

DGD- and dispersion-tolerance of QPSK self-homodyne detection based on a polarization-multiplexed pilot carrier

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Abstract: We experimentally investigated DGD- and dispersion-tolerance of QPSK self-homodyne detection based on a polarization-multiplexed pilot carrier for both NRZ and RZ data formats. The results show that the tolerance is large enough to be used in deployed network systems. We also investigated receiver sensitivity penalty versus the ratio of pilot-carrier power to total optical power. The ratio had a detunable margin of as large as $\pm 15\%$ at around the optimum point of 50%.

Keywords: optical fiber communications, QPSK, self-homodyne, DGD, dispersion

Classification: Fiber-optic communication

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1 Introduction

Multi-level modulation formats, such as differential quadrature phase-shift keying (DQPSK), have been investigated to enhance spectral efficiency [1]. For further enhancement, such as that achievable using 8-PSK and beyond, synchronous homodyne detection using an absolute optical phase reference is required. Optical phase-locked loops (OPLLs) [2] and phase-diversity receivers employing bit-rate-compatible analogue-to-digital converters (ADCs) [3] have been proposed for this purpose. We previously proposed and experimentally demonstrated self-homodyne multi-level modulation/demodulation using a polarization-multiplexed pilot carrier as a phase-noise tolerant scheme without using any critical feedback control or fast electronic devices [4, 5]. In the present study, we experimentally investigated the tolerance of our QPSK self-homodyne scheme to differential group delay (DGD) and dispersion with both return-to-zero (RZ) and non-return-to-zero (NRZ) data formats. Furthermore, receiver sensitivity penalty versus ratio of pilot-carrier power to total optical power was also investigated. The results show the feasibility of practical deployment of our proposed scheme.

2 Experimental setup

The principle of the proposed QPSK self-homodyne detection using a polarization-multiplexed pilot carrier is shown in Fig. 1(a). A lightwave linearly polarized at around 45° is introduced into a dual-electrode LiNbO₃ optical phase modulator, which has an effective phase modulation capability only for the TM polarization component of the input lightwave. Optical QPSK modulation is encoded by applying DATA1 and DATA2 to the dual electrodes, whereas the TE polarization component remains unmodulated to act as a pilot carrier which provides an absolute optical phase reference in the self-homodyne detection [4]. At the receiver side, the polarization state of the pilot carrier is rotated by 90° to perform the QPSK self-homodyne detection. However, if the system components and/or transmission lines have DGD comparable to or larger than the RZ-pulse width, the homodyne detection cannot be performed efficiently, as shown in Fig. 1(a). Figure 1(b) shows the experimental setup used for investigating the DGD- and dispersion-tolerance characteristics of the QPSK self-homodyne technique. A lightwave from a continuous-wave (CW) external-cavity laser diode (EC-LD) emitting

at 1546.5 nm was introduced into the pilot-carrier QPSK modulator. The EC-LD had a linewidth of 200 kHz. An electro-absorption modulator (EAM) was employed for pulse carving. The generated RZ pulses had a full width at half maximum (FWHM) of 22.5 ps. The EAM was removed when measurements for NRZ were performed. The QPSK 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 optical signal. 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 modulated optical signal with a polarization-multiplexed pilot carrier was launched into a variable DGD-generator and a dispersion-generator consisting of polarization-maintaining fibers (PMFs) and single-mode fibers (SMFs), respectively. At the receiver side, a LiNbO₃-based polarization beam splitter (PBS) hybrid module (LN-PBS hybrid) was employed for the self-homodyne detection by 90°-polarization rotation of the pilot carrier [4].

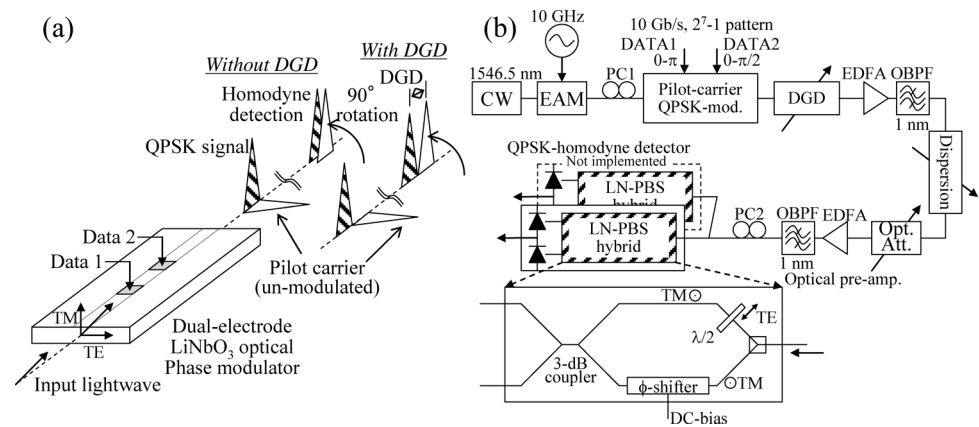


Fig. 1. (a) Principle of QPSK self-homodyne detection using a polarization-multiplexed pilot carrier and (b) experimental setup.

3 Results and discussion

Prior to the experiment, we measured the DGD of all the optical components. As a result, the pilot-carrier QPSK modulator had a DGD of 17 ps, whereas the others had negligibly small DGDs of less than about 1 ps. In this study, the fast axis of the variable DGD generator was adjusted to be coincident with the slow axis of the modulator so that we could observe the influence of the DGD-induced time shift between the modulated signal and the pilot carrier. During the experiment, the polarization state of the optical signal to the LN-PBS hybrid was manually controlled by using polarization controller 2 (PC2) in Fig. 1 (b).

First, we varied the introduced DGD and investigated the influence on the receiver sensitivity. Here, the dispersion was set to 0 ps/nm. Figure 2 (a) shows the receiver sensitivity penalty (defined at BER of 10^{-9}) of the detected

QPSK signal versus the introduced DGD. In the case of RZ (open circles), the power penalty increased as the DGD was varied from an optimum point of 17 ps where the modulator-DGD was completely compensated (i.e., the gross-DGD was 0 ps). The eye diagrams in the inset show that the eye opening of the RZ format was improved by the compensation. The DGD-tolerance to attain a power penalty of less than 1 dB was 13.3 ps, which corresponds to about 59% of the FWHM of the RZ pulses. In the case of NRZ (closed squares), however, the receiver sensitivity was almost insensitive to the DGD within the range of ± 15 ps. This is because the introduced DGD was much smaller than the coherence time of the lightsource, about 5 μ s, and did not degrade the coherency between the modulated signal and the pilot carrier. In both the RZ and NRZ cases, the DGD tolerance was large enough in comparison with practical DGD fluctuation of installed optical fiber cables [6]. We think that the phase-diversity technique is also applicable to our system to cope with the DGD fluctuation [3]. Next, we introduced dispersion while keeping the modulator DGD compensated. Figure 2(b) shows the receiver sensitivity penalty versus introduced dispersion. The dispersion-tolerances to attain a power penalty of less than 1 dB were larger than 170 ps/nm and 635 ps/nm for the RZ and NRZ data formats, respectively. The dispersion in a 1000-km link can vary by about 100 ps/nm over a 50°C temperature range [7]. The measured tolerance is thus large enough, especially for systems where dispersion is compensated properly. We also investigated the receiver sensitivity penalty versus the ratio of pilot-carrier power (P_{pilot}) to total optical power (P_t), to determine the optimum splitting ratio (P_{pilot}/P_t), which is sensitive to the polarization detuning of the introduced lightwave to the modulator. The ratio was measured for the NRZ format with both dispersion and gross-DGD set to zero. The measurement results are shown in Fig. 3. We found that a 50:50 splitting ratio between the pilot-carrier and the QPSK signal achieved the minimum power penalty. To attain a power penalty of less than 1 dB, the ratio has to be controlled within about $\pm 15\%$

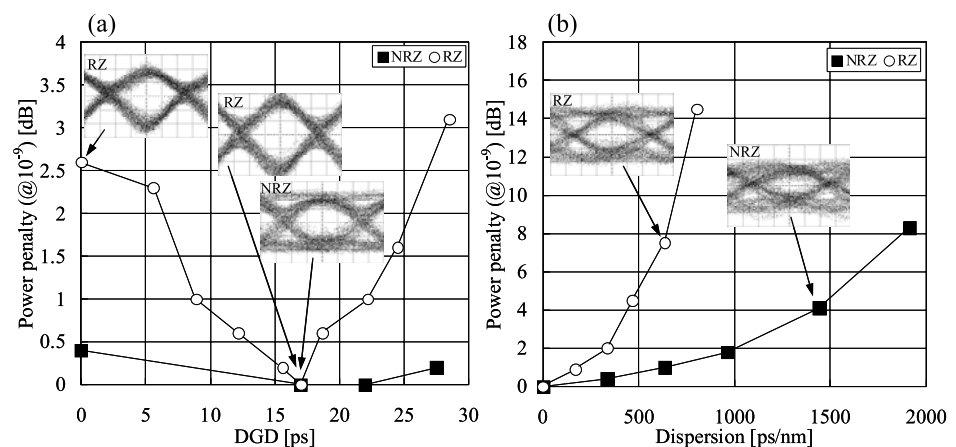


Fig. 2. Receiver sensitivity penalty (defined at BER of 10^{-9}) of detected QPSK signal versus (a) introduced DGD and (b) introduced dispersion.

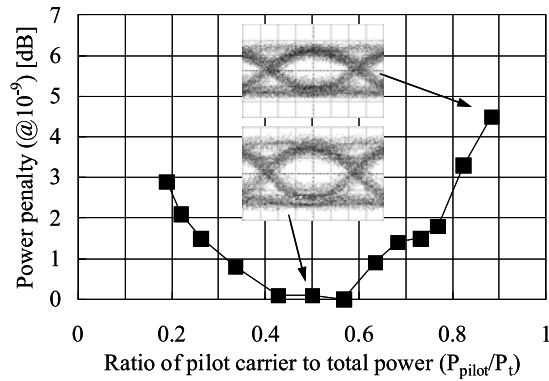


Fig. 3. Receiver sensitivity penalty (defined at BER of 10^{-9}) of detected NRZ-QPSK signal versus ratio of pilot carrier to total optical power.

at around the optimum point of 50%. This corresponds to a polarization control of $\pm 10^\circ$ around 45° in the linear polarization state. This large tolerance against polarization misalignment is available so long as dispersion and DGD are compensated.

4 Conclusion

We experimentally investigated DGD- and dispersion-tolerance of the proposed QPSK self-homodyne scheme for both NRZ and RZ data formats. The tolerance was large enough to be used in deployed network systems. It was also experimentally clarified that the optimum ratio of the pilot-carrier power to total optical power is 50%. The results show the feasibility of practical deployment of our proposed scheme.