A Self-tracked High-dielectric Wireless Power Transfer System for Neural Implants

Rupam Das and Hadi Heidari
Microelectronics Lab (meLAB), School of Engineering, University of Glasgow, G12 8QQ, UK
hadi.heidari@glasgow.ac.uk

***Abstract*— This paper introduces a novel, efficient and long-range (0.5λ) wireless power transfer system for implantable neural devices. The operating principle of this system is based on the high-dielectric coupling, which occurs between an external lossless high-dielectric metamaterial (permittivity, ε_r = 100, loss tangent, tanδ = 0.0001) and lossy dielectric such as rat (ε_r = 54.1, conductivity, σ = 1.5 S/m). As magnetic field coupling occurs between two dielectric resonators, therefore, the rat (lossy dielectric) itself acts as a self-tracking energy source. The Ansoft HFSS simulation software was used to verify the concept. Initially, the rat was modelled as a phantom box and the resonant frequency was found to be 1.5 GHz. Then, for matching this intrinsic mode of the rat model, the external high-dielectric metamaterial designed accordingly to realize a highly efficient ($\eta = 1\times10^{-3}$) and self-tracked wireless power system for neural implants.**

Keywords*— High-dielectric, Implantable neural device, Metamaterial, Wireless Power Transmission.

I. INTRODUCTION

Implantable neural probes are now widely exploited to access and record extracellular potential signals, including action potentials and local field potentials. Such invasive neural interfacing devices have been extensively employed in various clinical applications ranging from cochlear and retinal implants, spinal, and peripheral nerve interfaces, to monitoring epilepsy, and deep brain stimulation [1]. Traditional methods for powering these implantable devices depend on rigid and tethered systems to transfer power at a great depth of the brain from outside power supplies. Such tethered systems cause disturbance with natural behaviour of animals, thus preventing chronic *in vivo* neural modulation. The mechanical mismatch and micro-motion introduced by the interconnection between the device in the brain tissue and the connector mounted on the skull (i.e. tether), can be minimized by using a wireless power system (WPT) [2].

The implantable wireless technologies mainly include ultrasound, electromagnetic, and photovoltaic cells. However, wireless technologies like electromagnetic requires external tracking system, whereas, ultrasound based WPT has a very complex circuitry and solar based system depends on nature, proximity, and direction of light sources [3, 4], thus limiting the scope of the WPT. Recently

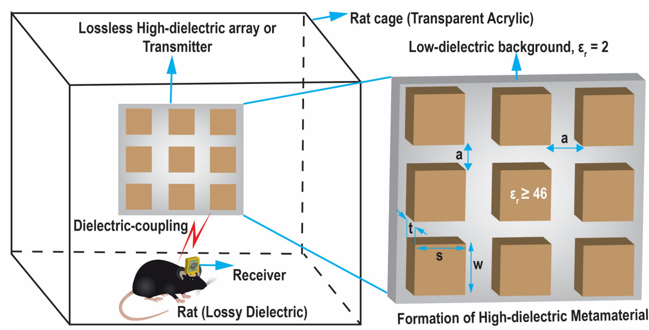

Fig. 1. Conceptual illustration of the high-dielectric metamaterial based WPT system for implantable neural devices.

it is demonstrated that owing to the high-dielectric contrast between free space and high dielectric, excitation of a dielectric resonator leads to strong localization of energy [5]. This localized energy can be coupled efficiently to another dielectric object resulting in a significant improvement in WPT efficiency and range. J. S. Ho *et al.* shown that, small animals as dielectric objects support a series of electromagnetic modes that give rise to strong localization of energy [6].

For the first time, originating from these concepts, a self-tracked high-dielectric based WPT system for implantable devices by tailoring the properties of dielectric resonators (i.e. array) coupling the intrinsic electromagnetic modes of a rat is proposed, as shown in Fig. 1. As magnetic field coupling occurs between two dielectric resonators, the rat (lossy dielectric) itself acts as a self-tracking energy source. Therefore, to extract power from the self-energized rat, the receiver size (i.e. antenna) can be miniaturized, which is one of the critical aspects for wireless neural devices [1]. For WPT frequency, the low-GHz range (~1 GHz to 3 GHz) was chosen, as it is the most suitable band for WPT in electromagnetically exposed biological tissue considering the specific absorption rate (SAR) [7].

II. METHODOLOGY

Theoretically, a rectangular cavity resonator with a metal wall has the resonant frequencies given by:

$$f_{mnp} = \frac{1}{2\sqrt{\varepsilon\mu}}\sqrt{\left(\frac{m}{s}\right)^2 + \left(\frac{n}{t}\right)^2 + \left(\frac{p}{w}\right)^2}, \qquad (1)$$

where, integers m, n, and p denote the number of half-wave variations, and s, t, and w represent the dimensions of the rectangular cavity, respectively. In the case of a high-

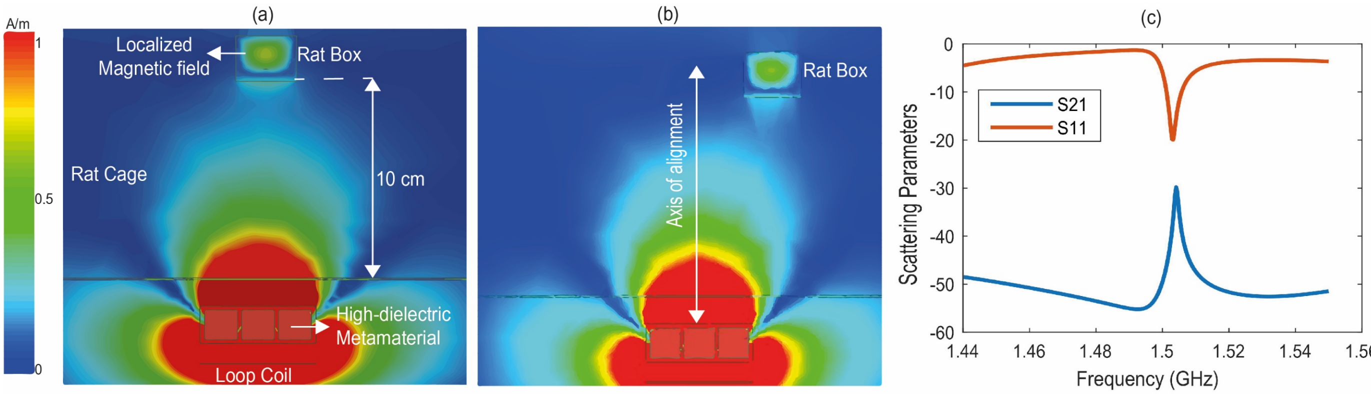

Fig. 2. a) Magnetic field (**H**-field) overlays between high-dielectric metamaterial and lossy biological tissue. b) **H**-field when the rat model displaced by 4 cm from the metamaterial axis. c) Scattering parameters.

dielectric resonator, boundary conditions at the walls can be considered as an open circuit; hence, resonant frequencies of the modes can also be approximated by Eq. (1). As depicted in Fig. 1, if these high-dielectric resonators (permittivity, ε_r = 100) are composed periodically in a low-dielectric background (ε_r = 2), it gives rise to the metamaterial properties [5]. The periodicity (a) of the structure controls the macroscopic resonance or the Bragg resonance, and the lattice resonance, whereas the microscopic resonance is due to the individual unit cell characteristics and is known as the Mie resonance. The combination of these two resonances gives rise to a negative refractive index.

For coupling this high-dielectric based metamaterial transmitter with the biological tissue, the intrinsic resonance mode of the rat should be determined. For simplicity, in this study a phantom box size of 28 mm × 22 mm × 16 mm, having ε_r = 54 and conductivity, σ = 1.5 S/m is considered. To determine the resonance mode of this lossy dielectric material Ansoft HFSS software was used. By analysing the model, analysing the model shows an agreement of the resonance at 1.5 GHz, which is identical to the study [6]. In order to match this intrinsic resonance mode of rat, the high-dielectric transmitter is tuned by choosing s = w = t = 15 mm, a = 2 mm (Fig. 1) in HFSS. To have the metamaterial properties, a 3 × 3 array is created which has an overall dimension of 53 mm × 53 mm × 19 mm. A simple square loop coil of dimension 53 mm × 53 mm was chosen for excitation. The rat cage (ε_r = 3.4) in Fig. 1, has a dimension of 60 cm × 40 cm × 30 cm that mimic the realistic environment for neural experiments on Rat [8]. Fig. 2 demonstrates the HFSS simulation results by considering the all above-mentioned parameters. The separation between the rat box model and high-dielectric transmitter was chosen as 10 cm, and a tiny receiver coil of size 2 mm × 2 mm is considered. Fig. 2a indicates the magnetic field (H-field) distribution between lossless dielectric (transmitter) and lossy dielectric (rat model). It is obvious from Fig. 2a that, upon excitation, highly localized energy is induced inside the high-dielectric metamaterial structure. Similarly, strong localized magnetic field is visible in the rat box model. This localization of energy occurs due to strong coupling between the two dielectric structures. In Fig. 2b, the rat model is displaced by 4 cm from the high-dielectric metamaterial axis. However, the magnetic field still follows or track the rat box, thereby establishes a self-tracking WPT system.

The simulated scattering parameters (reflection coefficient, S_{11} and transmission coefficient, S_{21}) is plotted in Fig. 2c. The transmitter is perfectly tuned at 1.5 GHz as revealed by the S_{11}. The proposed method yields significantly improved power transfer efficiency ($\eta = 1\times10^{-3}$) for implantable devices than traditional WPT methods at a 10-cm distance [2].

III. Conclusion

This study addressed a self-tracking WPT system based on the coupling between high-dielectric resonators and lossy biological tissue. The Ansoft HFSS simulation software were used to verify the proposed method that can significantly improve the WPT efficiency and track the off-axis rat phantom model. As future work, more rigorous analysis and measurements will be carried out to develop this system for wireless powering of the implantable neural devices.

Acknowledgement

This work was supported by the EU H2020 Hybrid Enhanced Regenerative Medicine Systems (HERMES, GA n.824164).

References

[1] P. Gutruf *et al.* "Implantable, wireless device platforms for neuroscience research," *Curr. Opin. Neurobiol.,* vol. 50, pp. 42-49, Jun 2018.

[2] K. O. Htet, J. W. Zhao, R. Ghannam, and H. Heidari, "Energy-Efficient Start-up Power Management for Batteryless Biomedical Implant Devices," *IEEE International Conference on Electronics, Circuits and Systems (ICECS),* pp. 597-600, 2018.

[3] J. Zhao, R. Ghannam, Q. Abbasi, M. Imran, and H. Heidari, "Simulation of Photovoltaic Cells in Implantable Application," *Proc. IEEE SENSORS Conference, New Delhi, India,* 2018.

[4] J. Zhao, *et al.*, "Design, Test and Optimization of Inductive Coupled Coils for Implantable Biomedical Devices," *Journal Low Power Electronics,* vol. 15, no. 1, pp. 76-86, Mar 2019.

[5] R. Das, A. Basir, and H. Yoo, "A Metamaterial-Coupled Wireless Power Transfer System Based on Cubic High-Dielectric Resonators," *IEEE Trans. Ind. Electron.,* vol. 66, no. 9, pp. 7397-7406, Sep 2019.

[6] J. S. Ho *et al.*, "Self-Tracking Energy Transfer for Neural Stimulation in Untethered Mice," *Phys Rev Appl,* vol. 4, no. 2, Aug 4 2015.

[7] R. Das and H. Yoo, "A Multiband Antenna Associating Wireless Monitoring and Nonleaky Wireless Power Transfer System for Biomedical Implants," *IEEE Trans. Microw Theory,* vol. 65, no. 7, pp. 2485-2495, Jul 2017.

[8] G. Shin *et al.*, "Flexible near-field wireless optoelectronics as subdermal implants for broad applications in optogenetics," *Neuron,* vol. 93, no. 3, pp. 509-521. e3, 2017.