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Development of a Small-Sized Wireless Power Transfer System with High Efficiency for Wireless Charging of Biomedical Implants

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論 文 名　：**Development of a Small-Sized Wireless Power Transfer System with High Efficiency for Wireless Charging of Biomedical Implants**

（医療機器のワイヤレス給電に向けた体内への小型・高効率無線電力伝送システムの開発）

区　　分　：甲

論　文　内　容　の　要　旨

Wireless power transfer (WPT) plays a vital role in various practical applications, particularly in the biomedical field. It offers the advantage of wirelessly charging implanted sensors, eliminating the need for batteries, and mitigating associated risks. Among the different techniques, near-field WPT is commonly employed in biomedical applications due to its compatibility with compact implanted devices, insensitivity to misalignment, and electromagnetic compatibility. However, the presence of biological tissue poses challenges, such as performance degradation caused by misalignment and variations in resonance frequency.

To tackle these challenges, we have developed a frequency-misalignment-insensitive WPT system specifically designed for biomedical applications. Our system utilizes short-length inductors and stacked metamaterials, capitalizing on the self-shielding and high-coupling properties of the metamaterials. The key element in our design is the unit cell comprising multi-ring resonators (MRR) with low magnetic loss, which enhances the intensity of the magnetic field. Through this approach, we have achieved excellent system performance, allowing for further reduction in the size of the implanted receiver (RX). Moreover, we have successfully implemented a matching-less rectifier without increasing the overall system area.

By addressing these challenges and implementing our frequency-misalignment-insensitive WPT system, we have made significant strides in improving the efficiency and practicality of wireless power transfer in biomedical applications.

In this dissertation, first, A multi input single output wireless power transfer (WPT) system insensitive to resonance shift is proposed. This Wireless Power Transfer (WPT) system is working effectively in overcoming the influence of tissue properties. This achievement was made possible through the introduction of a short inductor theory. It seems to have played a crucial role in enhancing the efficiency of the system. Transmitter (TX) of WPT system consists of three cooperative DGS resonators, which are designed to improve the kQ-product and maximize the achievable efficiency. The proposed system achieves measured efficiencies of 68% and 62% at 49 MHz in the air and the tissue respectively. The proposed structure consumes a 166-mW input power to achieve the limitation of SAR.

Secondly, A novel metamaterial composed of a multi-ring resonator (MRR) with exceptionally low magnetic loss is presented. This MRR metamaterial is employed in a stacked configuration, serving as the transmitter (TX) for wireless power transfer (WPT) to a miniaturized receiver (RX) embedded in biomedical tissue. Our fabricated prototype demonstrates an impressive efficiency of 51% at 50 MHz, with a TX/RX separation distance of 9 mm. The transmitter and receiver sizes are 20 mm × 20 mm and 7 mm × 7 mm, respectively. As a result, our proposed system exhibits a remarkable figure-of-merit of 0.42, surpassing previously reported WPT systems. Furthermore, simulations indicate that the specific absorption rate remains within the recommended level for an input power of 21 dBm

Thirdly, an innovative integration of a matching-less rectifier into our wireless power transfer (WPT) system, utilizing a low magnetic loss metamaterial is presented. Our approach leverages the high coupling achieved through our previous metamaterial, which comprises a multi-ring resonator (MRR), effectively minimizing magnetic loss. In addition, we have employed a Defected Ground Structure (DGS) as our receiver, further enhancing the system's performance. On the reverse side of the receiver (RX) substrate, we have seamlessly integrated the rectifier, ensuring that no additional space is required. To minimize magnetic field leakage to and from the surrounding equipment, we designed an isolator using a unit cell of metamaterial with lower magnetic loss. Notably, our assessment of this isolator layer in the WPT system demonstrated that it has no detrimental effects on system performance. The fabricated prototype, and both RF-dc simulations and measurements indicate an efficiency of 43% and 39% at 50 MHz, respectively, with a TX/RX separation distance of 9 mm. The transmitter (TX) has dimensions of 20 mm × 20 mm, while the receiver (RX) integrated with the rectifier measures 7 mm × 7 mm. The isolator layer comprises a 5-loop inductor with dimensions of 20 mm × 20 mm and consists of three layers, each spaced 5 mm apart.