Experimental Demonstration of Phase-Matched OCDM Using PLC-LN Multi-Frequency Self-Homodyne Module

Shin Kaneko (1), Hiro Suzuki (1), Noriki Miki (1), Hideaki Kimura (1), Makoto Tsubokawa (1), Koichi Takiguchi (2), Takashi Yamada (2), and Makoto Abe (2)
1: NTT Access Network Service Systems Laboratories, NTT Corporation
1-6 Nakase, Mihama-ku, Chiba-shi, Chiba 261-0023 Japan e-mail: kaneko.shin@ansl.ntt.co.jp
2: NTT Photonics Laboratories, NTT Corporation

Abstract

We propose and demonstrate phase-matched OCDM transmission based on multi-frequency self-homodyne detection. The feasibility is verified based on experiments using a developed PLC-LN module at the bit rate of 1.5 Gbit/s.

Introduction

Optical code division multiplexing (OCDM) is attractive due to its advantageous characteristics such as scalability, asynchronous transmission, ability to accommodate a variable bit rate, and physical layer security. A major issue concerning OCDM technologies is that the number of multiplexed codes is severely limited by multiple access interference (MAI) and the interference beat noise between OCDM signals [1, 2]. To suppress these sources of interferences, spectral amplitude encoding OCDM schemes employing coherent detection such as heterodyne detection [3] and homodyne detection [4] were recently proposed. In the former however, optical phase differences between OCDM signals and the multi-frequency local light must be identical among all frequencies when they are detected at the receiver. Establishing these conditions is not practical after transmission through optical fibers. In the latter, on the other hand, a complicated receiver configuration including two phase diversity schemes is essential.

In this paper, we propose a phase-matched OCDM technique based on multi-frequency self-homodyne detection in which optical phases at the same frequency are simply matched on the transmitter side among all OCDM signals and the multi-frequency continuous wave (CW) light for self-homodyne detection. The proposed OCDM technique allows us to suppress effectively both the beat noise and MAI using a simple receiver configuration. The feasibility of the proposed technique is verified through a 1.5 Gbit/s × 3 user OCDM transmission experiment.

Proposed phase-matched OCDM technique

Fig. 1 shows a schematic of the proposed phase-matched OCDM based on multi-frequency self-homodyne detection. A phase-matched signal transmitter (Tx) is connected to a number of OCDM receivers (Rxs) through a power splitter. The transmitter simultaneously outputs spectral amplitude encoded OCDM signal lights and a multi-frequency CW light for self-homodyne detection. Among all these lights, both the optical phases and the polarization states at the same frequency are matched. The optical power at each frequency of the multi-frequency CW light, P_{CW}, is much higher than that of the OCDM signals, P_S.

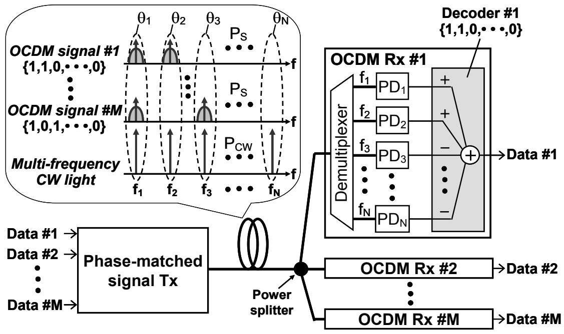

Fig. 1 Proposed phase-matched OCDM based on multi-frequency self-homodyne detection

The OCDM Rx comprises a demultiplexer, photo-detectors (PDs), and a decoder. Demultiplexed frequency components are detected at each PD. As both phases and polarization states are matched at the Tx among OCDM signals and the multi-frequency CW light, neither the phases nor polarization states need to be controlled for homodyne detection at the Rx. Due to homodyne detection, the influence of beat noise is negligible [4].

The output of the PDs is added or subtracted according to the orthogonal code assigned to the decoder. Due to the orthogonality of the code, MAI is eliminated and only the desired data is successfully demodulated. Therefore, the proposed OCDM technique is tolerant to both the beat noise and MAI.

Numerical simulation

To evaluate the performance of the proposed technique, numerical simulation was carried out assuming 1.5 Gbit/s × 3 user OCDM transmission. Fig. 2 shows the bit error rate (BER) characteristics against the loss between the Tx end and the PDs in the Rx. P_{CW} at the Tx end is fixed at 0 dBm. When ΔP (= P_{CW} - P_S) was 20 dB, the power penalty for the BER of 10^{-12} due to the code multiplexing was only 1.2 dB which shows sufficient suppression of the beat noise. Furthermore, the acceptable loss can be expanded with a larger P_{CW} value.

978-1-4244-2229-6/08/$25.00 ©2008 IEEE

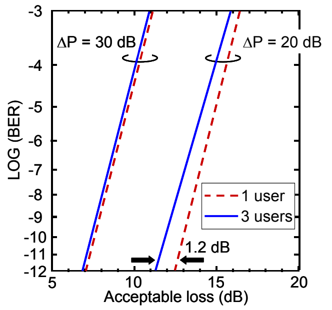

Fig. 2 BER characteristics ($\Delta P = P_{CW} - P_S$)

Experiment

Fig. 3(a) shows the experimental configuration for the phase-matched signal transmitter that consists of a power-flattened multi-frequency light source and a planar lightwave circuit integrated with $LiNbO_3$ modulators (PLC-LN module) comprising three OCDM Txs. The 12.5-GHz spaced multi-frequency light was generated by multiplexing the output of three distributed feedback laser diodes (DFB-LDs) through an arrayed waveguide grating (AWG). The multi-frequency light was divided, and all but one were launched to the OCDM Txs, while the remaining one was coupled to the OCDM signals.

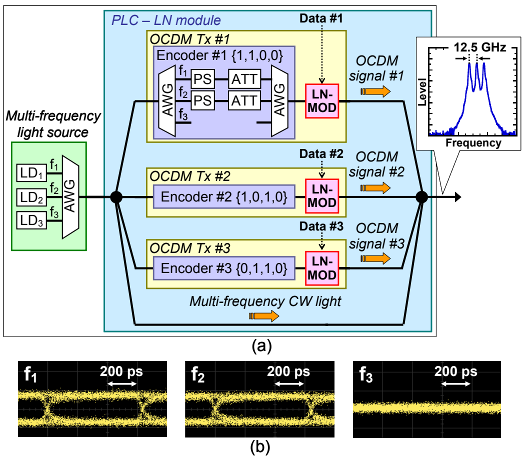

Fig. 3 (a) Experimental configuration for phase-matched signal transmitter (b) OCDM signal #1 {1,1,0,0}

The OCDM Tx integrates an encoder and a LN-modulator (MOD) using the hybrid assembly technique [5]. All frequency components extracted through the encoder were simultaneously modulated with the 1.5-Gbit/s data. The Hadamard codes, {1,1,0,0}, {1,0,1,0} and {0,1,1,0}, were used as orthogonal codes. Since the last chip of each code is "0," OCDM signals with the code length of four can be generated. Fig. 3(b) shows the eye pattern of each frequency component of OCDM signal #1. Spectral amplitude encoding can be achieved following the assigned code, {1,1,0,0}. Each encoder is equipped with phase shifters (PSs) and attenuators (ATTs). The optical power of the multi-frequency CW light was set to be higher than that of each OCDM signal by 18 dB with the ATTs.

At the receiver, the input lights were demultiplexed through an AWG, and detected with PDs. The output of the each PD was sampled and digitized individually with an analog-to-digital converter (ADC) using a real time oscilloscope (Tektronix DPO71604), and added or subtracted according to the orthogonal code assigned to the decoder.

Initially, to confirm the elimination of MAI, each OCDM signal was input to the OCDM Rx #1 without multiplexing. As shown in Fig. 4, when OCDM signal #1 is input, the desired data can be successfully demodulated. On the other hand, in the case of only OCDM signal #2, no output was obtained, which clearly shows that MAI can be removed effectively.

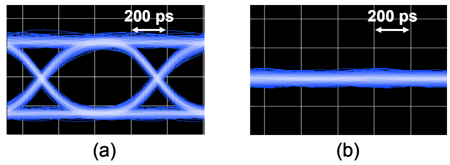

Fig. 4 Eye patterns of OCDM Rx #1 output (a) OCDM signal #1 (b) OCDM signal #2

Next, the performance was evaluated in the case that three signals were asynchronously multiplexed. Fig. 5(a) shows the PD_1 output. Since the first frequency chips of OCDM signals #1 and #2 correspond to "1," an eye pattern similar to that for multi-level modulation was obtained. Fig. 5(b) shows the decoder output. Error free operation (BER $< 10^{-12}$) was stably achieved for more than an hour, which verifies the sufficient suppression of the beat noise.

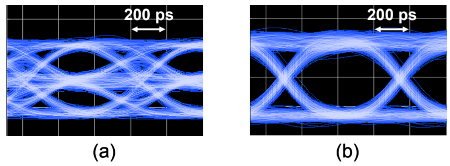

Fig. 5 Eye patterns when three OCDM signals are multiplexed (a) PD_1 output (b) Decoder output

Conclusion

We proposed a phase-matched OCDM technique based on multi-frequency self-homodyne detection, which can effectively suppress both MAI and the beat noise using a simple receiver configuration. Simulation results assuming 1.5 Gbit/s × 3 user OCDM transmission show that the power penalty for the BER of 10^{-12} is 1.2 dB when ΔP is 20 dB. Based on the simulation results, the OCDM transmission was experimentally demonstrated using the developed PLC-LN module. Error free operation was achieved and the effectiveness of the proposed technique was clearly confirmed.

References

1. E. D. J. Smith et al., Electron Lett., vol. 31, no. 17, pp. 1469-1470, 1995.
2. X. Wang et al., J. Lightwave Technol., vol. 22, no. 10, pp. 2226-2235, 2004.
3. A. T. Phan et al., J. Optical Networking, vol. 4, no. 10, pp. 621-631, 2005.
4. S. Kaneko et al., ECOC'07, P088, 2007.
5. T. Yamada et al., OFC'08, OThC3, 2008.