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20-Gbit/s QPSK self-homodyne transmission experiment using a multi-wavelength Fabry-Perot laser diode

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Abstract: We experimentally demonstrated phase-noise-tolerant 20-Gbit/s QPSK self-homodyne transmission over 80 km using a spectrum-sliced lightwave from an inexpensive Fabry-Perot laser diode (FP-LD). We employed an optical phase-noise cancellation technique based on self-homodyne detection using a polarization-multiplexed pilot-carrier. A BER of $< 10^{-8}$ after 80-km transmission was successfully attained without using error correction. To the authors' best knowledge, this is the first experimental demonstration of multi-level modulation/demodulation using an FP-LD.

Keywords: optical fiber communications, QPSK, self-homodyne, spectral slicing, Fabry-Perot laser diode
Classification: Fiber-optic communication

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1 Introduction

Recently, multi-level modulation formats such as differential quadrature phase-shift keying (DQPSK) have received increasing interest due to their high spectral efficiency and large tolerance to dispersion and differential group delay (DGD) [1]. However, multi-level modulation formats require a laser linewidth narrower than a few MHz for 10 Gsymbol/s [2]. Therefore, low-cost broadband light-sources are not suitable for these modulation schemes. We have previously proposed and experimentally demonstrated phase-noise-tolerant QPSK self-homodyne transmission at a modulation speed of 10 Gsymbol/s using a polarization multiplexed pilot-carrier [3]. This scheme does not require any critical feedback loop [4] or fast electronic devices [5], and is expected to relax the complex design of encoders/decoders which are usually required in DQPSK. We have also experimentally demonstrated the phase-noise-tolerant characteristics of the scheme by using spectrum-sliced amplified spontaneous emission (ASE) as a light source in a QPSK transmission system [7]. In the present paper, we describe our experimental demonstration and investigation of the characteristics of 20-Gbit/s (10-Gsymbol/s) QPSK transmission with a Fabry-Perot laser diode (FP-LD) as a light source. Using the inexpensive FP-LD, better bit error rate (BER) performance could be obtained compared with use of ASE. To the authors' knowledge, this is the first experimental demonstration of multi-level modulation/demodulation using an FP-LD as a cost-effective multi-wavelength light-source.

2 Experimental setup

In the proposed self-homodyne scheme, a pilot carrier, which provides an absolute optical phase reference, is polarization-multiplexed with an optical signal modulated in a multi-level format. Such a modulation scheme can be realized by using an optical modulator having an effective modulation capability only for the TM polarization component of the input lightwave, while leaving the TE component unmodulated. At the receiver side, the polarization state of the pilot carrier is rotated by 90° to perform self-homodyne detection; phase noise cancellation is performed because the pilot carrier has identical phase noise to the optical signal [3]. Figure 1 (a) shows the experimental setup using an FP-LD as a broadband light-source. Continuous-wave (CW) light from a thermally controlled FP-LD was filtered using a wavelength-tunable optical band-pass filter (OPBF) with an optical bandwidth of 1 nm. The spectrum-sliced optical beam was introduced into the pilot-carrier QPSK modulator, which had modulation capability only for the

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TM component. The modulator included two integrated straight-line phase modulators in tandem, where one was used for 0–π modulation and the other for 0–$\pi/2$. The modulation was encoded by applying DATA1 for 0–π 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 optical signal. A 20-bit delay between DATA1 and DATA2 was employed to de-correlate the two modulation signals, because they originated from the same data generator. A variable DGD generator composed of polarization-maintaining fibers (PMFs) was introduced to compensate for the DGD of the modulator (17 ps); the other optical components had negligibly small DGD of less than about 1 ps. A prepared 80-km transmission line consisted of a 58-km length of standard single mode fiber (SMF) and a 22-km length of slope-compensating dispersion-compensating fiber (DCF). The dispersion slope of the entire transmission line was less than 0.015 ps/nm^2/km. The PMD coefficients of the SMF and the DCF were 0.05 ps/km$^{0.5}$ and 0.03 ps/km$^{0.5}$, respectively. At the receiver side, a $LiNbO_3$-based polarization beam splitter (PBS) hybrid module (LN-PBS hybrid) was employed for homodyne detection by 90°-polarization rotation of the pilot carrier [3].

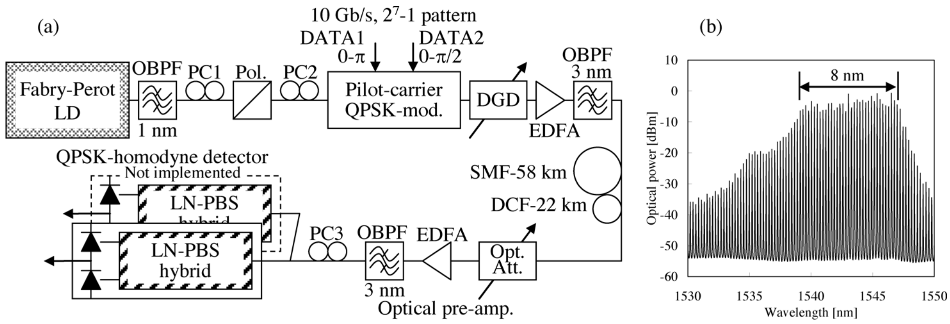

Fig. 1. (a) Experimental setup for FP-LD-based QPSK homodyne transmission system with polarization-multiplexed pilot carrier and (b) spectrum of the FP-LD.

3 Results and discussion

Figure 1 (b) shows the spectrum of the FP-LD used in the experiment (resolution bandwidth of 0.01 nm). The mode spacing was about 0.23 nm. The spectral bandwidth was defined by the spacing between points where the envelope drops by 3 dB, which was about 8 nm (1 THz), covering the region from 1539 nm to 1547 nm. The spectrum slicing was performed in this spectral bandwidth. First, we measured the receiver sensitivity penalty (defined at the BER of 10^{-7}) versus wavelength in a back-to-back (BtB) condition. The result is shown in Fig. 2 (a). We observed some large penalty at the edge of the 3-dB bandwidth. However, the penalty was less than 1 dB in a bandwidth range of about 4 nm. Next, we increased the introduced DGD to characterize the DGD-tolerance of the system. Here ΔDGD is defined as the

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detuned DGD value from the compensating condition where the modulator-DGD was completely compensated. The measurement results are shown in Fig. 2 (b). For comparison, Fig. 2 (b) also shows the DGD-tolerance when using a tunable external-cavity laser diode (EC-LD), having a linewidth of about 200 kHz, as the light source. The center wavelength of both light sources was set at 1542.5 nm. The results show that the DGD-tolerance was not deteriorated by the large bandwidth of the spectrum-sliced light source in comparison with the EC-LD case. Figure 3 shows the BER characteristics when a wavelength of 1542.5 nm was selected. A BER of less than 10^{-9} was achieved without any error correction in a BtB condition, whereas some degradation of the BER performance was observed in the 80-km transmission. In both cases, however, clear eye-openings were observed, as shown in the insets in the figure. The power penalty for the transmission was less than 2 dB at a BER of 10^{-8}. It should be noted that the BER characteristics were improved compared with the case using a spectrum-sliced ASE light source, which gave a BER higher than 10^{-7} in the BtB condition [7]. We also attempted DQPSK detection with an integrated one-bit delay line using the same experimental setup. Here, the pilot-carrier power was eliminated by properly adjusting polarization controller 2 (PC2) in Fig. 1 (a). The observed eye diagram is shown in the inset in Fig. 3. The BER characteristics could not be measured due to synchronization loss, because DQPSK requires a linewidth narrower than few MHz [2]. The experimental results clearly show the advantage of the linewidth-tolerant characteristics of the proposed QPSK homodyne scheme and suggest that the scheme allows us to employ a spectrum-sliced broadband light source instead of an expensive tunable narrow-linewidth source.

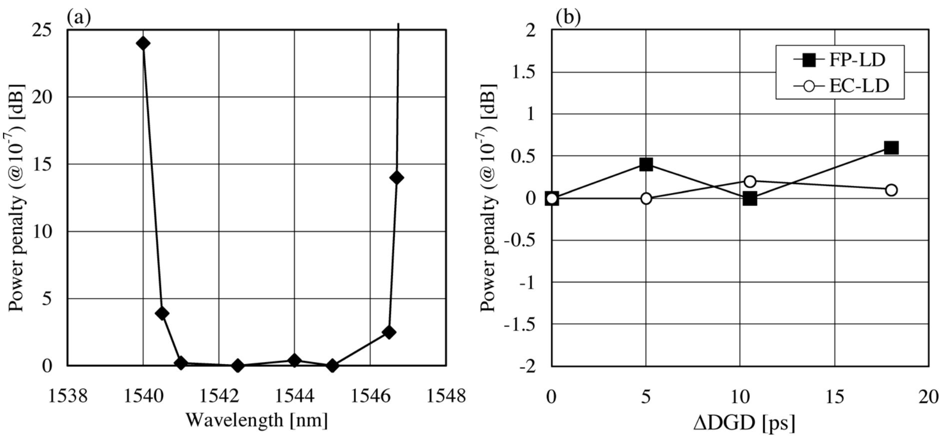

Fig. 2. Receiver sensitivity penalty versus (a) center wavelength of the spectral slicing and (b) increased DGD ($\lambda = 1542.5$ nm) in a BtB condition.

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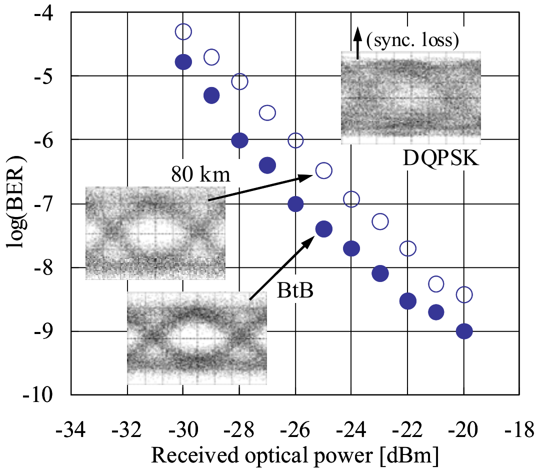

Fig. 3. BER characteristics before (closed circles) and after (open circles) 80-km transmission using a 1-nm spectrum-sliced FP-LD light source (λ = 1542.5 nm.).

4 Conclusion

We experimentally demonstrated phase-noise-tolerant 20-Gbit/s QPSK self-homodyne transmission over 80 km using a 1-nm spectrum-sliced FP-LD. The phase noise of the FP-LD was effectively cancelled by the self-homodyne detection using a polarization-multiplexed pilot-carrier. BER characteristics were studied in a BtB condition and in the transmission. The BER was improved compared with the case using a spectrum-sliced ASE light source. We hope that the results will encourage the application of inexpensive FP-LDs to future high-speed, cost-effective fiber-optic network systems.

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