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# Ultimately phase-noise tolerant QPSK homodyne using a spectrum-sliced ASE light source

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**Abstract:** We experimentally demonstrated ultimately phase-noise tolerant 20-Gbps QPSK-homodyne transmission over 160 km using a 3-nm spectrum-sliced ASE light source. We applied an optical phase noise cancellation technique based on self-homodyne detection using a polarization-multiplexed pilot-carrier, which included identical phase noise to that of modulated optical signal. BER of less than $1 \times 10^{-6}$ after the transmission was achieved. We also characterized DGD and dispersion tolerances. To the author's best knowledge, this is the first experimental demonstration of multi-bit-per-symbol modulation/demodulation using an incoherent ASE light source.

**Keywords:** optical communication, homodyne detection, phase modulation, phase shift keying, phase noise

**Classification:** Photonics devices, circuits, and systems

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## 1 Introduction

Multilevel modulation formats such as differential quadrature phase-shift keying (DQPSK) have received increasing interest due to their high spectral efficiency and large tolerance to chromatic dispersion and polarization mode dispersion (PMD) [1, 2, 3]. Multilevel modulation formats, however, are sensitive to phase noise and need a light source with a narrow linewidth, typically less than a few hundred kilohertz [2, 3]. We have proposed a linewidth-tolerant self-homodyne technique using a polarization-multiplexed pilot-carrier and experimentally demonstrated its phase noise cancellation capability using distributed-feedback laser diodes (DFB-LDs) with linewidth of up to 30 MHz [4]. However, the tolerance for much broader linewidth has not been investigated. In this study, we used an incoherent broadband light source based on spectrum-sliced amplified spontaneous emission (ASE), for the first time, to demonstrate ultimately linewidth tolerant 20-Gbps QPSK-homodyne (QPSK-H) 160-km transmission by applying the previously proposed polarization-multiplexed pilot-carrier technique [4, 5, 6]. Furthermore, we investigated the differential-group-delay (DGD) and dispersion tolerances for the scheme. The experimental results suggest the linewidth-tolerant capability by our scheme in higher-order multilevel modulation formats, such as M-ary PSK and quadrature amplitude modulation (M-QAM) format. The proposed scheme is also promising for realizing future high-speed and cost-effective optical network systems using incoherent broadband light sources [7].

## 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-bit-per-symbol format, e.g., QPSK. 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 polarization unmodulated [4]. 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 that of the modulated

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signal. However, if the system components and/or transmission lines have DGD comparable to or larger than the coherence time of the light source, the phase noise cancellation cannot be performed efficiently [8]. One notable point of this scheme is that the modulated optical signal is equivalent to that of polarization-shift-keying (PolSK), and it should be noted that the receiver can be constructed using inexpensive polarization beam splitters (PBSs) [6]. Figure 1 shows the experimental setup. An erbium-doped fiber amplifier (EDFA) serving as a broadband ASE light source and a narrowband continuous-wave (CW) light source with a linewidth of 200 kHz were prepared to generate a lightwave with an arbitrary optical signal-to-noise ratio (OSNR). The center wavelength of optical band-pass filters (OBPFs) was adjusted to 1546.5 nm, which was the same as that of the CW light source. Here, the bandwidths of the OBPFs for ASE spectral slicing as well as in the optical pre-amplifiers were optimized to be 3 nm by monitoring the receiver sensitivity for PSK-H when only ASE light source was used. The ASE slicing bandwidth almost agrees with the theoretically expected value for 10 Gbps [7]. The spectrum-sliced lightwave was linearly polarized through a polarizer and a polarization controller (PC) and introduced into a pilot-carrier QPSK modulator. The modulation was encoded by applying DATA1 for 0-$\pi$ and DATA2 for 0-$\pi/2$ at 10 Gbps with a pseudorandom binary sequence (PRBS) of $2^7$-1, resulting in a 20-Gbps QPSK optical signal. A 10-Gbps binary PSK (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. A variable DGD generator composed of polarization-maintaining fibers (PMFs) was introduced to compensate for the DGD of the modulator (17 ps) [8]. A prepared 160-km transmission line consisted of two 58-km lengths of standard single mode fibers (SMFs) and two 22-km lengths of slope-

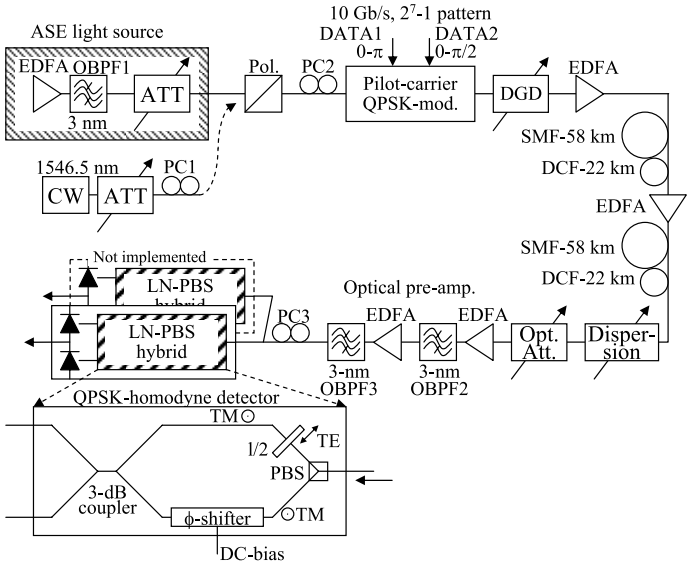



**Fig. 1.** Experimental setup for QPSK self-homodyne detection using spectrum-sliced ASE light source.

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compensating dispersion-compensating fibers (DCFs). 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. A variable-dispersion generator was used only in a dispersion-tolerance characterization process. 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 because the module had $\phi$-shifter which made the adjustment of the homodyne much easier in this preliminary experiment [4]. However, this LN-PBS hybrid module can be replaced by using a PBS to realize simple and inexpensive receiver configuration [6].

## 3 Results and discussion

Figure 2 (a) shows the receiver sensitivity (at a BER of $10^{-6}$) for 20-Gbps QPSK-H (closed circles) and 10-Gbps BPSK-H (closed triangles) versus the OSNR of the light source in a BTB condition. Here, the OSNR of the light source was measured with an optical spectrum analyzer (resolution bandwidth of 0.1 nm) at the output of the polarizer. The receiver sensitivities for both QPSK-H and BPSK-H degraded gradually by decreasing the OSNR below 30 dB. However, a clear eye-opening was observed in the region where the OSNR was negative and even when the CW light source was turned off because of the phase-noise cancellation capability. For comparison, we also attempted DPSK detection using the same experimental setup but with the LN-PBS hybrid module replaced by a one-bit delay line interferometer; here, the pilot-carrier power was eliminated by adjusting PC2. The results are indicated by the open squares in Fig. 2 (a). In this case, DPSK detection was not possible in a region where the OSNR was less than about 30 dB. If DQPSK was employed, the receiver sensitivity must have been degraded at a higher OSNR than 30-dB. In the measurements below, the CW laser was kept off and only the ASE light source was used. Figures 2 (b) and (c)

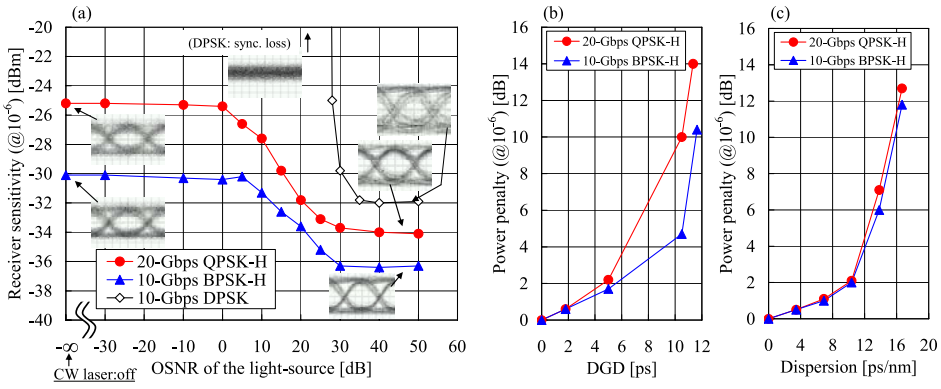



**Fig. 2.** (a) Received optical power sensitivity versus OSNR of light source (Resolution bandwidth: 0.1 nm) and receiver sensitivity penalty versus introduced DGD (b) and dispersion (c) in a BTB condition.

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shows the receiver sensitivity penalty versus introduced DGD and dispersion in a BTB condition, respectively. The DGD-tolerance to attain a power penalty of less than 1 dB was as small as about 3 ps, which is nearly equal to the coherence time of the 3-nm sliced ASE light source. The dispersion-tolerance to attain a power penalty of less than 1 dB was about 7 ps/nm for both QPSK-H and BPSK-H. This dispersion-tolerance was restrained by the spectrum-slice bandwidth of as large as 3 nm. Figure 3 shows BER characteristics for QPSK-H and BPSK-H before and after 160-km transmission. Eye diagrams after 160-km transmission are shown in the inset. A BER on the order of $10^{-8}$ was achieved without any error correction in BTB conditions, whereas some power penalty was observed in the transmission of QPSK-H. We think the phase-diversity technique [2] is also applicable to our system to cope with DGD fluctuations experienced in practice.

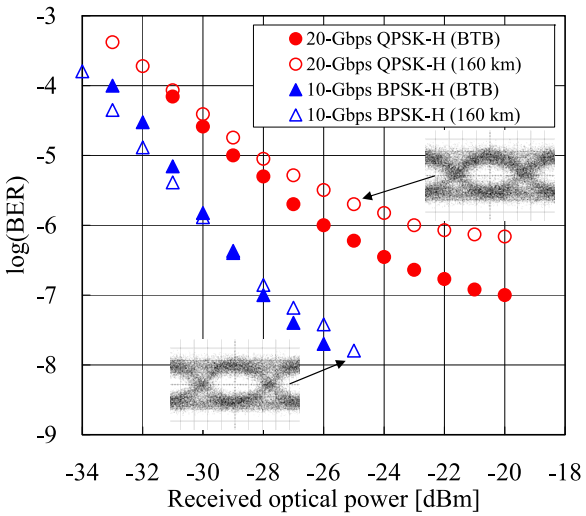



**Fig. 3.** BER characteristics before (closed symbols) and after (open symbols) 160-km transmission using a 3-nm spectrum-sliced ASE light source.

## 4 Conclusion

We have experimentally demonstrated ultimately linewidth-tolerant 20-Gbps QPSK-H transmission over 160 km using a 3-nm spectrum-sliced ASE light source. The phase noise of ASE was effectively cancelled by the proposed self-homodyne detection using a polarization-multiplexed pilot-carrier. The results indicate that the proposed self-homodyne scheme is expected to offer a solution to improve the performance of multilevel transmissions systems, such as optical M-PSK or M-QAM where stringent linewidth requirement is indispensable, and is applicable to future high-speed and cost-effective optical network systems using incoherent broadband light sources.

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