Coherent Detection Using Incoherent Spectrally Sliced ASE With a Polarization Insensitive Self-Homodyne Receiver

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Abstract *We successfully demonstrate 10 & 20 GBaud QPSK and 5 & 10 GBaud 16QAM after 1 km transmission using incoherent spectrally sliced ASE as a light source and a self-homodyne detection receiver.*

Introduction

In recent years, coherent detection has become increasingly competitive for short-reach applications, such as data-center interconnects, by supporting high spectral efficiency modulation[1]. In this context, the use of polarization-insensitive self-homodyne detection (SHD), also referred to as stokes vector receiver[2], has been proposed to reduce costs by eliminating the need for a receiver local oscillator laser and simplifying the required digital signal processor (DSP)[3]. However, although the SHD requirement for low linewidth sources is reduced or removed, these techniques still require the use of coherent laser light sources. The use of incoherent light sources, such as light-emitting diodes or spectrally sliced amplified spontaneous emission (ASE) noise has been considered in the 1980's and 1990's for intensity-modulated directly-detected (IM-DD) systems[4]. The spectrally sliced ASE has been demonstrated in WDM applications owing to the cost reduction of multiple-wavelength light sources[5-6]. The data rate of at least 10 Gb/s per channel can be demonstrated with the IM-DD system. In[7], the coherent receiver can retrieve the 12.5 Gb/s data signals even applying the spectrally sliced light source, and the offset optical filtering was applied to suppress the excess intensity noise. However, its application to coherent systems has had limited interest, possibly due to the difficulty in recovering the higher modulated information signal such as 16QAM. Nevertheless, SHD systems have been shown to accommodate the use of spectrally sliced ASE[8], albeit with significant limitations with regard to manual polarization alignment.

Here, we demonstrate the use of spectrally sliced ASE noise as the light source to transmit and coherently detect 10 and 20 GBaud quadrature-phase-shift-keyed (QPSK) as well as 5 and 10 GBaud 16-ary quadrature-amplitude-modulation (QAM) signals. The signals are produced by modulating a 1 nm bandwidth spectrally sliced ASE noise lightwave, which is transmitted along with a polarization-multiplexed unmodulated replica, as shown in Fig. 1. After transmission, the SHD receiver can digitally recover the field of the information signal with a linear combination of the received polarization components as well as their differential intensity, implemented with a multiple-input single-output (MISO) sub-system. We evaluate the system performance in back-to-back and after 1 km transmission. The results of this work demonstrate the applicability of incoherent lightwaves in low-cost, short-reach coherent systems, opening up the possibility of a new family of light sources for optical communications.

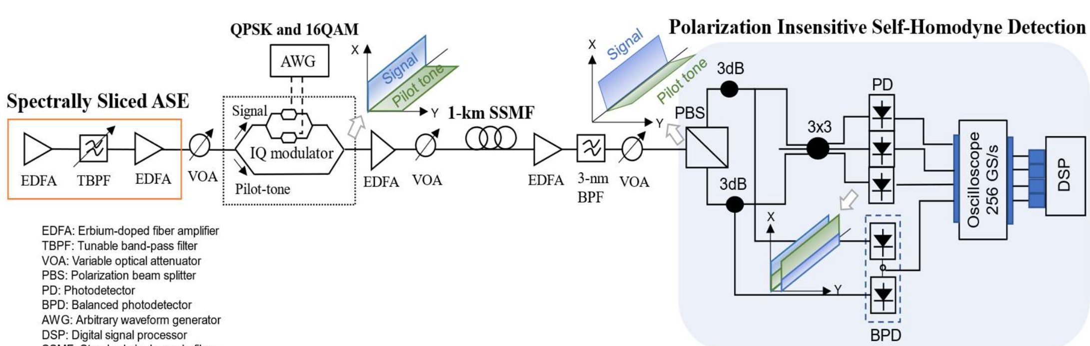

Fig. 1: Experimental setup of spectrally sliced ASE and SHD receiver applied in the self-homodyne system

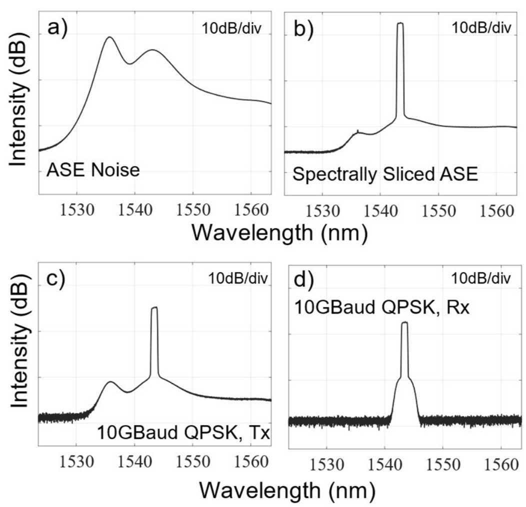

Fig. 2: Spectra of a) ASE noise, b) spectrally sliced ASE, c) 10 Gbaud QPSK at the transmitter, and d) 10 Gbaud QPSK at the receiver.

Experimental Demonstration

Fig. 1 shows the experimental setup. The spectrally sliced ASE was produced using two erbium-doped fiber amplifiers (EDFAs) before and after a tunable band-pass filter (TBPF) centered at 1543.5 nm. The ASE power was adjusted by a variable optical attenuator (VOA) before a dual-polarization IQ modulator. The latter modulated only one of the polarization components of the input ASE with an information signal, leaving the remaining polarization component unmodulated. The modulator was driven by a 260 GS/s arbitrary waveform generator (AWG) to produce 10 or 20 GBaud QPSK signals, or 5 or 10 GBaud 16-QAM signals. An EDFA followed by a VOA was used to adjust the launch power before transmission over 1 km of standard single-mode fiber (SSMF). At the receiver, an EDFA amplified the signal before a 3 nm BPF used to limit the noise bandwidth. The

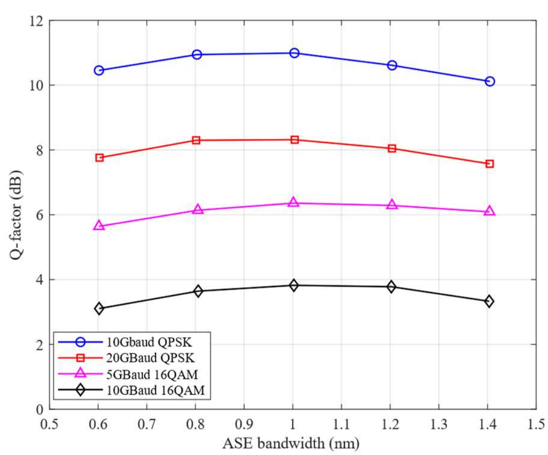

Fig. 3: ASE bandwidth of QPSK & 16QAM.

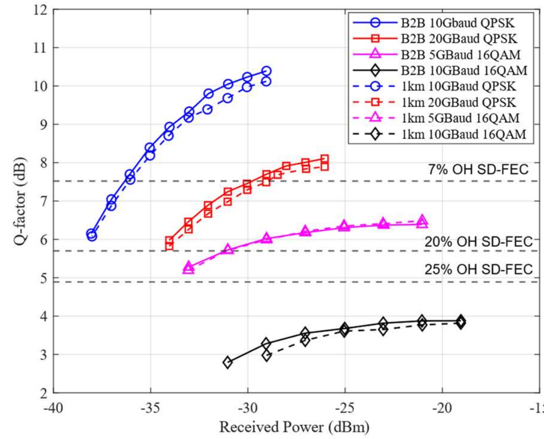

Fig. 4: Back-to-back & 1-km transmission cases of QPSK & 16QAM.

SHD receiver was previously described in[3] and consisted of a polarization beam splitter (PBS) to split the incoming polarization components, which were then mixed with the information signal and pilot tone at a 3x3 coupler and detected by three photodetectors (PDs). An additional balanced photodetector (BPD) was used to detect the difference in power between the polarization components at the PBS output. A digital sampling oscilloscope operating at 256 GS/s was used to capture and store traces for offline processing. The DSP operated at 2 samples per symbol and consisted mainly of a 4x1 time-domain MISO with 61 taps[3]. The taps were updated using a data-aided least-mean squares algorithm, switching to decision-directed after convergence. The performance was evaluated by direct error counting.

Experimental Result and Discussion

The ASE noise was generated by the first EDFA and its spectrum is shown in Fig. 2 a). After that, a TBPF was placed and cantered at 1545.5 nm to produce the spectrally sliced ASE and its

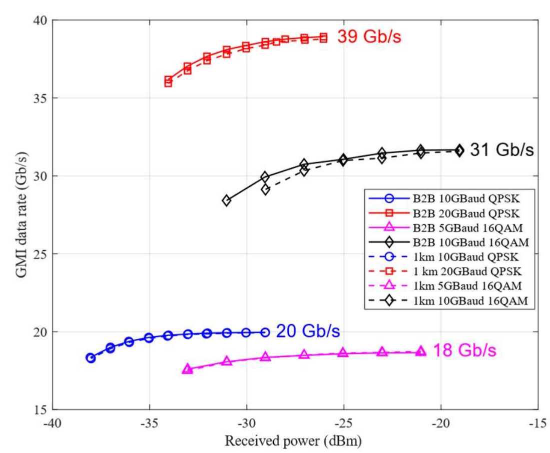

Fig. 5: GMI data rate and constellations of QPSK & 16QAM.

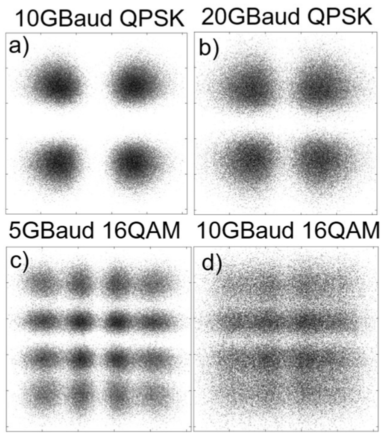

Fig. 6: Constellations of a) 10 GBaud QPSK, b) 20 GBaud QPSK, c) 5 GBaud 16QAM, and d) 10 GBaud 16QAM.

spectrum shown in Fig. 2 b). The spectra of spectrally sliced ASE at the transmitter after booster amplifier and receiver after pre-amplifier and 3-nm BPF are illustrated in Fig. 2 c) and d), respectively. We first evaluated the performance dependence on the bandwidth of the spectrally sliced ASE, as shown in Fig. 3. We considered 10 & 20 GBaud QPSK as well as 5 & 10 GBaud 16-QAM signals, in back-to-back. For all cases, the best performance was achieved with a 1 nm bandwidth with Q-factor values between 3.82 dB for 10 GBaud 16-QAM and 11 dB for 10 GBaud QPSK. Using the optimum ASE bandwidth, we then evaluated the sensitivity of the system.

Fig. 4 shows the Q-factor dependence on the power at the receiver input in back-to-back and after 1 km transmission for all considered cases. The power was adjusted by setting the VOA after the transmitter EDFA. Assuming soft-decision forward error correction (SD-FEC) with 7% overhead and a Q-factor threshold of 7.52 dB would lead to sensitivities of approximately -36 dBm and -30 dBm for 10 and 20 GBaud QPSK, respectively. While 5 GBaud 16QAM can reach the 20% overhead SD-FEC threshold at a sensitivity of -31 dBm. For these cases, the transmission penalty was below 1 dB. For the case of 10 GBaud 16-QAM, the signal distortion due to the spectrally sliced ASE limited the Q-factor to approximately 3.82 dB, which would require a higher overhead.

Fig. 5 illustrates the GMI data rate calculation and constellations. These results show the total net bit rate of up to 20 Gb/s, 39 Gb/s, 18 Gb/s, and 31 Gb/s for 10 and 20 GBaud QPSK, 5 and 10 GBaud 16QAM, respectively. Although 16QAM provides a low Q-factor, the total net bit rate of 10 GBaud 16QAM can achieve up to 31 Gb/s. For all considered cases, polarization alignment at the receiver input was unnecessary. The constellations of 10 & 20 GBaud QPSK and 5 & 10 GBaud 16QAM are shown in Fig. 6.

Conclusion

We demonstrate coherent detection of spectrally sliced ASE modulated with 10 & 20 GBaud QPSK and 5 & 10 GBaud 16QAM signals using a polarization insensitive self-homodyne detection system. We show a negligible transmission penalty after 1 km with 10 and 20 GBaud QPSK as well as 5 GBaud 16-QAM signals, which renders this approach suitable for low-cost short reach systems. The sensitivities can reach -36 dBm and -30 dBm for 10 and 20 GBaud QPSK, respectively. In this system, the local oscillator at the receiver can be eliminated as well as the carrier recovery DSP resulting in low cost and simple DSP. Besides, our SHD system does not require any complex electro-optic polarization alignment subsystems to control the polarization. As a result, this work shows the potential for coherent detection systems supported by incoherent light sources, which typically have substantially reduced cost with respect to laser light sources.

References

[1] C. Xie et al., "Coherent Optics for Data Center Networks," IEEE Photonics Society Summer Topicals Meeting Series (SUM) 2020, pp. 1-2 (2020), DOI: 10.1109/SUM48678.2020.9161052.

[2] D. Che et al., "160-Gb/s stokes vector direct detection for short reach optical communication," OFC 2014, p. Th5C.7 (2014), DOI: 10.1364/OFC.2014.Th5C.7.

[3] B. Boriboon et al., "Polarization Insensitive Self-Homodyne Detection Receiver for 360 Gb/s Data Center Links," ECOC 2022, p. Th3A.2 (2022).

[4] J. S. Lee et al., "Spectrum-sliced fiber amplifier light source for multichannel WDM applications," PTL, 5, 1458-1461 (1993), DOI: 10.1109/68.262573.

[5] Q. Hu et al., "25-Gb/s ASE-seeded WDM PON," OECC/PS 2016, p. ThA3-3 (2016).

[6] Z. Al-Qazwini et al., "Ultranarrow Spectrum-Sliced Incoherent Light Source for 10-Gb/s WDM PON," Journal of Lightwave Technology, 30, 3157-3163 (2012), DOI: 10.1109/JLT.2012.2214435.

[7] Q. Hu et al., "Performance Improvement of Ultranarrow Spectrum Sliced Incoherent Light Using Offset Filtering," IEEE Photonics Technology Letters, vol. 26, no. 9, pp. 870-873, (2014), DOI: 10.1109/LPT.2014.2308545.

[8] M. Nakamura et al., "Ultimate Linewidth-Tolerant 20-Gbps QPSK-Homodyne Transmission using a Spectrum-Sliced ASE Light Source," OFC 2007, p. OThD4 (2007), DOI: 10.1109/OFC.2007.4348659.