Design of Implantable Antenna on the Dielectric/Ferrite Substrate for Wireless Biotelemetry

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***Abstract*— A miniature and broadband implantable antenna is designed for wireless biotelemetry in the medical implantable communications service (MICS) frequency band (402 – 405 MHz). To minimize antenna size and enhance bandwidth, a meandered planar inverted-F antenna (PIFA) structure is adopted on a dielectric/ferrite substrate. The potential of the proposed antenna is verified through a prototype fabrication and measurement with 2/3 human muscle-emulating material environment. Good agreement is observed between the simulation and measurement in terms of resonant characteristics and gain radiation patterns of the antenna. The measurement shows broad bandwidth (return loss of 10 dB) of 226 MHz and maximum gain of -27.7 dBi at 403.5 MHz. Analysis of 1-g SAR distribution is conducted to satisfy the specific absorption rate limitation (1.6 W/ kg) of the American National Standards Institute.**

Keywords*— *antenna miniaturization, broadband antenna, implantable antenna, medical biotelemetry, medical implantable communication service (MICS) band, SAR

I. INTRODUCTION

In recent years, there has been an increasing interest in the body area network (BAN)[1]-[3]. In particular, wireless biomedical telemetry between implantable devices and external equipment has been attracting considerable attention for diagnostic and monitoring purposes [4]. Of the implantable devices, the implantable antenna is a key and crucial component to guarantee reliable communication link [5], [6]. However, the design of implantable antenna is quite challenging in that it should take the miniaturization and broadband operation into account. In the conventional implantable antennas, dielectric substrate with high permittivity (ε_r) has been usually used for the miniaturization of the antenna, which unfortunately results in decreased bandwidth. In an attempt to overcome these problems, it is one of candidates to adopt a magneto-dielectric material as a substrate for the antenna [7], which can be artificially realized by introducing the ferrite layer into a dielectric substrate [8].

In this paper, a miniature and broadband implantable antenna on the dielectric/ferrite substrate is designed for wireless biotelemetry in medical implantable communications service (MICS) frequency band (402 - 405 MHz). By inserting the thin low-loss ferrite sheet layer ($\mu_r > 1$) beneath a dielectric

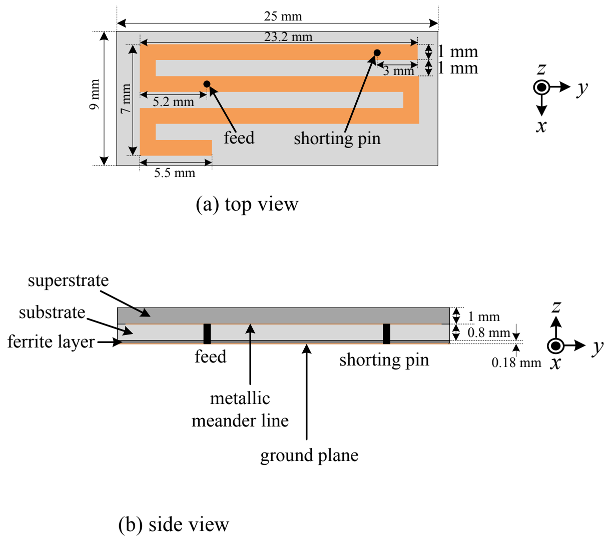

Fig. 1. Configuration of proposed antenna.

substrate, the antenna size and operating bandwidth are minimized and improved as a result of the shortened wavelength by $1/\sqrt{\mu\varepsilon}$ and increased medium impedance by $\sqrt{\mu/\varepsilon}$ [8]-[10]. A prototype antenna is fabricated and measurement is performed to estimate the potential of the proposed antenna in terms of resonant characteristics, bandwidth, and gain radiation patterns. A 1-g averaged specific absorption rate (SAR) is additionally analyzed to satisfy the regulated limitation (1.6 W/kg) of the American National Standards Institute (ANSI) [8].

II. ANTENNA CONFIGUATION AND DESING

Fig. 1 shows the configuration of the designed implantable antenna, which has a volume of 25 mm x 9 mm x 2.05 mm. The meandered planar inverted-F antenna (PIFA) structure is adopted to lengthen the current flow path, which can give rise to minimize the antenna size. The radiating element (width = 1 mm, thickness = 35 μm) is printed on a dielectric substrate (FR-4: ε_r = 4.4, thickness = 0.8 mm) and covered with a biocompatible superstrate layer (polyurethane: ε_r = 4.8,

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thickness = 1 mm). Since human tissue is lossy and conductive, the superstrate layer plays a role in preventing unwanted short-circuit by separating the metallic radiator from the human tissue. The low-loss NiCo-ferrite layer (ε_r = 7.59, μ_r = 13, tanδe = 0.05 and tanδm = 0.03 at 400 MHz from measurement) with the thickness of 0.18 mm is inserted between the substrate and ground plane. For simulation and measurement, the proposed antenna is placed inside of a block of 2/3 human muscle (ε_r = 42.807, σ = 0.6463 S/m at 403 MHz), which is commonly used to represent average human body properties. The antenna parameters are optimized to resonate in the MICS band by using Ansys high frequency structure simulator (HFSS) and determined parameters are presented in Fig. 1.

III. SIMULATION AND MEASUREMENT RESULTS

Simulated return loss of the proposed antenna with the determined parameters is illustrated in Fig. 2, in which good resonance is achieved in the MICS band and broad bandwidth of 280 MHz (return loss of 10 dB) is satisfied. The antenna model with no ferrite layer is simulated and compared in Fig. 2, in which the resonant frequency is shifted to 508 MHz and the bandwidth is decreased to 85 MHz.

To verify the potential of the proposed antenna, an experimental prototype antenna is fabricated as Fig. 3. For the measurement, the 2/3 human muscle- emulating material is also made with deionized water, sucrose, and sodium chloride. The measured permittivity (ε_r) and conductivity (σ) of the material using an Agilent 85070E dielectric probe kit and a network analyzer are 45.58 and 0.57 S/m at 403 MHz, respectively. The measured return loss of the prototype implanted into the 2/3 human muscle-emulating material is also shown in Fig. 2. Good agreement between simulation and measurement are obtained in terms of resonant frequency, however, the measured bandwidth is 226 MHz. The measured bandwidth is narrower than that of the simulation, which is possibly caused due to the errors in the fabrication of the prototype, electrical properties of medium, and frequency-dependent properties of the tissue emulating material, etc.

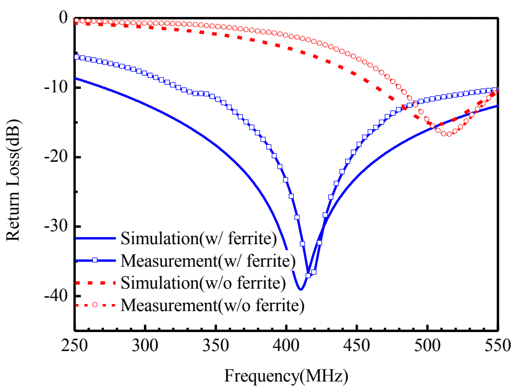

Fig. 2. Return loss

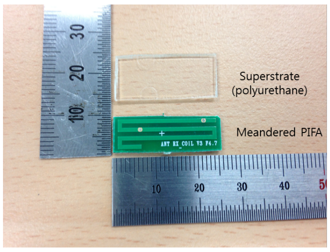

Fig. 3. Photo of fabricated prototype.

The gain radiation patterns in the x-z and y-z planes are simulated and measured at 403.5 MHz as shown in Fig. 4. Maximum gains of -30.7 dBi and -27.7 dBi are obtained from simulation and measurement, respectively. Fig. 5 shows the simulated 1-g SAR distribution for the proposed antenna embedded into the 2/3 muscle block. When the power of 1 W is assumed to be delievered to the antenna, the peak SAR value of 39.44 W/kg is obtained, therefore, the delivered power should be less than 40.5 mW to satisfy the SAR limitation (1.6 W/kg) of ANSI.

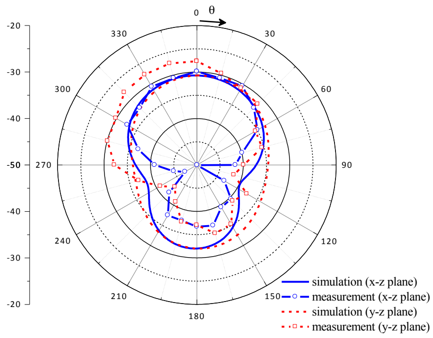

Fig. 4. Gain radiation patterns.

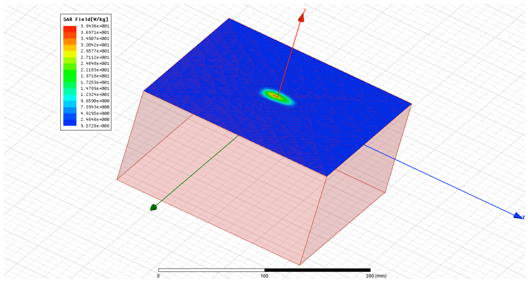

Fig. 5. Simualted 1-g SAR distribution at 403.5 MHz for proposed antenna when input power is 1 W.

IV. CONCLUDING REMARKS

A miniature and broadband implantable antenna is proposed for wireless biotelemetry in the MICS band. By introducing the thin low-loss ferrite sheet layer into the dielectric substrate, the antenna of meandered PIFA structure achieved minimization and broadband. The potential of the proposed antenna is verified through a prototype fabrication and measurement with 2/3 human muscle-emulating material. The measurement shows that the resonant characteristics and gain radiation patterns are in good agreement with the simulation. In measurement, the antenna achieved the broad bandwidth (return loss of 10 dB) of 226 MHz and a maximum gain of -27.7 dBi. A 1-g SAR distribution is also analyzed to satisfy the SAR regulation of ANSI.

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