

Design of Implantable Rectangular Spiral Antenna with U-shaped Loop for Biomedical Applications

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Abstract – In this study, an implantable rectangular spiral antenna with U-shaped loop is designed for medical biotelemetry in the medical implant communication service (MICS) frequency band (402 – 405 MHz). To verify the potentials of the antenna for the desired applications, a prototype is fabricated and measurement of its performance is carried out in terms of the resonant characteristics and gain radiation patterns. The measured resonant characteristics show good agreement with the predictions, and the -10 dB frequency band is within the range of 398 to 420 MHz. The antenna exhibits a maximum gain of -22.26 dBi and efficiency of 0.215 % in measurement.

Index Terms — Implantable antenna, rectangular spiral antenna, U-shaped loop, medical biotelemetry, medical implant communication service (MICS) band.

I. INTRODUCTION

Recently, wireless medical biotelemetry between implanted devices and external equipment has been studied for diagnostic and monitoring purpose [1]. For wireless communication with medical implants, the most commonly used frequency band is the medical implant communications service (MICS) band (402 – 405 MHz) [2]. Among the implanted components, an implantable antenna is key and crucial part to ensure wireless biotelemetry. The fact that the implantable antenna has to work inside the human/animal body makes the antenna design very challenging. In general, implantable antenna design needs to take account of the miniaturization, biocompatibility, impedance matching, far-field gain, and patient safety, among other aspects [3],[4].

In this study, an implantable rectangular spiral-shaped configuration is designed and evaluated in terms of the potentials for use in biotelemetry in the MICS band. To minimize the antenna size, a spiraling of the conductor patched on a high-permittivity dielectric substrate and a U-shaped loop structure is attached to transform the antenna impedance to the 50- Ω feeding. The potential of the antenna design is demonstrated by manufacturing a prototype and measuring its resonant characteristics and gain radiation patterns in the MICS band.

II. GEOMETRY AND DESIGN OF THE PROPOSED ANTENNA

A. Antenna Geometry and Design Parameters

Fig. 1 shows the geometry of the designed antenna and its design parameters. A conducting spiral configuration with a

U-shaped loop structure, 0.5 mm in width and 18 μ m in thickness, is printed on a 0.635-mm thick high-permittivity dielectric substrate (Rogers 3210, $\epsilon_r = 10.2$) and covered with a 1-mm thick bio-compatible superstrate (Quartz, $\epsilon_r = 3.78$). The superstrate layer prevents an undesired short-circuit by separating the metallic radiator from the human body. To simply the design parameters, the value of u_1 for the U-shaped loop is fixed to 1.6mm. The total size of the antenna is 20 mm x 10 mm x 1.653mm, which is quite suitable to the implantable application.

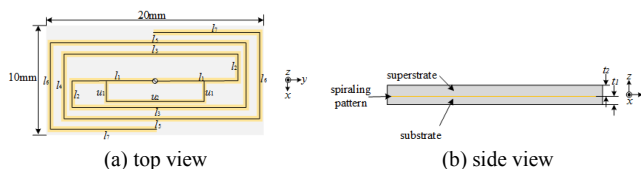


Fig. 1. Geometry of the designed antenna.

B. Antenna Design

The antenna is assumed to be located inside a simplified canonical skin tissue model ($\epsilon_r = 46.7$ and $s = 0.69$ at 402 MHz) as shown in Fig. 2. The initial antenna has a total spiral length of about half a wavelength (58.7 mm), and then is manually adjusted to resonate at the design frequency (403.5 MHz). In the next, the U-shaped is attached to the spiral configuration to provide the antenna with an impedance transformation and the spiral length and U-shaped loop length are iterated for the antenna resonance at the design frequency. The finally determined parameters of the designed antenna are summarized in Table 1. The antenna simulation and design are performed using the Ansoft HFSS based on FEM.

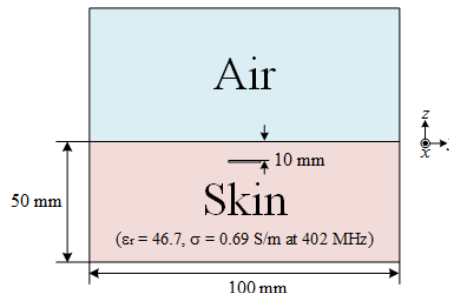


Fig. 2. Simulation model for the antenna design.

TABLE I
DETERMINED PARAMETERS OF THE ANTENNA [UNIT : MM]

parameters	value	parameters	value
l_1	7.25	l_6	8
l_2	2.5	l_7	7.7
l_3	16	u_1	1.6
l_4	6	u_2	8
l_5	18		

III. SIMULATION AND MEASUREMENT RESULT

The simulated reflection coefficient of the antenna with the determined parameters in the skin tissue model, in which good resonance is achieved in MICS band, is shown in Fig. 3. However, if the antenna is placed in air, the resonant frequency increases to 478 MHz and the matching deteriorates, as also shown in Fig. 3.

To assess patient safety, a numerical SAR distribution is analyzed at 403.5 MHz. Fig. 4 presents the 1-g SAR distribution in dB normalized to 321 W/Kg (peak SAR value) when 1W-power is delivered to the antenna. The simulation results suggest that the delivered power should be less than 4.99 mW to satisfy the IEEE C95.1 ($SAR_{1g,max} \leq 1.6$ W/kg) [4].

To verify the performance of the designed antenna, a prototype is fabricated and measured. For the in-body environment, the antenna is imbedded in the gel-type tissue-emulating material whose electrical properties are similar to those of human skin in terms of permittivity and conductivity.

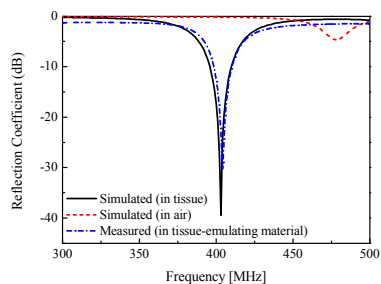


Fig. 3. Simulated and measured reflection coefficient of the designed antenna.

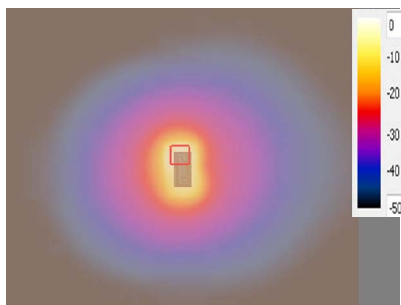


Fig. 4. Simulated 1-g average SAR distribution for the designed antenna.

The measured reflection coefficients are added in Fig. 3 for comparison with the simulated results. The frequency band is within the range of 398 to 410 MHz with -10 dB bandwidth criterion (from 395 to 409 MHz in simulation). The measured gain radiation pattern is the x-z and y-z planes at 403.5 MHz are shown in Fig. 5. Maximum gain of -22.26 dBi and antenna efficiency of 0.215 % are measured.

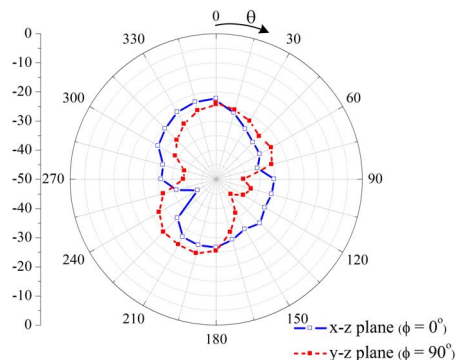


Fig. 5. Gain radiation pattern of the designed antenna at 403.5 MHz.

IV. CONCLUSIONS

In this study, we designed an implantable rectangular spiral antenna for wireless medical biotelemetry in the MICS band (402 - 405 MHz). To reduce the antenna size, a spiral configuration was adopted and realized on a high-permittivity dielectric substrate. The antenna impedance was adjusted using a U-shaped loop structure. To verify the potentials of the antenna for the desired application, a prototype is fabricated and performance measurement is carried out in the tissue-emulating material. The measurements showed that the resonant characteristics were in good agreement with the simulated prediction, and the frequency band ranged from 398 to 410 MHz with a -10 dB bandwidth criterion. A maximum gain of -22.26 dBi and an antenna efficiency of 0.215 % were obtained in measurement.

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