Develop an Implantable CPW-fed Antenna on the $MgTa_{1.5}Nb_{0.5}O_6$ Ceramic Substrate

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Abstract

An implantable antenna for the applications of biomedical telemetry has been widely studied in the modern medical science. The purpose of this study is to design and fabricate an implantable antenna which exhibits enhanced bandwidth (25%) and miniaturization for the use of implantation. In this letter, the microwave dielectric ceramic ($MgTa_{1.5}Nb_{0.5}O_6$) substrate which possesses high dielectric constant (ε_r = 28) and high quality factor is used as the substrate of the implantable antenna, a CPW-fed monopole dual spiral structure is adopted as the antenna pattern and fabricated by the print-screening technique. The effects of shape, length, size, and thicknesses of the proposed antenna would be evaluated and investigated in this letter. In addition, the center frequency is required to conform to the band (402 ~ 405 MHz) provided by Medical Implant Communication Services (MICS). From the experimental results of the proposed antenna immersed in phantom fluid, the optimum antenna exhibits a miniaturized volume of 288 mm^3, bandwidth of 134 MHz (33%), return loss −16.32 db at 404 MHz, the SAR of 142 W/Kg, and gain of −16 db, respectively.

Introduction

Recently, numerous researches on implantable antennas which focused on specific medical devices such as Glucose monitor [1], retinal prosthesis [2], or cardio pacer [3] have been reported. An implantable antenna for biotelemetry medical device discussed in [4] can obtain both broadband and compact advantages attributed to the stacked multilayer structure. As the implanted antennas are immersed into human tissue that is highly dynamic lossy environment, the problems of antenna resonant frequency shifting, low radiating efficiency, mismatch loss, and limitation of SAR value have to be overcome. Generally, a superstrate is covered at the top of the implanted antennas to prevent tissue from damaging the antenna metal pattern. Moreover, those PIFA type Probe-Fed implanted antennas studied in [1-5], to locate optimum positions for probe feeding and shorted ground is critical and difficult to design. Therefore, their final fabrication and tuning procedures are quite complicate.

In this letter, in order to simplify fabrication as well as easily integrate with solid state active devices, we proposed a low profile uniplanar monopole antenna fed by a coplanar waveguide (CPW). The proposed antenna is fabricated on the microwave dielectric ceramic ($MgTa_{1.5}Nb_{0.5}O_6$) substrate [9] without any superstrate covered on the top layer. Subsequently the characteristics of the implanted antennas implemented on different substrates such as FR-4 (ε_r = 4.4), RO3210 (ε_r = 10.2) and microwave dielectric ceramic ($MgTa_{1.5}Nb_{0.5}O_6$) (ε_r = 28) are compared in term of fractional bandwidth, radiating efficiency, gain, return loss and average SAR value.

Antenna configuration

The metal pattern of the proposed antenna printed with silver paste by the print-screening technique consists of two parts, one is a simple monopole for radiating and the other with symmetric rectangles is a dual spiral for inductive load. The proposed antenna has a volume of (16 × 18 mm^2) × 1 mm, as demonstrated in Fig. 1(a). Its optimal parameters indicated in Fig. 1 (a) are obtained by the Ansoft High Frequency Structure Simulator (HFSS). For setup measured environments, it is immersed in a container with a depth of 10 mm, as shown in Fig. 1(b). The container is filled with the phantom fluid that emulates tissue (ε_r = 45.2, σ = 0.61 S/m at 402 MHz) [3]. The phantom fluid is made from deionized water, sugar, salt, cellulose etc.

Analysis and Discussion

From the demonstration of Fig. 2, the electric current distribution created distinctly in the dual spiral at 402 MHz generates inductive loading effect. While the dual rectangular spiral resonates at 402 MHz, its structure is equivalent to a series resonator. Simultaneously, the monopole radiating section is equivalent to a parallel resonator. It is the combination structures of a parallel resonator and a series resonator that enhances the impedance matching over a wider fractional bandwidth. Both simulated and measured resonant frequencies agree well, as shown in Fig. 3. However, the measured bandwidth at the return loss of 10 dB is better than the simulated one. Comparing to broadband stacked multilayer implantable antennas [4], the proposed antenna has achieved the improvement of bandwidth from 335 MHz to 469 MHz**.** Additionally**,** compared with the size of traditional uniplanar implanted antennas [5], the reduction of our proposed uniplanar antenna is 61% (32 × 24 mm^2 to 18 × 16 mm^2).

As the proposed antenna is implanted into phantom fluid, its two-dimensional simulated far-field patterns (xz, yz, and xy-plane) at 402 MHz are shown in Fig. 4, respectively. Each pattern is presented with co-polar and cross-polar using a 10 dB scale. Obviously, the pattern in the xz-plane is nearly omnidirectional. The other far-field patterns are symmetric since the structure of the antenna is symmetric. Furthermore, from the SAR distribution demonstrated in Fig. 5, if we confine the antenna transmitting power to 0.01 mW, which is under EIRP limitation (0.025 mW), the maximum SAR value produced by the proposed antenna is under the safety limitation of the SAR [7].

The characteristics of the implanted antennas that are implemented on different substrates (FR-4, RO3210, and $MgTa_{1.5}Nb_{0.5}O_6$) are compared and shown in Table 1. Due to high dielectric constant and high quality factor, the proposed antenna implemented on the microwave dielectric ceramic ($MgTa_{1.5}Nb_{0.5}O_6$) substrate exhibits better antenna characteristics than the others, such as higher radiation efficiency, lower average SAR value, and symmetric monopole-like radiation patterns. Moreover, the measured return loss (S_{11}) exhibit stable characteristics, as shown in Fig. 6, while the proposed antenna is immersed into the phantom fluid over a period of 14 days.

4. Conclusion

In this paper, an implanted broadband antenna has been designed and experimented in lossy phantom fluid. The proposed uniplanar, low profile antenna without superstrate makes it both easily fabricated and conformable to various housing architectures of different implantable medical devices, such as the biotelemetry capsule.

Due to the high dielectric constant and high quality factor of the microwave dielectric ceramic ($MgTa_{1.5}Nb_{0.5}O_6$) substrate, the proposed antenna exhibits good antenna characteristics, such as higher radiation efficiency, lower average SAR value and symmetric radiation pattern. The proposed antenna also exhibits miniaturized volume of 288 mm^3, bandwidth of 134 MHz (33%), the return loss of −16.32 db at 404 MHz, the SAR of 142 W/Kg, and gain of −16 dB, respectively. Obviously, both enhancements in the bandwidth and size reduction will facilitate the proposed antenna to be a valuable candidate for implanted medical telemetry system applications.

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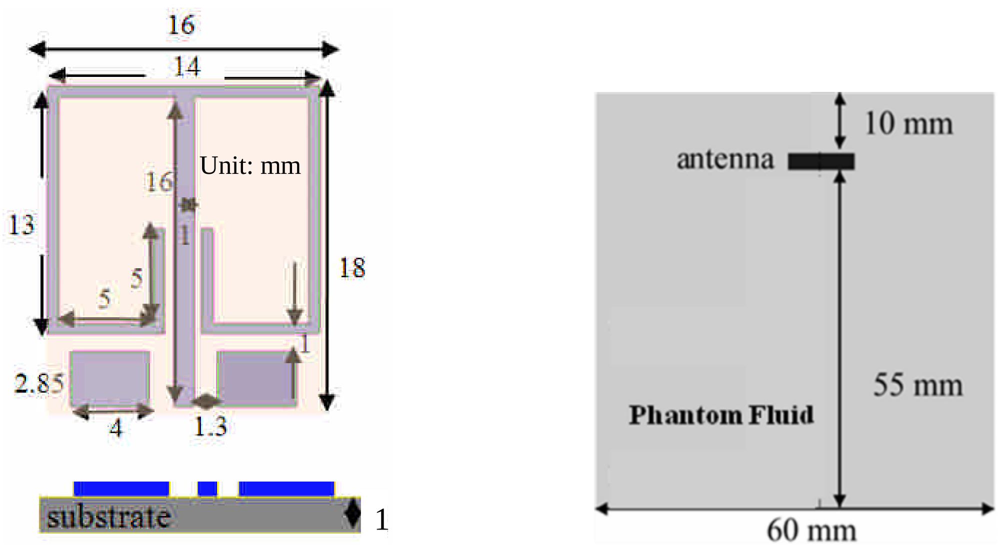


(a) (b)

Fig. 1. (a) Top view and cross section of the proposed antenna. (b) The proposed antenna immersed into the phantom fluid.

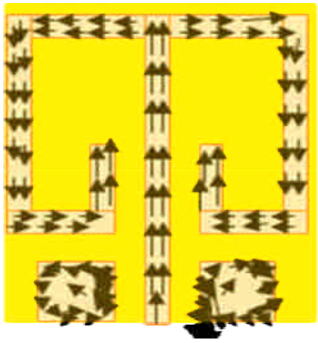


Fig. 2. Schematic of electric current distribution at 402 MHz.

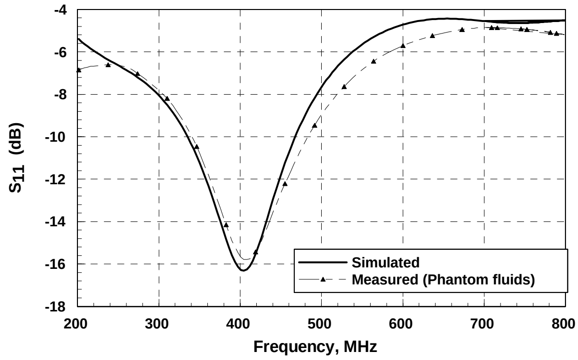
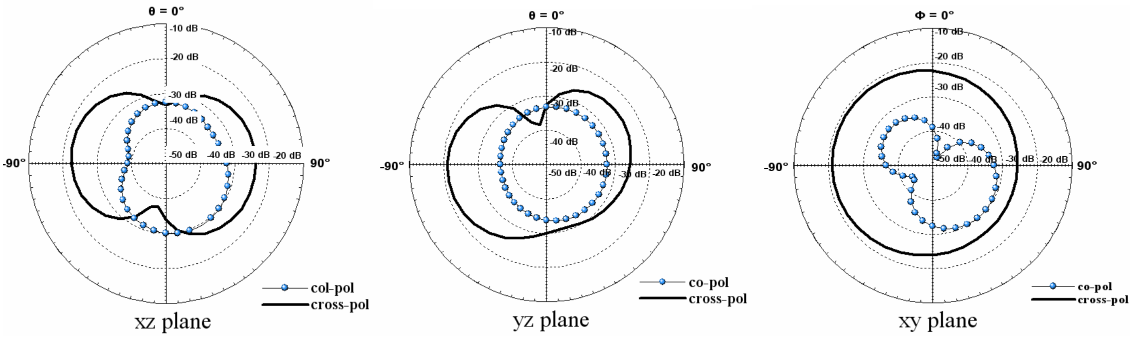


Fig. 3. Measured and simulated return loss (S_{11}) for the proposed antenna into the phantom fluid.



(c)

Fig. 4. Simulated (a) xz, (b) yz and, (c) xy-plane at 402MHz for the proposed antenna into the phantom fluid.

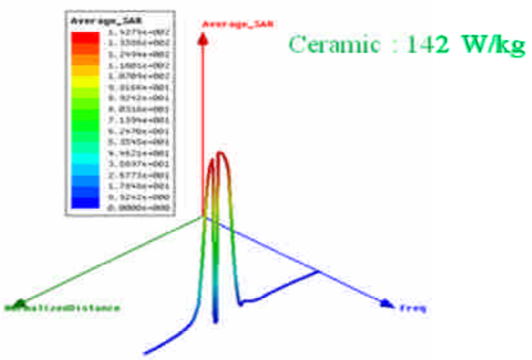


Fig. 5. SAR distribution at 402 MHz for the proposed antenna into the phantom fluid.

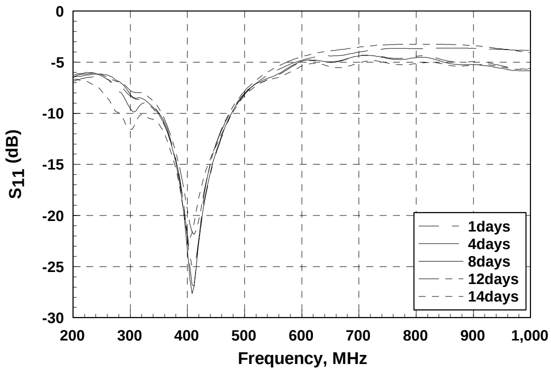


Fig. 6. Measured return loss (S_{11}) for the proposed antenna into the phantom fluid over a period of 14 days.

Table 1. Return loss, fractional bandwidth, gain, SAR and radiating efficiency for three different substrates.

Substrate	FR-4	RO	ceramic ($MgTa_{1.5}Nb_{0.5}O_6$)
Return Loss (dB)	-20.64	-20.93	-16.32
10 dB-FBW (%)	50 %	40 %	33 %
Gain	-24	-30	-16
SAR (W/Kg)	228	192	142
Radiation	0.026%	0.027%	0.026%