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# 論文 / 著書情報
# Article / Book Information

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| 題目(和文) | 1060nm 単一モード VCSEL とモードフィルタを使用した標準単一モードファイバー伝送に関する研究 |
| Title(English) | Study on standard single-mode fiber transmission using 1060nm VCSELs and mode filters |
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（博士課程）
Doctoral Program

# 論 文 要 旨

THESIS SUMMARY

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


This study addresses critical issues such as mode coupling and modal noise in optical communication systems based on conventional single-mode optical fiber and 1060nm single-mode VCSELs through both theoretical analysis and empirical validation. By constructing a dual-mode fiber transmission model, an in-depth analysis of the mode coupling process was facilitated. The model established in this paper presents several improvements and breakthroughs over previous similar studies. Firstly, it performs precise calculations considering the transmission losses of both the fundamental and higher-order modes. Secondly, through simulation modeling, it accurately analyzes the coupling efficiency of the fundamental and higher-order modes within fiber connectors. The simulation results reveal that the coupling loss of higher-order modes in connectors is largely radiated outside the fiber, a finding that significantly diverges from the assumption in many previous studies that all coupling loss is converted to the fundamental mode. Thirdly, the study separately calculates the modal noise generated by the fundamental and higher-order modes, incorporating laser phase noise for a quantitative analysis of noise. Additionally, the impact of modal noise on the system's bit error rate (BER) and the corresponding power penalty was calculated. A solution proposed to address the modal noise issue generated by the LP11 mode involves the use of a mode filter, with its effects predicted alongside the dual-mode transmission model.

Experimentally, a system was established using 500 meters of conventional single-mode fiber and a 1060nm single-mode VCSEL. This fiber demonstrated controllable coupling loss through lateral-offset splicing technology, simulating the coupling loss caused by mode field mismatch in connectors within real-world fiber-optic communication systems. Initial measurements focused on system modal noise under continuous wave (CW) conditions, yielding results consistent with the calculations. Moreover, in data transmission experiments involving various modulation rates and techniques, the eye pattern results vividly illustrated the impact of modal noise on the system's signal-to-noise ratio. The effectiveness of the mode filter in improving the quality of the eye pattern was also evident. By comparing calculated and measured signal-to-noise ratios, further validation was provided for the accuracy of our transmission model. The implementation and effect of mode filters were evaluated in both CW and eye-pattern experimental scenarios, conclusively demonstrating that mode filters effectively reduce modal noise and enhance system transmission capacity.

The study designed two types of mode filters - a bending fiber-based mode filter and a compact mode filter based on a 90-degree fiber array, each suitable for different scenarios.

For the bending fiber-based mode filter, a simulation model was established to compute bending loss, which was subsequently validated through experimentation. The experiment suggested using lateral-offset splicing fiber to excite the LP11 mode, a method whose effectiveness was scrutinized both theoretically and empirically.

Regarding the compact mode filter based on a 90-degree fiber array, preliminary calculations of bending loss for three fiber types adhering to G.652-D, G.657-A1, and G.657-B3 standards assessed its feasibility. The study concluded that the fiber following the G.657-B3 standard, due to its low bending loss, could not function as a mode filter. The bending loss for fibers adhering to the other two standards was then empirically measured, with results aligning with the computations.

Moreover, given that 90-degree fiber arrays typically use smaller bending radii (less than 4mm), the coupling loss at the junction between straight and bending fibers is significant and merits attention. This issue was analyzed based on the simulation model, alongside the effects of two strategies for mitigating coupling loss - gradual bending and eccentric connection. Both methods were proven effective in reducing coupling loss induced by bending fibers. Selecting an appropriate fiber type and bending radius allows a 90-degree fiber array to achieve an insertion loss of less than 1dB and an LP11 mode rejection ratio exceeding 20dB.

In summary, this research provides theoretical and practical insights into understanding and managing modal noise issues within optical communication systems based on conventional single-mode optical fiber and 1060nm single-mode VCSEL. These results contribute to the optimization and enhancement of optical communication system performance, laying a solid theoretical foundation for further investigation and application of innovative optical communication technologies.

備考 ： 論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。
Note : Thesis Summary should be submitted in either a copy of 2000 Japanese Characters and 300 Words (English) or 1copy of 800 Words (English).

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