

Development of High-Efficiency Platinum Band CMOS Rectifier for Beamforming-Based Wireless Power Transfer Systems

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論 文 名 : Development of High-Efficiency Platinum Band CMOS Rectifier for
Beamforming-Based Wireless Power Transfer Systems
(ビームフォーミング技術を用いた無線電力伝送システム用プラチナバンド CMOS 整流回路の開発)

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論 文 内 容 の 要 旨

With the rapid global deployment of 5G systems, the focus on wireless power transfer (WPT) has become increasingly prominent, driving innovation in energy delivery technologies. Researchers have long sought to replace conventional wired power systems with WPT to cater to a wide range of applications. Over the past few decades, significant progress has been made in wireless energy harvesting (EH) and WPT, particularly in developing systems that operate within the 400–900 MHz frequency range, often referred to as the platinum band. Beamforming-based WPT systems, in particular, have gained significant attention for their ability to power devices across the spectrum—from low-power Internet of Things (IoT) sensors, wearable electronics, and biomedical implants to high-power appliances such as personal computers and refrigerators. At the heart of these systems lies the CMOS rectifier, a critical component responsible for converting alternating current (AC) from harvested electromagnetic waves into usable direct current (DC) power. However, the efficiency and compactness of CMOS rectifiers are often limited by input-side matching networks. To address these challenges, this research focuses on developing advanced CMOS rectifiers tailored for beamforming-based WPT applications, with a particular emphasis on efficiency, self-impedance matching, and compact design, as detailed in the subsequent chapters.

Chapter 1 an Overview that introduces the foundational concepts and technologies underpinning wireless power transfer (WPT). The discussion starts by highlighting the significance of Platinum Band Frequencies (400–900 MHz) in WPT, known for their advantageous propagation characteristics, and their role in powering diverse applications. The section also explores the growing reliance on Beamforming-based Wireless Power Transfer, a technology that enables focused energy delivery to targeted devices, enhancing the efficiency and range of WPT systems. Following this, the Problem Definition and Conventional Studies section identifies key challenges in traditional rectifier designs, such as limited Power Conversion Efficiency (PCE), complex input matching requirements, and bulky circuit designs, while reviewing existing approaches in the literature. These challenges form the basis for the Research Motivation and Objective, which emphasizes the need for innovative CMOS rectifiers capable of efficient, compact, and wideband operation, particularly in beamforming-based WPT applications. Finally, the Thesis Outline provides a roadmap for the document, detailing

the progression of topics from initial concepts to experimental validation and concluding with the contributions and implications of this research.

In Chapter 2, we develop a 2-stage Dickson circuit with PMOS transistors, exploring the use of body-biasing techniques to maximize Power Conversion Efficiency (PCE). Experimental results demonstrate a peak PCE of 67.49% at 16 dBm input power and 0.7 GHz operating frequency. This novel application of body-biasing to high-power PMOS rectifiers marks a significant advancement in rectifier design, addressing efficiency challenges for high-frequency, high-power scenarios. By optimizing the electrical characteristics of PMOS transistors, this study paves the way for innovative solutions in energy-intensive systems and next-generation WPT technologies.

In Chapter 3, the development of an inductor-less wideband rectifier, implemented using 0.18 μm CMOS technology and incorporating NMOS Native transistors. This innovative design eliminates the need for bulky passive components such as inductors and transmission lines, which are traditionally required for input matching and impedance control. By removing these components, the rectifier not only achieves a significantly more compact but also simplifies the fabrication process, making it more suitable for integration into space-constrained and cost-sensitive applications. The use of NMOS Native transistors plays a crucial role in this design, by reducing threshold voltage losses lead to enhanced energy conversion efficiency and optimized circuit performance. The rectifier achieves a peak Power Conversion Efficiency (PCE) of 48.78% at an operating frequency of 250 MHz and an input power level of 17 dBm, as validated by experimental results. This level of efficiency and performance establishes a new benchmark for wideband rectification, that meets the demands of modern wireless power transfer (WPT) systems.

In Chapter 4, we design a wideband PMOS rectifier incorporating a modified matching network and body-biasing technique is presented. This design, implemented using 0.18 μm CMOS technology, in achieving high PCE for wideband, high-power rectifiers. The optimized matching network minimizes impedance mismatches, enabling efficient power transfer across a broad frequency range, while the body-biasing technique enhances PMOS transistor performance by lowering the threshold voltage. Simulation results reveal a peak PCE of 60.5% at 700 MHz with 20 dBm input power, significantly outperforming conventional designs. This work establishes a strong foundation for the development of robust, efficient rectifiers tailored to next-generation WPT systems.

Chapter 5 presents a summary of the thesis, this research collectively advances the design and performance of CMOS rectifiers for WPT applications. By addressing challenges such as efficiency, compactness, and operational reliability, it introduces groundbreaking approaches like body-biasing techniques for PMOS transistors, inductor-less designs with NMOS Native transistors, and modified matching networks. These efforts contribute to the realization of efficient, scalable, and versatile wireless power solutions for a wide array of applications, from IoT devices to large-scale appliances. Additionally, the future prospects are discussed, focusing on Low-Dropout (LDO) circuit and integration of rectifier with LDO and Power Management Unit (PMU).