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Miniaturization of Implantable Antenna and Discussion of Concentration of Fields

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***Abstract*—In this paper, a two-coil design for implantable antenna miniaturization is presented. As implantable medical devices (IMDs) get smaller, prior work has shown that a set of focusing rods made of a biocompatible, conductive material may be useful to guide power from an external plane wave to the IMD. Prior research has also optimized a 3D ring array design for medical telemetry focusing. In this work, we evaluate the effect of these field focusing designs if coils are used as the transmitting and receiving antennas. A comparison of the coils with and without the focusing rods is presented.**

Keywords—biopolymer; wireless telemetry; implantable antenna; implantable medical devices; focusing; wireless power transfer

I. Introduction

Implantable medical devices (IMDs) are used for many applications including cardiac pacemakers, implantable hormone pumps, neural stimulators, receivers and more. Implantable antennas are used to transmit and receive data (telemetry) and to transmit power to recharge the battery (wireless power transfer (WPT)). Today's IMDs are getting smaller in dimensions, and future devices may be as small as 4 mm^3 as discussed in this paper. This creates a significant challenge for antenna designers. Previous work [1], [2] explores the concept of 3D printing biopolymer conductive rods or loops to act as a focusing lens antenna. The addition of the focusing lens guides the fields to the IMD, focusing them around the tip [1]. These rods are meant to create a constructive coupling effect, allowing more power to be guided to the embedded IMD.

Inductive transmit (TX) and receive (RX) coils for an IMD were modeled in CST Microwave Studio (MWS) [3]. This design was modeled with and without the focusing systems as show in Fig. 1. We are interested in wireless telemetry in the Medical Implant Communications Service (MICS) band (402-405 MHz) [4], but tuned the coils to operate at 433 MHz, which is the nearest Industrial Scientific Medical (ISM) band. This evaluation will compare the power transferred between the coils, as well as the specific absorption rate (SAR), which often limits the power than can be transmitted [1, 5].

This paper is organized as follows. In Section II, the conductive rod system is introduced. In Section III, the power transferred, and the SAR distributions of the systems are analyzed. Section IV describes the conclusion and future work pertaining to improving the full system design.

II. Proposed System Design

The simple layered model of the body is shown in Fig. 1. This is a good approximation for propagation over a small region from a TX coil near the surface of the body to a miniaturized RX coil on an IMD. We use the same dimensions as [1] and [2]. The same boundary conditions along the x-, y-, and z- axes are perfect electric conductor (PEC), perfect magnetic conductor (PMC), and open (add space), respectively. Three simulation setups were evaluated: one with only the TX and RX coils, one with the addition of the conductive rods (Fig. 1(a)), and one with the addition of the 3D ring array (Fig. 1(b)).

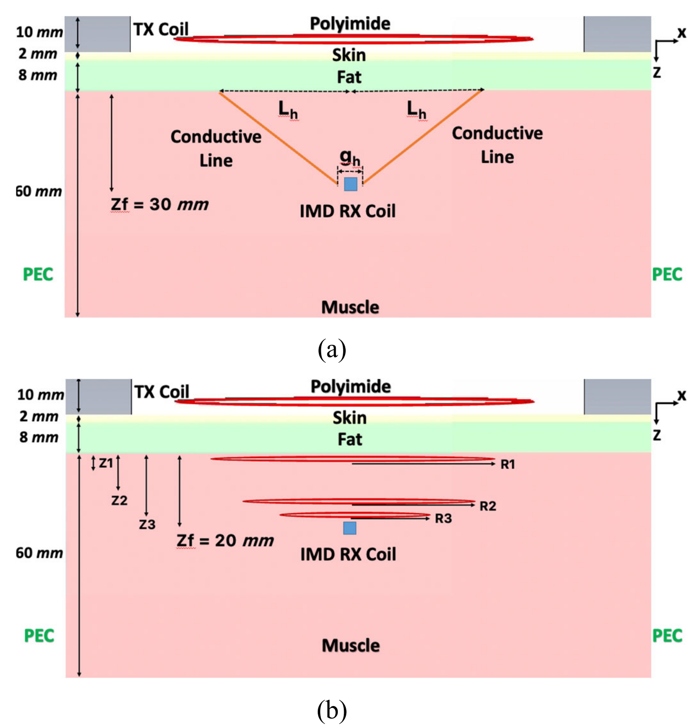

Fig. 1. The simulation setup of the layered model of the body. (a) includes the biocompatible biopolymer rods. The IMD is located at (x = 0 mm, y = 0 mm, and z = 30 mm). (b) includes the 3D ring array where R1 = 57.91 mm, R2 = 39.68 mm, R3 = 31.63 mm, Z1 = 10 mm, Z2 = 18.88 mm, Z3 = 19.21 mm. The IMD is located at (x = 0 mm, y = 0 mm, and z = 20 mm).

The design parameters for the two coil, two rod system can be seen in Table I. The TX and RX coils are modeled on FR4 circuit board material, and insulated with polyimide. The IMD is modeled to be 4 X 4 X 2 mm. For this model, each coil is modeled as 1-turn, knowing that the power transmitted and received can be enhanced by increasing the number of turns. The slit width is a small gap for the feed point. The biopolymer conductive rods have line length (L_h), come together with a gap width (g_h), at a focus depth (z_f) are modeled as thin cylinders with flat ends, as in [1]. They are initially modeled as copper, giving the best possible focusing [1]. In reality, biocompatible polymer rods can be expected to have conductivities on the order of 10^4 to 10^5 S/m. The cross sectioned surface area of the layered body model, A_s, is 180 X 180 mm^2. The material properties at 433 MHz are shown in Table II.

TABLE I
DESIGN PARAMETERS

TX Coil (mm)	RX Coil (mm)	Rods (mm)
Inner radius: 54	Inner radius: 1.25	Gap width, g_h = 5
Outer radius: 57	Outer radius: 1.75	Focus depth, z_f = 30
FR4: 130 X 130 X 0.07	FR4: 3.8 X 3.8 X 0.07	Line length, L_h = 40
Polyimide: 140 X 140 X 10	Polyimide: 4 X 4 X 2	Rod diameter = 0.1
Slit width: 2.2	Slit width: 0.2	
Wire diameter: 0.1	Wire diameter: 0.1	

TABLE II
MATERIAL PROPERTIES AT F = 433 MHZ

Material	Thickness (mm)	ε_r	σ (S/m)
Polyimide	10 (TX); 2 (RX)	3.5	6.25 X 10^{-5}
FR4	0.07	4.3	6.02 X 10^{-4}
Skin	2	45.8	0.015
Fat	8	5.56	0.008
Muscle	60	56.77	0.014
Lines	0.2		5.8 X 10^7

III. SIMULATION RESULTS

The simulated S-parameters for the TX and RX coil with no focusing are shown in Fig. 2. The S11 has a resonance at our desired operating frequency. The S21/S12 are small, which is to be expected from a lossy body system. The S22 is minimal since the receiving coil is so small and embedded in lossy muscle tissue. This system can be improved by adding a matching network to the TX and RX ports.

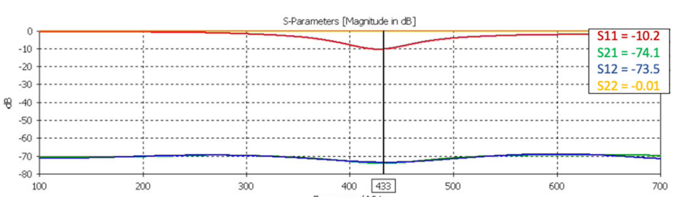

Fig. 2. S-Parameters [dB] of the simulated two coil, two wire system.

The power transmitted from the TX coil (port 1) was 0.5 W. To obtain the power at the RX coil, we multiply this by S21 to get 0.636 µW. Although the focusing systems augmented the fields available at the location of the RX coil (as shown in Table III), the power it received did not increase substantially, showing that the small RX coil is not picking up enough of the focused fields. The RX antenna will need to be adjusted to better capture these focused fields. The 1-g SAR for the simulation setups is shown in Table III. The maximum SAR exceeds the FCC limits of 1.6 W/kg, so the power transmitted (0.5 W) would need to be reduced for compliance.

TABLE III
MAXIMUM 1-GRAM SAR AT F = 433 MHZ

TX and RX Coil	2 Conductive Rods	3D Ring Array
1.68 W/kg	3.91 W/kg	2.14 W/kg

IV. CONCLUSION

A focusing system has been proposed for power transmission in the body for a miniature IMD. Next steps would include improving the receiver by using a cross dipole antenna rather than a coil design. Further research will also include fabrication and testing of this design.

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