

## 学 位 論 文 の 要 旨

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学位論文題目: Study on MMI Coupler Integrated Electro-Optic Modulator for Space Division Multiplexing Wireless - Wavelength Division Multiplexing Optical Signal Conversion (和訳: 空間分割多重無線 - 波長分割多重光信号変換用 MMI カプラ集積電気光学変調器の研究)			
<p>In the Beyond-5G (B5G) communication system, the important technical features that should be achieved are high data rates (~100 Gbps), low latency (&lt;1ms) and massive connectivity (up to 106/km2). Achieving these ambitious goals requires innovative techniques and technologies. Especially to meet demand of both high data rates and massive connectivity, Space Division Multiplexing (SDM) and Wavelength Division Multiplexing (WDM) are important. SDM efficiently manages the wireless spatial domain by allocating unique spatial channels to each device, preventing interference, and enabling simultaneous data transmission. This is particularly crucial in densely populated areas where a dense devices population must communicate concurrently without signal overlap. Due to the massive connection, a huge data capacity must be accommodated. Thus, WDM plays crucial role. WDM enhances data rates by transmitting multiple data streams on different wavelengths over a single optical fiber. This allows for a significant increase in the fiber's data-carrying capacity, enabling it to handle the high data rates required by B5G. By integrating SDM and WDM technique, the requirement of B5G to serve a dense population of devices can be achieved.</p> <p>In B5G, Radio over Fiber (RoF) can leverage the combined advantages of SDM and WDM. RoF technology integrates SDM and WDM by converting millimeter wave (MMW) signals managed by SDM into optical signals for transmission over fiber using WDM. Each wavelength carries a different MMW signal, significantly enhancing the data-carrying capacity of the fiber. Therefore, the development of a device capable of converting SDM wireless signals to WDM optical signals is crucial.</p> <p>In this dissertation a multimode interference (MMI) coupler integrated Electro-Optic Modulator (EOM) is discussed for SDM wireless to WDM optical signal conversion to meet the requirement in B5G communication system.</p> <p>The structure of this dissertation is as follows:</p> <p>Firstly, an overview of the fundamental concepts of the proposed device is presented, encompassing key elements, including the importance of SDM wireless-WDM optical technique to meet the requirement of massive connectivity in B5G communication system. This sets the stage for addressing the primary aim of the dissertation.</p>			

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Secondly, the introduction of the proposed device, emphasizing its compact structure and the unique combination of MMI couplers, Antenna-Coupled Electrode (ACE) arrays, and a polarization-reversed structure is presented. The device's potential to directly convert SDM wireless to WDM optical signals, without external power supply, is very promising. This chapter provides a description of the principle of conversion and the specific functions played by each of the main components of this device.

Thirdly, the design and modeling of an ACE-EOM operating in the 60 GHz band, which is pivotal in converting wireless MMW signals into optical signals, are presented. It includes a detailed description of an experiment that demonstrates the successful conversion of a wireless MMW signal to an optical signal using an 8-array ACE-EOM. This chapter highlights the significance of using array ACEs and a polarization-reversed structure to accurately differentiate SDM wireless signals depending on their angle of irradiation. Additionally, it presents the design and simulation of polarization-reversed structural patterns with 8-array ACEs, highlighting their significant role in SDM wireless signal discrimination.

Fourthly, the exploration of the design and simulation of MMI couplers, which serve as both power splitters and wavelength-selective couplers, are described. The study focused on MMI couplers fabricated on a  $z$ -cut LiNbO<sub>3</sub> substrate and considered several situations and parameters.

Fifthly, the successful fabrication and experimental validation of a wavelength-selective MMI coupler based on  $z$ -cut LiNbO<sub>3</sub> channel waveguides using the Annealed-Proton-Exchanged (APE) method have been demonstrated. The MMI coupler was set to select the input optical wavelength at 1.31 $\mu$ m and 1.582 $\mu$ m. Experimental evaluation confirmed the coupler's performance parameters, with near field images demonstrating effective wavelength division. The comparison between simulation and experiment showed good agreement.

Sixthly, a discussion about the integration of main components into the MMI coupler integrated EOM is presented with the objective of converting SDM wireless signals into WDM optical signal. This chapter includes two scenarios: one involving the integration of a 4-channel MMI coupler as a power splitter with an 8-array of ACEs, using various polarization reversed structure patterns; and another scenario involving the integration of a 2-channel wavelength-selective MMI coupler with an 8-array of ACEs, also using different polarization

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reversed structure patterns. The chapter showcases the successful signal discrimination and direct conversion of SDM wireless signals to WDM optical signals. It emphasizes the device's ability to operate efficiently at a frequency of 60 GHz without requiring additional power sources.

Overall, this dissertation represents a significant contribution to B5G communication, offering a comprehensive study of integrated device capable of direct SDM wireless to WDM optical signal conversion.