A Wideband Antenna for Biotelemetry Applications: Design and Transmission Link Evaluation

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***Abstract*—In this paper, the design of a miniature wideband antenna for biotelemetry applications is presented. We propose a biocompatible antenna to be printed on the outer surface of a capsule. The size of the antenna in planar form is 2.52 mm^3. The antenna shows a wide impedance bandwidth of 7.31 GHz (0.78 GHz – 8 GHz, for -10dB reflection coefficient) when implanted inside a simple three layer body model. The antenna gain values at 915 MHz and 2.45 GHz are -25.23 dBi and -27.51 dBi, respectively. The antenna resonance frequency is shown to be robust when implanted in a realistic anatomical body model. The performance of the communication link between the implanted antenna and an external half-wavelength dipole at 915 MHz and 2.45 GHz is also presented.**

***Keywords*—bandwidth enhancement, implantable antenna.**

I. Introduction

Implantable medical devices (IMDs) have gained substantial attention due to their advantage in improving patient's quality of life. In biotelemetry, wireless links are needed for the communication between an implanted system and an external receiver unit. Antennas are the most important components to ensure robust wireless link performance. It is a great challenge to design an implantable antenna due to the complexity and variation of human tissues, which have an effect on the antenna propagation characteristics, i.e., frequency detuning may happen due to the loading effects of tissue covering the antennas. This necessitates the design of implantable antenna of a wide bandwidth characteristic to withstand the frequency shift when implanted inside tissues with different dielectric properties. Furthermore, biocompatibility and small implant size are another critical constraints that should be considered [1-3]. In this paper, we propose a wideband biocompatible small capsule antenna for biotelemetry applications. Numerical investigations were carried out using CST Microwave Studio software [4].

II. Implantable Antenna Design

The configuration of the proposed implantable antenna is shown in Fig. 1 (a). It consists of a conformal meandered antenna, to achieve miniaturization, designed on the outer wall surface of a capsule, with a diameter of 11 *mm* and length of 24 *mm*. It is assumed that the capsule inner volume will be utilized for the necessary electronic circuits and sensors. A flexible biocompatible material, ultem of 0.5 *mm* thickness with a relative permittivity (ε_r) and loss tangent (tanδ) of 3.15 and 0.0013 S/m, respectively, is used as the capsule substrate.

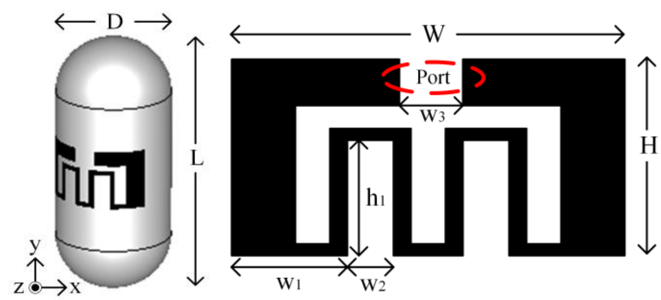

Fig. 1. Configuration of the proposed capsule antenna in: (a) conformal form and (b) planar form. Dimensions in *mm* are: L = 24, D = 11, W = 12, H = 6, h_1 = 3.5, w_1 = 3.5, w_2 = 1.5, and w_3 = 2.

This material is chosen because it has stable properties not affected by the variations of different parameters, such as temperature and frequency. For easy optimization of the antenna, the antenna is first embedded in a three-layer body model (named as Layered Model) that consisted of skin, fat and muscle body tissues of 2 *mm*, 8 *mm*, and 80 *mm* thicknesses, respectively. The dimensions of the body model are 100 × 100 × 90 mm^3, and the depth of embedding the capsule is 40 mm. Properties of dispersive tissue layers are obtained from the material library in CST Microwave Studio software. The antenna in planar form measures 12 × 6 × 0.035 mm^3 and the geometrical parameters of the antenna are shown in Fig. 1 (b).

When considering the influence of the electrical components of the implantable system on the antennas, the batteries are expected to have the most significant effects because of their size. Batteries are simply represented as a perfect electric conductor (PEC) cylinder with a length of 8 *mm* and diameter of 10 *mm* inside the capsule. This model is named as Layered_battery. Moreover, the proposed capsule antenna is analyzed in the anatomical Ella voxel model (without the battery) in two different locations: chest and shoulder, named as Ella_shoulder and Ella_chest, respectively. For the chest implanting the proposed antenna is envisioned as a pacemaker antenna, and for the shoulder implanting the application is for the patients suffering from osteoarthritis [1]. The Ella voxel model consists of various organs and represents a 26-year-old female with a height of 1.36 *m* and weight of 57.3 kg. In order to reduce the simulation time, we only imported the upper part of the human body torso, excluding the head, into our simulation model.

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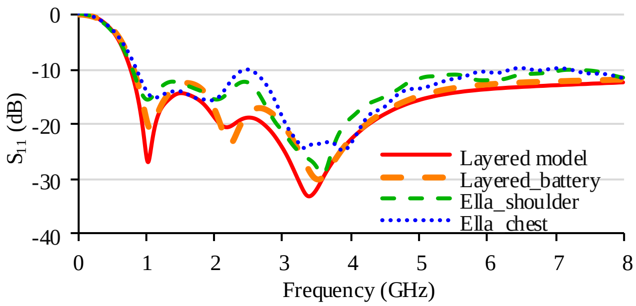

Fig. 2. Comparison of simulated reflection coefficients (S_{11}) of conformal capsule antenna for different simulations setups.

TABLE I. SUMMARY OF THE REALIZED GAIN OF CAPSULE ANTENNA

Scenario	915 MHz	2.45 GHz
Layered model	-25.23 dBi	-27.51 dBi
Layered_battery	-23.31 dBi	-25.32 dBi
Ella_shoulder	-21.77 dBi	-22.20 dBi
Ella_chest	-25.86 dBi	-28.78 dBi

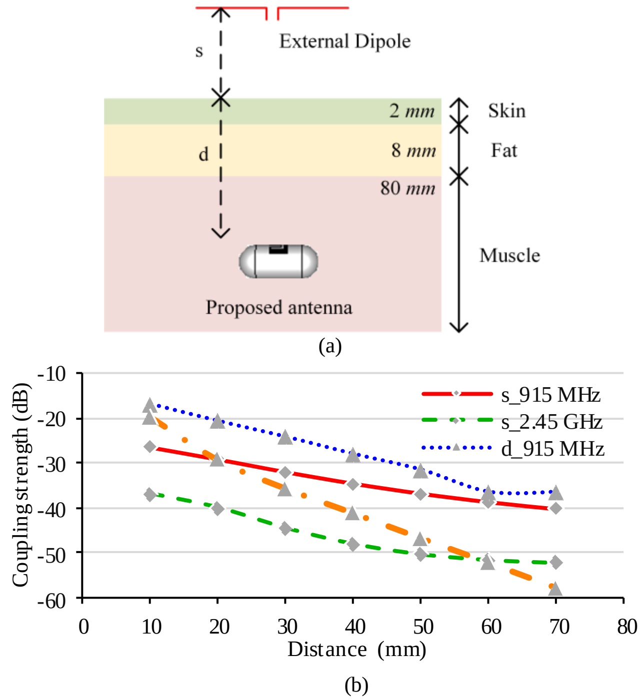

Fig. 3. Coupling strength for external half wavelength dipole: (a) simulation setup, and (b) results for different free space distances *(s)* and implant depths *(d).*

III. Results and Discussion

In order to test the robustness of the proposed antenna, reflection coefficients (S_{11}) for the aforementioned simulation setups are compared in Fig. 2. The antenna bandwidth (S_{11} < -10 dB) of the layered model implantation case is about 7.31 GHz (0.78 GHz – 8 GHz). Integrating the battery causes a slight shift in the resonance frequencies. The implanted antennas in Ella's shoulder or chest also show a reduction in the S_{11} level and a detuning effect. The most noticeable reduction in the obtained bandwidth, which is about 800 MHz, is observed in the case of implanting antenna in Ella's chest. However, since the antenna is a wideband, these detuning effects do not cause a significant effect on the bandwidth variation. The antenna gain at the center frequencies of the 902.8 MHz – 928.0 MHz, and 2.40 GHz – 2.50 GHz ISM bands are summarized in Table I. These frequency bands are selected as they are commonly used for biotelemetry applications [1], [5]. From Table I, it is clear that the antenna gain is higher within ISM–915 MHz for all the studied cases.

For accurate assessment of the antenna performance for near/far-field communication in biotelemetry applications, where the near-field boundary is approximated at $\lambda/2\pi$ [6], the coupling strength (S_{12}) between an external half-wavelength dipole and the proposed capsule antenna implanted in the layered body model is evaluated for two scenarios. First, the free-space distance (*s*) of the external dipole is changed in the range of 10 *mm* – 70 *mm*, while the implanting depth (*d*) is 40 *mm*. Second, distance *d* is changed in a range of 10 *mm* – 70 *mm*, while *s* is 10 *mm*. The simulation setup is shown in Fig. 3 (a). For each of the studied frequency bands, a different dipole is adopted. As shown in Fig. 3 (b), the coupling strength at 915 MHz is higher than that at 2.45 GHz for both studied cases due to the larger obtained gain values at 915 MHz with changing *d* and *s* distances (results are not shown here due to space limitations and will be discussed during the presentation).

IV. Conclusion

The design and performance evaluation of a miniaturized wideband implantable capsule antenna is presented. The advantage of the wideband property of the proposed antenna is demonstrated through the performance evaluation of this antenna when it is implanted in a simplified layered body model and an anatomical realistic body model, as well as when it is integrated with a battery. Also, the near/far-field communication analysis is carried out at 915 MHz and 2.45 GHz for different free space distances of the receiver and different implant depths. Findings of this study suggest that the proposed capsule antenna support the functionality of wireless data transmission and wake-up receiver signal within 902.8 MHz–928.0 MHz and 2.40 GHz–2.50 GHz ISM bands, respectively. The wake-up receiver signal is necessary to save power by transmitting data only when is needed.

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