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An Efficient Wireless Power Transfer for Retinal Prosthesis using Artificial Intelligent Algorithm

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Abstract — Wireless power transfer presents a robust method to provide a safe and convenient solution for powering biomedical implants. The implanted device is necessarily minimized conducive to the transfer efficiency degradation. This paper presents a wireless power transfer for retinal prosthesis using an artificial intelligent algorithm to optimize the power transfer efficiency with the minimizing implanted device dimension. A novel transmitter is designed based on the conformal strongly coupled magnetic resonator, which is proposed to attach to the glasses lens. An implanted receiver is optimized to obtain the highest efficiency with the minimal dimension of 9.7 x 9.7 x 1.9 mm³. The WPT system achieves approximately 17.5 % at the operating ISM frequency band of 433 MHz and a distance between transmitter and receiver of 20 mm.

Keywords — Artificial intelligent, ISM band, retinal prosthesis, wireless power transfer (WPT).

I. INTRODUCTION

Wireless power transfer (WPT) system presents an emerging and promising way for the power supply of biomedical implants, which has attracted a lot of attention in recent years [1], [2], [3], [4]. Beside the WPT technologies such as an inductive coupling system for very short distances of a few millimeters [5], [6], an electromagnetic wave system with the huge absorption rate in the human body [7], [8], a magnetic resonance WPT system is one of the most popular techniques for the implantable biomedical system [9], [10], [11]. In order to minimize the power loss due to human tissues, the implanted WPT typically operates at low frequencies of hundreds of kHz to dozens of MHz [12]. However, a different link is necessary for data transmission leading to exposure to interference [13]. In this paper, the industrial, scientific and medical (ISM) band at 433 MHz is chosen for simultaneous power and data transmission in a practical system, and the RF propagation losses through the human tissue are tolerable [14].

Furthermore, a large-sized implant increases the possibility of tissue inflammation, damage, and cell death [15], [16], [17]. The implant size should be minimized to reduce the risk of infection and increase the implant durability [18]. However, miniaturization causes strong degradation of transfer efficiency. Therefore, the efficiency improvement is necessary for the biomedical implanted WPT system. Therefore, in this paper, an artificial intelligent method is proposed not

Fig. 1. The proposed MCSCMR Tx antenna: a) top view; b) bottom view; c) retinal prosthesis scenario application.

only to optimize the power transfer efficiency (PTE) but also minimize the implanted receiver (Rx) dimension. In the last ten years, soft computing techniques have emerged as a powerful tool for discrete structural optimization. In particular, the Swarm Intelligence optimization algorithms, such as genetic algorithms, particle swarm optimization, and ant colony optimization algorithms (ACO), etc, have been used in antenna structural optimization [19], [20], [21]. In this work, the Rx component of the WPT system is designed as a meander line antenna by the ACO algorithm [22].

Finally, a real-case biomedical scenario is proposed to present the feasibility of the proposed WPT system for retinal prosthesis. The specific absorption rate (SAR) value is simulated to verify the safety regulations in the human body for a hypothetical context of retinal prosthesis application.

This paper is organized as follows. The proposed Tx and Rx coil are described and optimized by the ACO algorithm in Section II. The transfer efficiency is analyzed with the WPT system's characteristic due to the distance movement and axial misalignment in Section III. Finally, in Section IV, the WPT system for retinal prosthesis application is demonstrated with

Fig. 2. a) Diagram of flowchart program for the ACO algorithm; b) a 10 x 10 grid of points; c) a feasible connection of points.

the SAR verification for the safety constraints.

II. RESONATOR GEOMETRY DESIGN

A. Transmitting Resonator (Tx) Design

The proposed Tx coil is modified by the conformal strongly coupled magnetic resonator (MCSCMR) [23]. The Tx coil consists of a rectangular source coil and a transmitting 3-turns spiral loop, as shown in Fig. 1(a)-(b). The Tx coil is designed on two sides of the Rogers 5880 substrate with a relative dielectric constant of 2.2 and a thickness of 0.508 mm. The Tx component is proposed to attach to the glasses lens, which is placed face-to-face with the implanted device to transfer the power conveniently. The scenario application of the MCSCMR Tx coil is illustrated in Fig. 1(c). The proposed Tx component is feasible to implement a practical retinal prosthesis wireless charger.

B. Implanted Receiver (Rx) Design

Fig. 2(a) shows the flowchart of the program that presents the sequences to generate the satisfied Rx antenna. The inputs of the program are specifications of the Rx component such as operating frequency, the dimension of the substrate, etc. The program is coded by Python language to implement the ACO algorithm and simulate using HFSS software. Then, S-parameters are obtained to evaluate the designed requirement. Finally, the output of the process is a new meander-line Rx antenna.

To form the meander-line of the Rx antenna, a 10 x 10 grid of points is created in which each point can be connected directly to adjacent points in the horizontal or vertical direction, as shown in Fig. 2(b). It is noticed that there are four possible adjacent points that can be directed from an arbitrary point, except the boundary points with fewer adjacent points. Each point must form a part of the meander line until the generated Rx antenna satisfies the acceptable requirement. A feasible connection of points to generate the meander-line

Fig. 3. Proposed Rx antenna. a) perspective view, b) top view.

Fig. 4. a) Configuration of the WPT system with its coordinate system; b) a schematic of the WPT system.

Rx antenna is demonstrated in Fig. 2(c). The meander-line represents for the conducting line of the Rx antenna, which is produced by updating the pheromone trail coefficient from the previous iterations. The pheromone trail coefficient is validated by the PTE of the system. The Rx antenna is designed on Rogers RT/duroid 6010/6010LM substrate with a relative dielectric constant of 10.2 and a thickness of 1.9 mm. The optimized Rx antenna is satisfied with the high efficiency of the WPT system with a minimum dimension, as shown in Fig. 3. The performance of the WPT system is presented in the next section.

III. WPT SYSTEM AND RESULTS

The configuration of the proposed Tx and Rx coil is illustrated in Fig. 4(a). The Rx coil is placed at a position of (x,y,z) coordinate with the origin at the center of the Tx antenna. A schematic represents for the WPT system that is implemented by means of a magnetic coupling between Tx and Rx coils, as shown in Fig. 4(b). The scattering parameters can be used to determine the PTE as bellow:

$$PTE(\%) = |S_{21}|^2(1 - |S_{11}|^2)(1 - |S_{22}|^2) \times 100 \quad (1)$$

Fig. 5. Dependence of PTE on a) the transfer distance and frequency; b) axial XY misalignment.

The property of the whole WPT system is verified by changing the distance and the axial misalignment between the Tx and Rx antennas. Once the Tx and Rx parameters and their working frequencies were established, the Rx antenna was displaced in a range from 5 mm to 30 mm at a distance from the origin of the coordinate system. Fig. 5(a) demonstrates the dependence of PTE with the transfer distance and frequency. At 433 MHz, the PTE can be obtained the highest value of 90.4 % at 10 mm followed by a significant decrease with the increased distance. In the retinal prosthesis application, the Rx antenna is placed around 20 mm from the Tx antenna corresponding to 17.5 % PTE at 20 mm distance. To verify the performance of the system in the axial misalignment, the Rx antenna was varied in the XY plane at a distance of 20 mm from the origin of the coordinate system. In Fig. 5(b), the PTE of the system is slightly decreased and kept unchanged around 17 % in a wide moving range. The PTE is strongly declined when the Rx antenna moves around the boundary area of the Tx antenna. Fortunately, the moving range of the

Fig. 6. SAR simulation for the proposed WPT system in retinal prosthesis application.

eye is limited in a small range. Therefore, the proposed WPT system is suitable for the retinal prosthesis application.

IV. SPECIFIC ABSORPTION RATE (SAR) VERIFICATION

The electromagnetic field absorption in the human body is certified by the SAR value, which represents the absorbed energy in the human body. The SAR is set a restriction of 2W/kg for head and trunk at a frequency range of 100 kHz to 300 GHz [10]. The higher the SAR value is, the more harmful the WPT system induces. In this paper, the ANSYS HFSS simulation tool is used to validate the safety of the system by SAR value. Fig. 6 shows the 3-D graph of the WPT system to indicate the SAR simulation for the proposed WPT system. The SAR value is approximately 1.54 W/kg averaging over 1-g of tissue. The SAR values are smaller than the limitation restriction for the head/trunk, that are satisfied with the human safety regulations.

V. CONCLUSION

In this paper, we presented a WPT system for retinal prosthesis using the ACO algorithm to optimize the Rx antenna with a high PTE. A novel Tx antenna is based on the CSCMR coil which is proposed to attach to the glasses lens for practical application. The implanted Rx antenna is optimized to obtain a high PTE of 17.5 % at 20 mm with a minimal dimension of $9.7 \times 9.7 \times 1.9 \text{ mm}^3$. The WPT system has verified the performance when the Rx antenna is moved the transfer distance and axial misalignment.

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