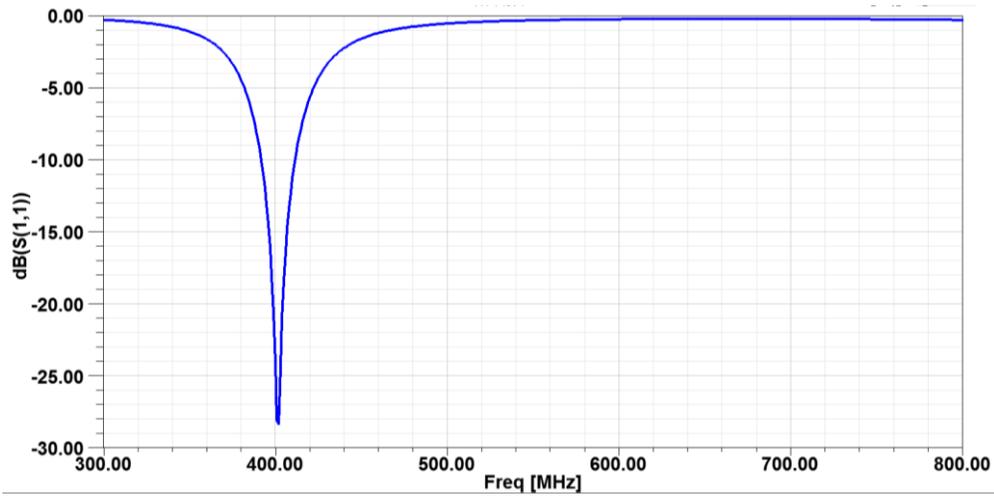


Fig. 5 Reflection coefficient of implanted PIFA inside the skin tissue of human body model

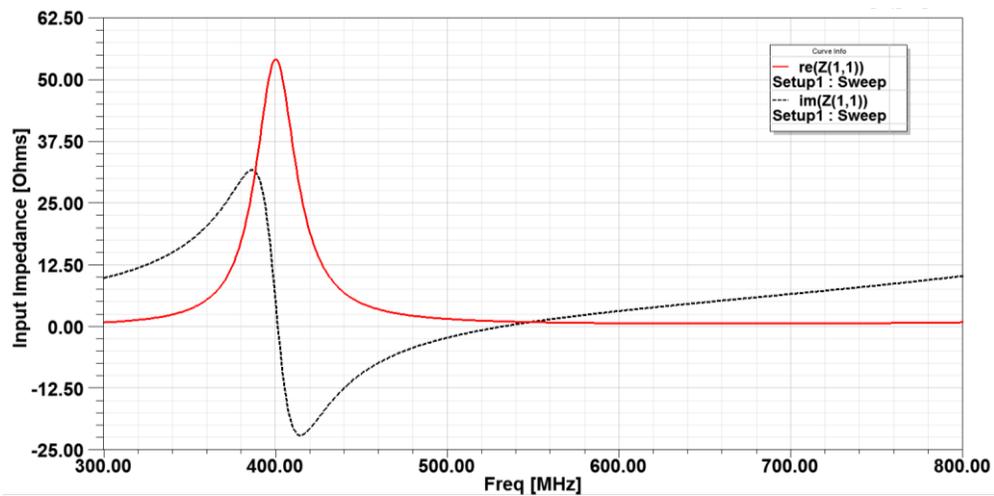


Fig. 6 Input Impedance of implanted PIFA inside the skin tissue of human body model

The Fig. 7 and Fig. 8 illustrate the far-field radiation pattern of the proposed PIFA at 402 MHz. Since the antenna is electrically small and the human body provides a lossy environment, the antenna gain is very small (~ 44 dBi) and the EM fields are reactively stored in the human body parts in vicinity.

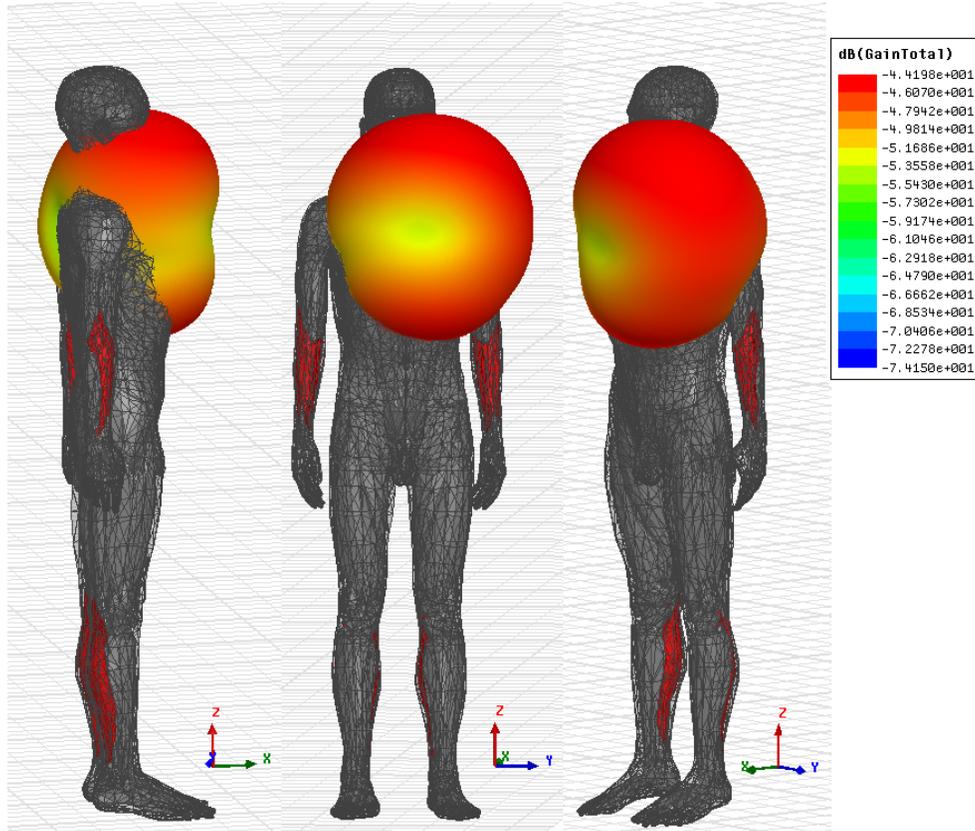


Fig. 7 3D Radiation pattern of implanted PIFA inside the human body model

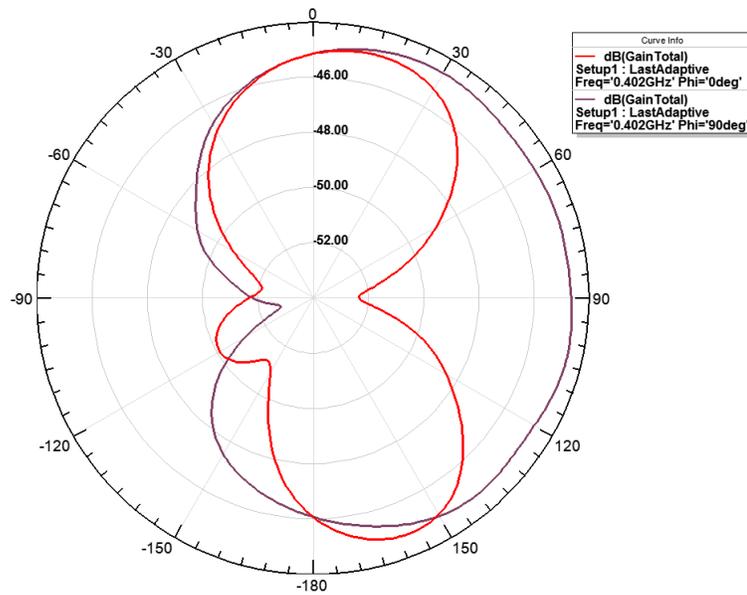


Fig. 8 Radiation pattern of implanted PIFA inside the skin tissue of human body model

Fig. 9 shows the simulated electric field distributions around the male human body model at 402 MHz center frequency. The electric field magnitude is large at upper side of the body, and it becomes weaker as going far away from the male body chest.

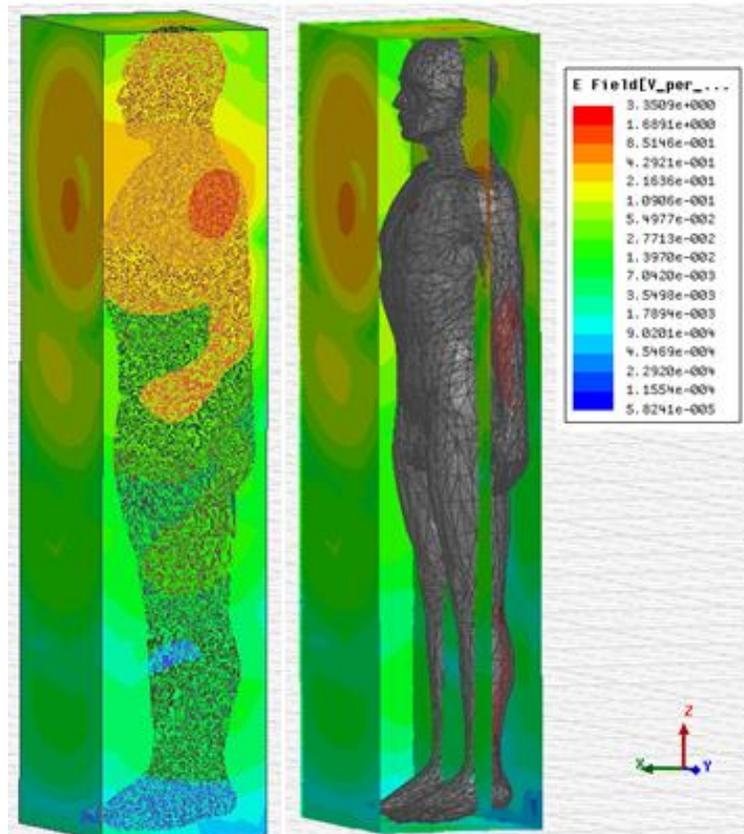


Fig. 9 Electric Field distribution around male body model at 402 MHz

The reflection coefficients are plotted for various lengths of radiating strip in Fig. 10. With HFSS Optimetrics, the radiating strip length is varied to optimize PIFA performance at 402 MHz. The variation of L_{strip1} and L_{strip4} are observed to be critical for changing the resonance frequency of PIFA. As can be seen, the resonance frequency is shifted upward by decreasing the L_{strip1} and L_{strip4} . The optimization results indicate that the $L_{strip1}=11.25\text{mm}$ and $L_{strip4}=8.5\text{mm}$ are the optimized values for antenna performance at MICS band.

The electromagnetic power absorbed by tissues surrounding the antenna inside the human body model is a critical parameter. Hence, SAR analysis is required to evaluate the antenna performance. The SAR measurement makes it possible to evaluate if a wireless medical device satisfies the safety limits. The SAR is calculated as:

$$SAR = \int_{sample} \frac{\sigma(r)|E(r)|^2}{\rho(r)} dr$$

where E is the root mean square (rms) electric field strength, σ is the electrical conductivity, and ρ is the mass density of the tissue sample.

The unit of SAR is watt per kilogram (W/kg). The SAR is averaged either over the whole body or a small volume (typically 1 g or 10 g of tissue). The IEEE standard limits the 10 grams averaged SAR value to 2W/kg while the Federal Communications Commission (FCC) uses the 1 gram averaged SAR value to 1.6 W/kg [8], [19]. The whole body SAR value is limited to 0.08 W/kg by both IEEE and FCC. The FCC limits the Effective Radiated Power (ERP) of such devices to 25 μ w outside of human body. ANSYS HFSS offers SAR calculations according to these standards. The 3D plots of the local SAR distribution are shown in Fig.11 and Fig. 12. In Fig. 11, the detailed male body model with heart, lungs, liver, stomach, intestines, and brain are included. It can be observed that the left upper chest region where SAR is significant is relatively small. The peak SAR of the PIFA is smaller than the regulated SAR limitation. Fig. 12 shows the SAR distribution on the skin tissue of the full human body model for MICS band.

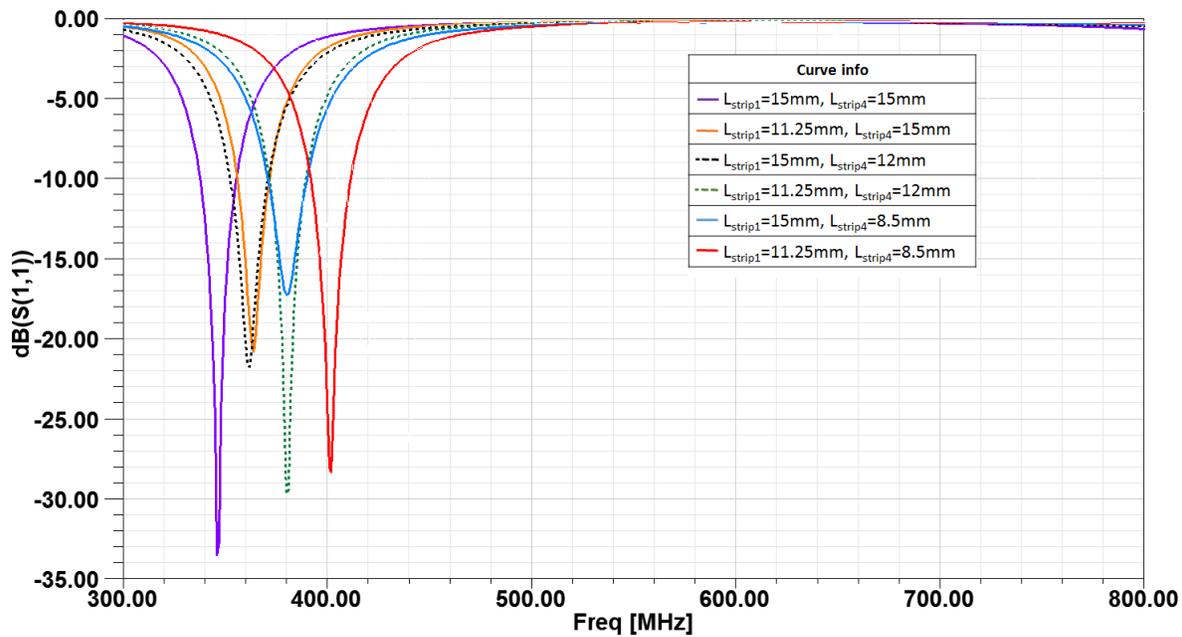


Fig. 10 Reflection coefficient of implanted PIFA inside the skin tissue of the human body model for different lengths of radiating strips

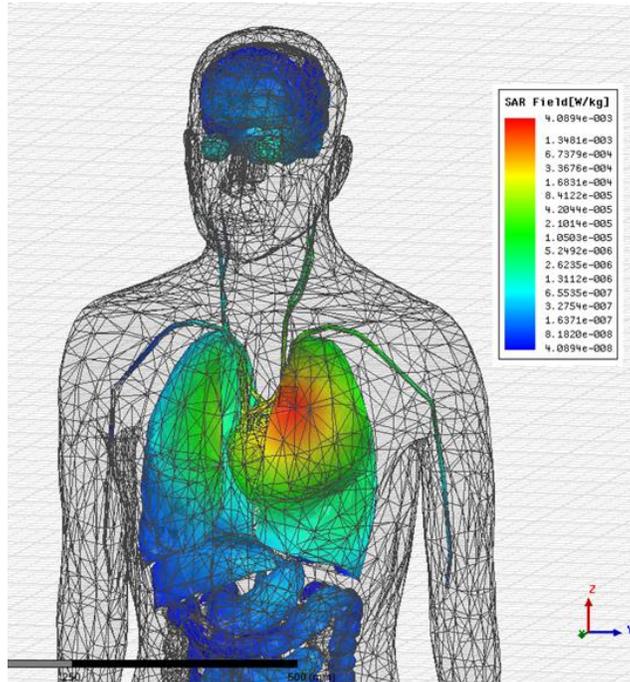


Fig. 11 Local SAR distribution on upper side of male body model at 402 MHz

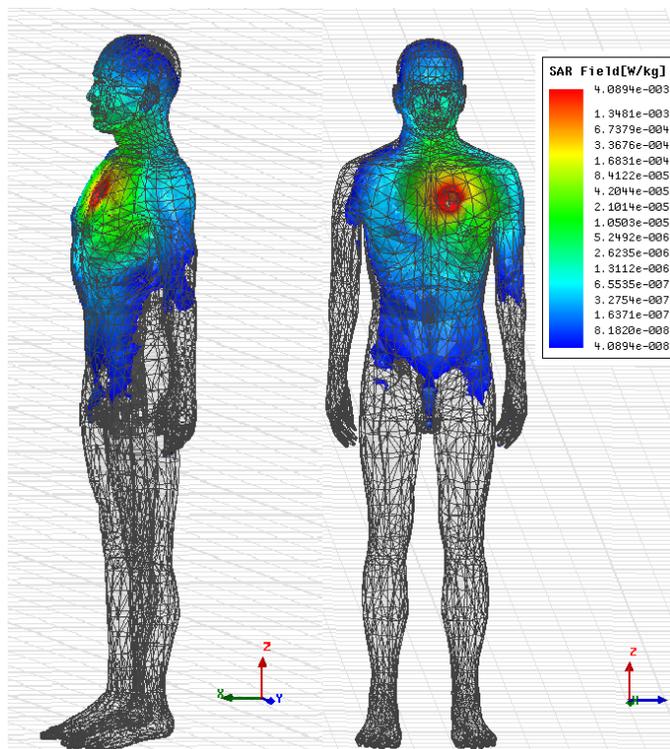


Fig. 12 Local SAR distribution on the skin tissue of male body model at 402 MHz

V. Conclusion

In this study, we presented an implanted PIFA inside skin tissue of human body model for biomedical telemetry at MICS band. The design and simulation of the antenna were performed using ANSYS HFSS FEM electromagnetic solver. The Optimetrics feature of ANSYS HFSS was employed to optimize the antenna performance at 402 MHz. The optimization results demonstrate that the length variation of the radiating strip affects the resonance frequency significantly. The resonance frequency, reflection coefficient, input impedance, radiation characteristic, and SAR of the implanted antenna were evaluated. The SAR analysis inside human body model was performed to meet the standard requirements.

For sake of more investigations, an extensive antenna optimization could be performed to obtain miniaturized antenna size and improved antenna performance for implantable medical devices. Furthermore, the effect of implanted antenna placement in different location of human body model could be investigated to satisfy safety limits for wireless medical devices.

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