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Coherence-multiplexing experiment with 10-Gsymbol/s BPSK and QPSK signals using spectrum-sliced ASE

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Abstract: Fiber-optic coherence multiplexing of 10-Gsymbol/s BPSK and QPSK signals was experimentally demonstrated for the first time. Spectrum-sliced amplified spontaneous emission (ASE) was used as a light source, and two-channel signals were multiplexed. The reference signal was polarization-multiplexed with the modulated signals and transmitted through an optical fiber. At the receiver side, we successfully retrieved the channels by properly adjusting the time shift between the reference signal and the multiplexed signals using a DGD generator. BER performances of $< 10^{-4}$ for BPSK and $< 10^{-3}$ for QPSK were obtained without using error correction.

Keywords: coherence multiplexing, optical fiber communications, QPSK, self-homodyne, ASE noise

Classification: Fiber-optic communication

References

[1] P. Cielo and C. Delisle, "Multiplexing in optical communications by interferometry with a large path-length difference in white light," *Can. J. Phys.*, vol. 54, no. 23, pp. 2322–2331, 1976.

[2] J. L. Brooks, R. H. Wentworth, R. C. Youngquist, M. Tur, B. Y. Kim, and H. J. Shaw, "Coherence multiplexing of fiber-optic interferometric sensors," *J. Lightw. Technol.*, vol. LT-3, no. 5, pp. 1062–1072, Oct. 1985.

[3] R. H. Wentworth, "Theoretical noise performance of coherence-multiplexed interferometric sensors," *J. Lightw. Technol.*, vol. 7, no. 6, pp. 941–956, June 1989.

[4] Z.-G. Guan, D. Chen, and S. He, "Coherence multiplexing of distributed sensors based on pairs of fiber bragg gratings of low reflectivity," *J. Lightw. Technol.*, vol. 25, no. 8, pp. 2143–2148, Aug. 2007.

[5] D. W. Smith, P. Healey, G. P. Fry, and K. Clayton, "A frequency chirped heterodyne spread spectrum optical fibre multiple access technique," *Proc. European Conference on Optical Communication (ECOC1988)*, Brighton, U. K., pp. 82–85, Sept. 1988.

[6] D. A. Blair and G. D. Cormack, "Optimal source linewidth in a coherence multiplexed optical fiber communications system," *J. Lightw. Technol.*,

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vol. 10, no. 6, pp. 804–810, June 1992.
[7] M. J. L. Cahill, G. J. Pendock, and D. D. Sampson, “Hybrid coherence multiplexing/coarse wavelength-division multiplexing passive optical network for customer access,” *IEEE Photon. Technol. Lett.*, vol. 9, no. 7, pp. 1032–1034, July 1997.
[8] A. Meijerink, G. H. L. M. Heideman, and W. van Etten, “Balanced optical phase diversity receivers for coherence multiplexing,” *J. Lightw. Technol.*, vol. 22, no. 11, pp. 2393–2408, Nov. 2004.
[9] A. Meijerink, R. O. Taniman, and W. van Etten, “Coherence-multiplexed optical RF feeder networks,” *J. Lightw. Technol.*, vol. 25, no. 11, pp. 3396–3406, Nov. 2007.
[10] S. Takeda, K. Tsukamoto, and N. Morinaga, “Proposal of coherence multiplexed optical communication system using balanced receiver and its application for space transmission,” *IEICE Trans. Commun. (Japanese edition)*, vol. J77-B-I, no. 3, pp. 158–171, March 1994.
[11] M. Nakamura, Y. Kamio, G.-W. Lu, and T. Miyazaki, “Ultimately phase-noise tolerant QPSK homodyne using a spectrum-sliced ASE light source,” *IEICE Electron. Express*, vol. 4, no. 13, pp. 406–410, July 2007.

1 Introduction

Coherence multiplexing (CM) is an optical multiplexing scheme categorized as a kind of optical code division multiplexing (OCDM) in which the noise of a broadband light source is used as a random code sequence [1]. It is expected to be used in inexpensive and comparatively small-scale network systems. CM has been studied for some applications such as fiber-optic sensor systems [2, 3, 4] and optical fiber communication systems [5, 6, 7, 8, 9]. However, it has been shown that fluctuation of the fiber path-length changes the phase difference between the modulated and reference signals and seriously degrades the performance of the system [6]. Consequently, to the authors' best knowledge, experiments involving CM systems have been demonstrated only with low transmission speeds of less than 100 Mbit/s [5, 7]. Using phase diversity receivers for CM is one way to overcome this problem [8]. In our experiment, we successfully realized a stable reference by employing a polarization-multiplexed reference signal that is transmitted to the receiver side together with the modulated and multiplexed signals through an optical fiber. The modulated signals were 10-Gsymbol/s binary phase-shift keying (BPSK) and quadrature phase-shift keying (QPSK) signals. The method of using a the polarization-multiplexed reference signal has been previously proposed, and theoretically analyzed, for free-space optical communication systems [10]. However, no experimental study has yet been conducted. In our scheme, the time shift of the reference signal is properly adjusted by a differential-group-delay (DGD) generator. The intended signal can be retrieved by using a self-homodyne receiver that consists of only a polarization beam splitter and a balanced photo-detector.

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2 Experimental setup

Figure 1 shows the experimental setup for 10-Gsymbol/s coherence-multiplexed BPSK and QPSK modulation/demodulation. In the experiment, spectrum-sliced amplified spontaneous emission (ASE) from an erbium-doped fiber amplifier (EDFA) was used as a broadband light source for CM. The bandwidth of the optical band-pass filter (OBPF) for the ASE spectral slicing was optimized to 3 nm by monitoring the receiver sensitivity [11]. The center wavelength of the OBPF was 1551 nm. The spectrum-sliced lightwave was linearly polarized through a polarizer and introduced into a QPSK modulator. The modulator had an integrated construction consisting of two straight-line phase modulators connected in tandem, where one was used for $0 - \pi$ modulation and the other for $0 - \pi/2$. The modulator had an effective modulation capability only for the TM polarization component of the input lightwave. The TE polarization was left unmodulated to serve as the reference signal. The modulation was encoded by applying DATA1 for $0 - \pi$ and DATA2 for $0 - \pi/2$ at 10-Gsymbol/s with a pseudorandom binary sequence (PRBS) of $2^7 - 1$, resulting in a 20-Gbit/s QPSK optical signal. A 10-Gbit/s BPSK signal could also be generated by turning DATA2 off. A 20-bit delay between DATA1 and DATA2 was employed to de-correlate the two modulation signals, which originated from the same data generator. The DGD of the QPSK modulator (17 ps) was compensated for by a variable DGD generator (DGD1) composed of polarization-maintaining fibers (PMFs). To realize two-channel multiplexing, the modulated signal was split in two by a half mirror (HM). One channel (Ch2) was delayed by 200 ps for de-correlation, which is much larger than the coherence time of the prepared spectrum-sliced ASE light source (2.7 ps), and recombined with the other one (Ch1). The delay path included a polarizer to cut off the duplicated reference signal. The delay path was constructed of stable free-space optical components. The receiver consisted of manual polarization controllers (PC2, PC3), a DGD generator (DGD2), a PBS, and balanced photo-detectors (PDs) with

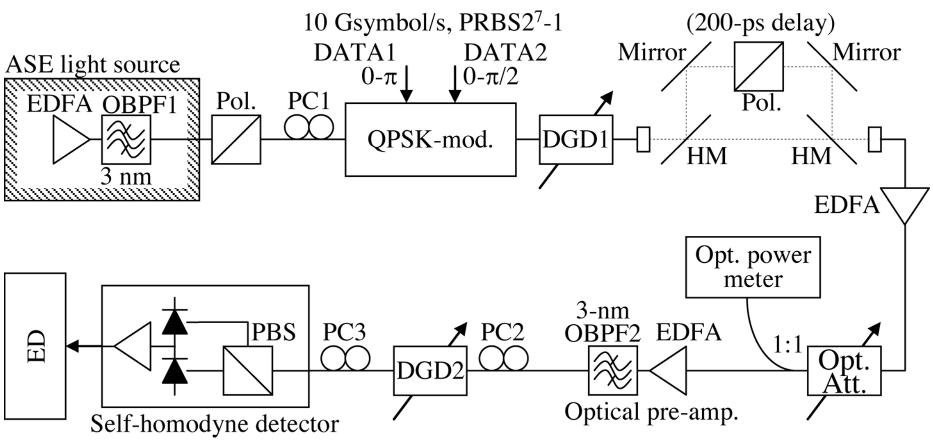

Fig. 1. Experimental setup for 10-Gsymbol/s coherence-multiplexed BPSK and QPSK modulation/demodulation.

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a RF pre-amplifier. PC2 and PC3 were used not only to control the polarizations, but also to bring about a $\pi/2$ phase difference to select in-phase (I) and quadrature (Q) data components of the QPSK signal. The time shift of the reference signal was adjusted by DGD2 to retrieve the intended optical channel (Ch1 or Ch2). The PBS worked to coherently mix the two polarization components of the multiplexed optical signals and the reference signal. The bit error rate (BER) performance was measured with an error detector (ED).

3 Results and discussion

Figures 2 (a) and (b) show the eye-diagrams of the retrieved 10-Gsymbol/s BPSK signals of Ch1 and Ch2, respectively. To select Ch1, DGD2 was adjusted to 0 ps. Clear eye-opening could be observed in spite of the noisy broadband light source, thanks to the phase-noise cancelling capability of the self-homodyne setup [11]. However, when selecting Ch2, where DGD2 was adjusted to 200 ps, the eye-opening was smaller than that of Ch1 because of the inadequate precision of the DGD generated by DGD2. Figure 2 (c) and (d) show the eye-diagrams of the retrieved 10-Gsymbol/s QPSK signals of Ch1 and Ch2, respectively. We could observe a clear eye-opening in this case as well. For Ch2, a smaller eye-opening was observed for the same reason as in the BPSK case.

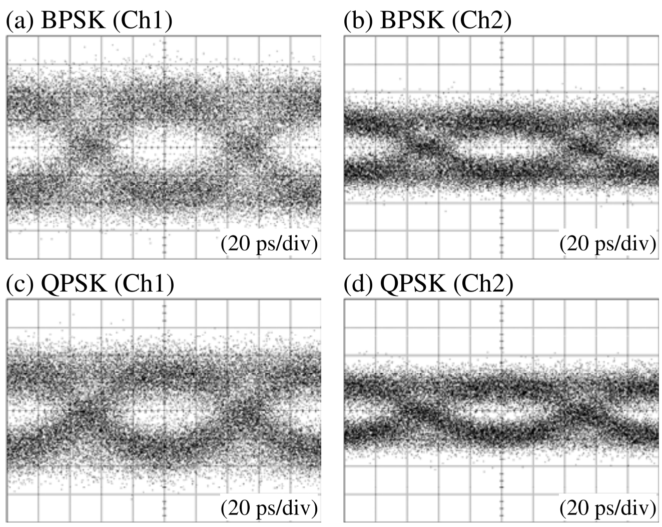

Fig. 2. Eye-diagrams of the retrieved 10-Gsymbol/s signals: (a) BPSK (Ch1), (b) BPSK (Ch2), (c) QPSK (Ch1), (d) QPSK (Ch2).

Figure 3 (a) shows the BER performance obtained in the experiment. Closed and open circles denote the BER performances of BPSK for Ch1 and Ch2, respectively. Closed and open triangles denote the BER performances for QPSK of Ch1 and Ch2, respectively. Although an error-floor was observed in both cases, a BER of less than 10^{-3} could be attained without using error correction. In the case of BPSK, the BER performance of Ch2

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was worse than that of Ch1 by about 1 dB at a BER of 10^{-3}. In the case of QPSK, however, the BER of Ch2 was worse than that of Ch1 by about 6 dB. This receiver sensitivity degradation of Ch2 will be improved by employing a DGD generator with higher precision. Figure 3 (b) shows the BER performance obtained by numerical simulation for 10-Gsymbol/s BPSK signals. We calculated the BER, while changing the number of multiplexed channels. Closed circles denote case of two-channel multiplexing. In the numerical simulation, we observed a BER with an error floor having a similar shape to that of the experimental result, whereas the receiver sensitivity at a BER of 10^{-3} was about 4 dB better than that of the experiment. For multiplexing of up to five channels in the simulation, we could obtain a BER performance of less than the threshold (2×10^{-3}) of enhanced forward error correction (FEC), which enables a post-FEC BER of less than 10^{-16} with an additional 7% overhead.

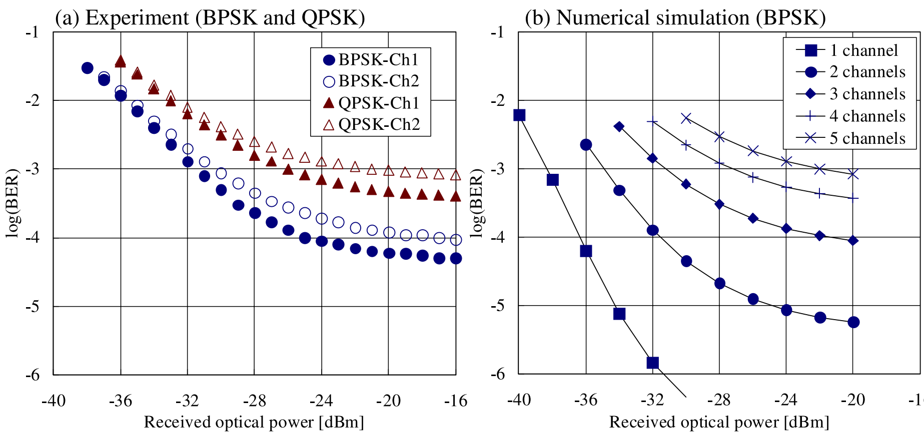

Fig. 3. BER performances. (a) Obtained in the experiment involving two-channel multiplexing of 10-Gsymbol/s BPSK and QPSK signals. (b) Obtained in the numerical simulation for 10-Gsymbol/s BPSK signals, while changing the number of multiplexed channels.

4 Conclusion

We experimentally demonstrated fiber-optic CM of 10-Gsymbol/s BPSK and QPSK signals. BER performances of less than 10^{-4} and 10^{-3} were attained without using error correction for two-channel multiplexing of BPSK and QPSK signals, respectively. It was shown that the scheme using a polarization-multiplexed reference signal is effective to realize stable self-homodyne operation, as well as phase diversity [8]. The results will encourage the application of CM to future cost-effective fiber-optic networks using inexpensive broadband light sources.

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