A Miniaturized, Wireless, Battery-Free Optogenetic Neurostimulation Implant for Obstructive Sleep Apnea Treatment in Mice

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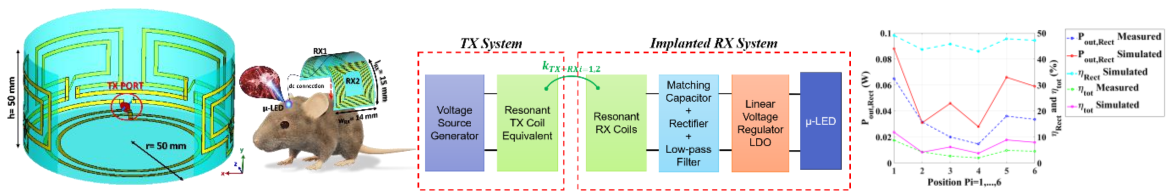
Optogenetic neurostimulation is an emerging technique enabling precise control of neuronal activity via light stimuli acting on exogenously expressed light-sensitive proteins. Recent advances in wireless, battery-free optogenetic systems address the limitations of well-established optical fiber-based methods for in-vivo neurostimulation on mice, replacing bulky batteries and heavy, tethered head-mounted configurations, with miniaturized, flexible, wirelessly powered optoelectronic implants, based on near-field inductive wireless power transfer (WPT). This work presents a flexible, soft, and conformal WPT system designed to power a battery-free, implantable device enabling optogenetic neurostimulation in laboratory mice affected by obstructive sleep apnea (OSA) — a common chronic respiratory disorder caused by the upper airway collapse during sleep, which leads to repeated episodes of apnea that may affect the brain and the cardiovascular function. In this framework, wireless optogenetic neurostimulation offers a less intrusive alternative to the gold standard treatment of continuous positive airway pressure, targeting the hypoglossal nuclei to induce tongue contraction and thus prevent upper airway obstruction. With this purpose, the proposed WPT system, illustrated in Fig. 1(a,b) and previously introduced in [1], features an inductive link operating at 13.56 MHz composed of a transmitting (TX) array of series-connected coils embedded within a semi-cylindrical experimental cage, specifically designed to generate a uniform and omnidirectional power distribution that maximizes the inductive coupling with a pair of miniaturized receiving (RX) coils implanted on the mouse back in a saddle-like configuration. The implanted device foresees, integrated with the RX coils, the electronic circuit for converting the harvested RF energy into DC power to supply the battery-free operation of a microscale light emitting diode (μ-LED) accurately positioned in the brain to target the selected neural tissue. The system is designed and optimized, by means of electromagnetic (EM) and nonlinear co-simulations, to ensure uninterrupted light delivery for effective optogenetic stimulation, regardless of the mouse's positioning or angular misalignment while moving within the cage. Fabricated in planar technology, on flexible Kapton film, the TX and RX components experimental validation confirm reliable WPT performance. The results, described in Fig. 1(c), demonstrate the system's ability to meet the μ-LED's power consumption requirement of 14.7 mW to deliver sufficient radiant flux for effective tongue motor response, even under the worst-case position and alignment conditions.



(a) (b) (c)

Figure 1. Overview of the WPT system: (a) TX multi-coil array and RX device on the mouse's back, and (b) block diagram of the WPT circuit, detailing the implantable RX device with coils, rectifiers, linear voltage regulator and μ-LED. (c) Simulated and measured WPT performance across six mouse positions (Pi=1,…,6) in the cage: left y-axis shows the rectified DC power ($P_{out,Rect}$), right y-axis shows the rectifier's efficiency (η_{Rect}) and the overall system efficiency (η_{tot}).

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1. G. Battistini et al., "Soft, Implantable, Battery-Free, and Wirelessly Controlled Optoelectronic System for Obstructive Sleep Apnea Treatment," *2024 IEEE MTT-S International Microwave Biomedical Conference (IMBioC)*, Montreal, QC, Canada, 2024, pp. 87-89.