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Category(English)	Doctoral Thesis
種別(和文)	論文要旨
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（博士課程）
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論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	電気電子　系 電気電子　コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of　（ 学術 ）
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要旨（英文800語程度）
Thesis Summary（approx.800 English Words ）

This thesis presents novel architecture and design techniques for millimeter-wave phased-array receivers to meet the demands of next-generation high-performance wireless communication systems.

This thesis focuses on millimeter-wave receiver ICs, a critical component of advanced communication systems. Chapter 1 introduces the background and evolution of communication systems, followed by an analysis of their applications and the demands of next-generation communication systems. The evolution of communication systems is explored in two dimensions in this thesis: achieving higher data rates for inter-device communication and increasing overall data traffic capacity across the network. MIMO technology is considered as essential for achieving higher data rates, while multi-band operation is considered crucial for expanding overall data traffic capacity. In line with the requirements of next-generation communication systems, scalable multi-band and MIMO techniques with high power and area efficiency are deemed indispensable. This thesis delves into the development and discussion of these techniques, providing insights and solutions to meet the demands of future communication networks.

Chapter 2 reviews the fundamentals of millimeter-wave phased-array receivers and identifies the key challenges in their design. By thoroughly examining the fundamental building blocks and architectures, the chapter lays the groundwork for devising precise solutions to meet the requirements of this thesis. The trade-offs inherent in various beamforming architectures are carefully analyzed to identify the most optimized approach for the research objectives. Additionally, as critical components of phased arrays, phase shifters and gain control units are evaluated in detail, with their respective advantages and limitations summarized. The chapter concludes by highlighting the importance of compact, low-power designs to address the stringent demands of next generation wireless communication systems. These foundational analyses and insights serve as a guide for the subsequent development of advanced phased-array receiver designs throughout the thesis.

To address the multi-band operation demands outlined in Chapter 1, Chapter 3 presents a scalable and power-efficient solution for multi-band receivers. Conventional millimeter-wave multi-band receivers are first reviewed, revealing significant limitations: they are not only power-inefficient but also lack scalability to accommodate higher frequency bands without extensive redesign. These shortcomings highlight the need for innovative approaches to meet the evolving requirements of modern communication systems. In response, the proposed harmonic-selection technique provides a transformative solution. This technique enables power-efficient reception of multi-band signals within a limited bandwidth while intrinsically rejecting inter-band interference. Its scalability ensures adaptability for future frequency bands without requiring substantial modifications. To validate the effectiveness of this approach, a 2-channel multi-band phased-array receiver prototype is developed, designed to comprehensively cover all 5G NR bands. Measurements confirm its exceptional performance, demonstrating robust rejection of inter-band blockers and maintaining high power efficiency across various operating conditions, including worst-case scenarios. This advancement establishes the proposed receiver architecture as a highly reliable and scalable solution for increasingly congested spectrum environments. It not only addresses current challenges but also positions the design as a foundation for future millimeter-wave communication systems, ensuring sustained performance and adaptability in a rapidly evolving technological landscape.

To address the high data rate demands of point-to-point communication in next-generation systems, Chapter 4 introduces a novel time-division MIMO (TD-MIMO) architecture. This scalable solution effectively balances the trade-offs between chip area and MIMO stream capacity, making it well-suited for compact phased-array designs. A comparative analysis of conventional MIMO phased-array receivers presented in Chapter 4 reveals their poor scalability and limited compatibility with multi-chip systems. In contrast, the proposed TD-MIMO architecture facilitates the development of cost-effective, large-scale multi-chip arrays with a simplified single-wire inter-chip connection. This approach minimizes hardware costs and streamlines design modifications to accommodate additional MIMO streams in future applications. To validate the proposed design, a 4-stream, 8-element TD-MIMO phased-array receiver prototype was implemented. Over-the-air (OTA) measurements using a PCB setup demonstrated successful 64-QAM MIMO reception across four streams, achieving a data rate of 9.6 Gbps—marking the highest reported area and spectral efficiency to date. Furthermore, the TD-MIMO architecture is extendable to phased-array transmitters, offering potential improvements in uplink communication. With continuous advancements in CMOS technology and further optimization of key circuit building blocks, the TD-MIMO architecture is well-positioned to scale further, setting new benchmarks for data rates and efficiency in next-generation wireless communication systems.

The proposed scalable multi-band architecture and TD-MIMO architecture complement each other, providing a universal solution for millimeter-wave receivers. Together, they enhance spectrum efficiency, scalability, and adaptability. By integrating these technologies, future communication systems will be better equipped to handle increasingly complex and high-capacity networks, ensuring reliable and efficient performance in the evolving wireless landscape. Moreover, the adaptability of these designs makes them well-suited for emerging applications beyond conventional mobile networks, such as satellite communications, IoT deployments, and high-speed wireless backhaul.

Ultimately, the research presented in this thesis lays the groundwork for the next generation of wireless communication systems. The methodologies developed here offer not only immediate solutions to pressing challenges but also long-term strategies for sustainable and scalable network development. By addressing key inefficiencies in traditional phased-array receiver designs, this work contributes to the advancement of high-performance millimeter-wave communication, enabling future innovations in the field.