SOA/SPD-based incoherent SAC-OCDMA system at 9 × 5 Gbps

Hamza M. R. Al-Khafaji[1a)]**, S. A. Aljunid**[1]**, Angela Amphawan**[2]**, and Hilal A. Fadhil**[1]

[1] *School of Computer and Communication Engineering, University Malaysia Perlis (UniMAP), Perlis, Malaysia*

[2] *InterNetWorks Research Group, School of Computing, University Utara Malaysia (UUM), Kedah, Malaysia*

a) *g1040810508@studentmail.unimap.edu.my*

Abstract: To boost the performance of spectral-amplitude coding optical code-division multiple-access (SAC-OCDMA) systems, the need for an effective solution to diminish phase-induced intensity noise (PIIN) is becoming progressively more crucial. In this letter, two PIIN suppression approaches: semiconductor optical amplifier (SOA)-based noise cleaning, and single photodiode detection (SPD) are employed. The performance of the hybrid SOA/SPD scheme is validated through simulation experiments. Our results show that SOA/SPD scheme remarkably improves the performance and increases the throughput of SAC-OCDMA system.

Keywords: SAC-OCDMA, PIIN, SOA, SPD

Classification: Fiber optics, Microwave photonics, Optical interconnection, Photonic signal processing, Photonic integration and systems

References

[1] K. Ohba, T. Miyazawa, and I. Sasase, "A mitigation technique of high-power MAI in the multimedia optical CDMA system with the optical power selector," *IEICE Trans. Commun.*, vol. E91–B, no. 3, pp. 700–709, March 2008.

[2] H. M. R. Al-Khafaji, S. A. Aljunid, and H. A. Fadhil, "Spectral efficiency analysis of bipolar spectral-amplitude coding optical code-division multiple-access systems using different one-dimensional codes," *IET Optoelectron.*, vol. 6, no. 5, pp. 215–222, Oct. 2012.

[3] H. M. R. Al-Khafaji, S. A. Aljunid, and H. A. Fadhil, "Improved BER based on intensity noise alleviation using developed detection technique for incoherent SAC-OCDMA systems," *J. Modern Optics*, vol. 59, no. 10, pp. 878–886, June 2012.

[4] A. D. McCoy, M. Ibsen, P. Horak, B. C. Thomsen, and D. J. Richardson, "Feasibility study of SOA-based noise suppression of spectral amplitude coded OCDMA," *J. Lightwave Technol.*, vol. 25, no. 1, pp. 394–401, Jan. 2007.

[5] A. Ghazisaeidi and L. A. Rusch, "Capacity of SOA-assisted SAC-OCDMA," *IEEE Photon. Technol. Lett.*, vol. 22, no. 7, pp. 441–443,

April 2010.

[6] H. M. R. Al-Khafaji, S. A. Aljunid, A. Amphawan, and H. A. Fadhil, "Improving spectral efficiency of SAC-OCDMA systems by SPD scheme," *IEICE Electron. Express*, vol. 9, no. 24, pp. 1829–1834, Dec. 2012.

[7] F. N. Hasoon, S. A. Aljunid, M. K. Abdullah, and S. Shaari, "New code structure for spectral amplitude coding in OCDMA system," *IEICE Electron. Express*, vol. 4, no. 23, pp. 738–744, Dec. 2007.

[8] S. B. Ahmad-Anas, M. K. Abdullah, M. Mokhtar, and S. D. Walker, "Multiple access interference elimination with enhanced chromatic dispersion tolerance in SAC OCDMA," *IEICE Electron. Express*, vol. 5, no. 16, pp. 617–623, Aug. 2008.

1   Introduction

Optical code-division multiple-access (OCDMA) technology offers clear benefits, such as efficient use of bandwidth, high security, and ability to transmit data from multiple users over the network concurrently [1]. Since OCDMA receivers extract their codewords in the presence of other users' codewords, the principal deterioration in performance is due to interference from other users' signals, termed multiple-access interference (MAI). Consequently, spectral-amplitude coding (SAC) is an attractive OCDMA technique that prevents the negative effects of MAI by using an advantaged detection approach [2]. Incoherent sources appear as compelling candidates for SAC due to their broad emission bandwidth, a required characteristic of SAC. However, PIIN severely restricts the data transmission rates of each user, degrades the communication quality, and limits the capacity of SAC-OCDMA systems [3].

In some of the earliest studies, researchers have explored the use of SOA in the noise cleaning process to inhibit PIIN in SAC-OCDMA systems [4, 5]. More recently, the authors have proposed a cost-effective solution by using the SPD technique to restrain both PIIN and MAI efficiently in the optical domain [6]. Motivated by all the above, in this letter, we merge two PIIN elimination techniques for unprecedented use in SAC-OCDMA systems. Modified double weight (MDW) codes are utilized as the signature sequences for our SAC-OCDMA systems. MDW codes are characterized by unity cross-correlation, which is the ideal cross-correlation value. For a weight of four, the code length is [7]:

$$N = 3K + \frac{8}{3}\left[\sin\left(\frac{K\pi}{3}\right)\right]^2 \tag{1}$$

where N is the code length, and K is the number of users. The outline of the letter is as follows. The simulation setup is described in Section 2. Afterward, discussions of results are detailed in Section 3. Lastly, the conclusions from this study are drawn in Section 4.

2 SAC-OCDMA simulation setup

The simulations of SAC-OCDMA systems have been conducted by using OptiSystem software from *optiwave*^{TM}, which is widely used in optical fiber simulations. Each simulation accommodates nine simultaneous channels as an example to demonstrate different PIIN suppression schemes. Fig. 1 shows the simulation setup of SOA/SPD-based SAC-OCDMA system. Tests are carried out by using one broadband light-emitting diode (LED) for each user. The LED optical bandwidth is set at 20 nm. To generate the OCDMA codes, the LED is sliced into four wavelengths using WDM demultiplexer. Each chip has a spectral width of 0.8 nm. The SOA is deeply saturated ($P_{in} = 6$ dBm), and its injected current is set at 350 mA. The transmitted power for each user is adjusted via the variable optical attenuator (VOA) in each branch to avoid four-wave mixing (FWM). The information signals are generated from the pseudo random bit sequence (PRBS) generator with the non-return-to-zero (NRZ) line coding before being modulated with the codes using an external Mach-Zehnder modulator (MZM). The attenuation and the dispersion of single mode fiber (SMF) at a wavelength of 1550 nm are 0.25 dB/km and 18 ps/nm km^{-1} respectively. The dispersion is post compensated by employing a dispersion compensating fiber (DCF) with the SMF. The dispersion of DCF at a wavelength of 1550 nm is -90 ps/nm km^{-1}. Nonlinear effects are specified as close to typical industrial values as possible to emulate the real

(a)

(b)
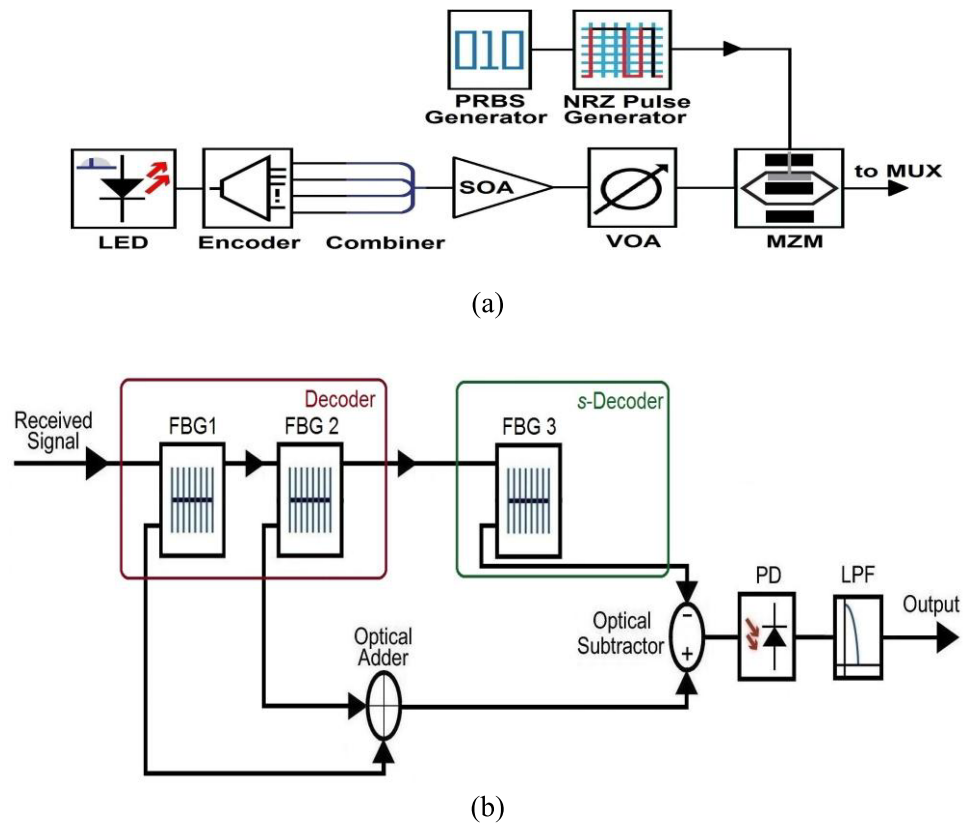
Fig. 1. Simulation setup of SAC-OCDMA; (a) SOA-based transmitter, and (b) SPD-based receiver.

environment. Fiber Bragg-gratings (FBGs) are used to decode the received signal. The noise generated at the receivers is set as random and totally uncorrelated. The dark current value is set at 5 nA, and the thermal noise coefficient is 1.8×10^{-23} W/Hz for the photo-diode (PD) at the detection part. After the user signal is detected, the transmitted data are restored and filtered by the low-pass filter (LPF).

3   Results and discussions

In this section, the performance of SAC-OCDMA systems is assessed by referring to the bit-error rate (BER), Q-factor, and eye diagrams. To compare the effectiveness of different PIIN suppression approaches, the SOA-based noise cleaning is used with SPD detection (SOA/SPD case) and conventional direct detection (DD) [8] (SOA/DD case).

Fig. 2 (a) compares the variation of BER with respect to fiber length at different transmission rates. The fiber length L in Fig. 2 (a) refers to the total fiber link length

$$L = L_{SMF} + L_{DCF} \qquad (2)$$

where the length of DCF used in the simulation is computed from [8]

$$L_{DCF} = -\frac{L_{SMF} D_{SMF}}{D_{DCF}} \qquad (3)$$

where L and D denote the fiber length and dispersion, respectively.

Fig. 2 (a) clearly demonstrates that the BER performance of the hybrid SOA/SPD configuration at 2.5 Gbps significantly surpasses the BER performance of the SOA/DD configuration. Even at a data rate of 5 Gbps, the hybrid SOA/SPD configuration is capable of achieving an acceptable BER up to a distance of 60 km. A comparison of eye diagrams for the three cases of interest are given in Fig. 3 at a fiber length of 60 km. It is clearly observed
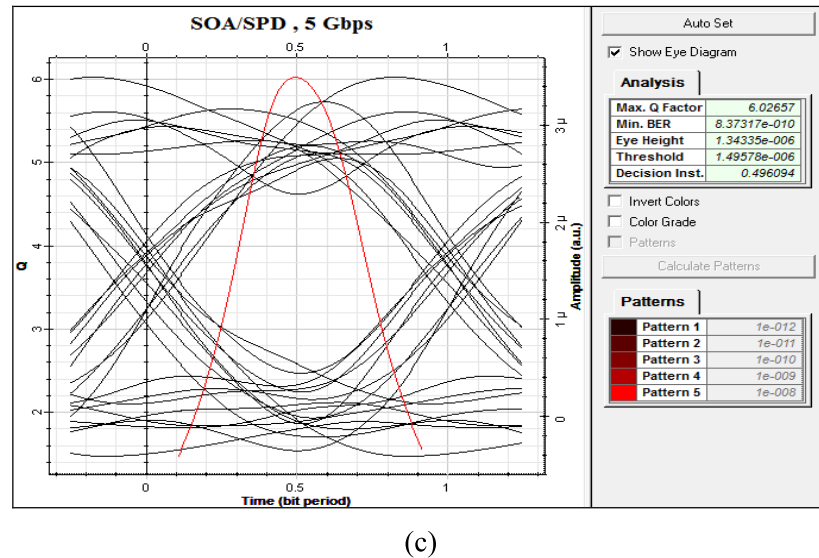

(a)

(b)
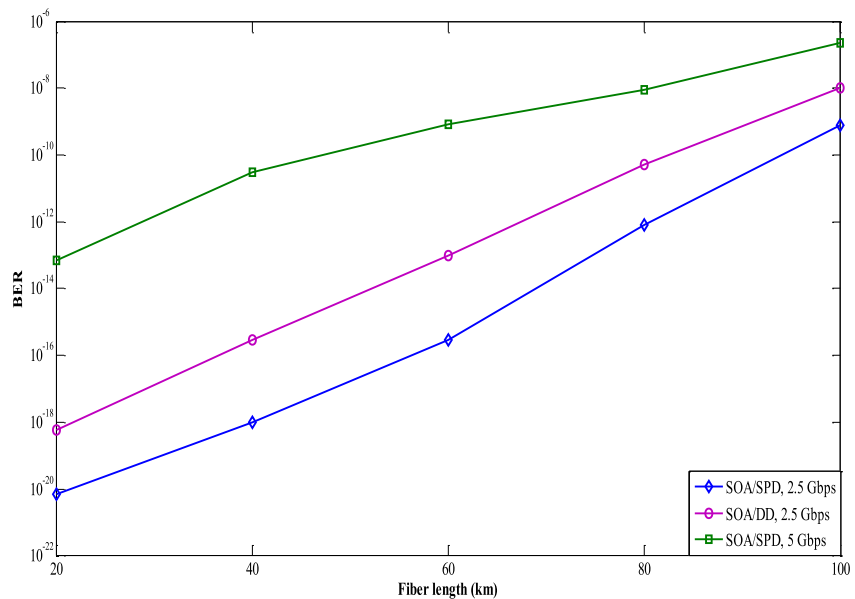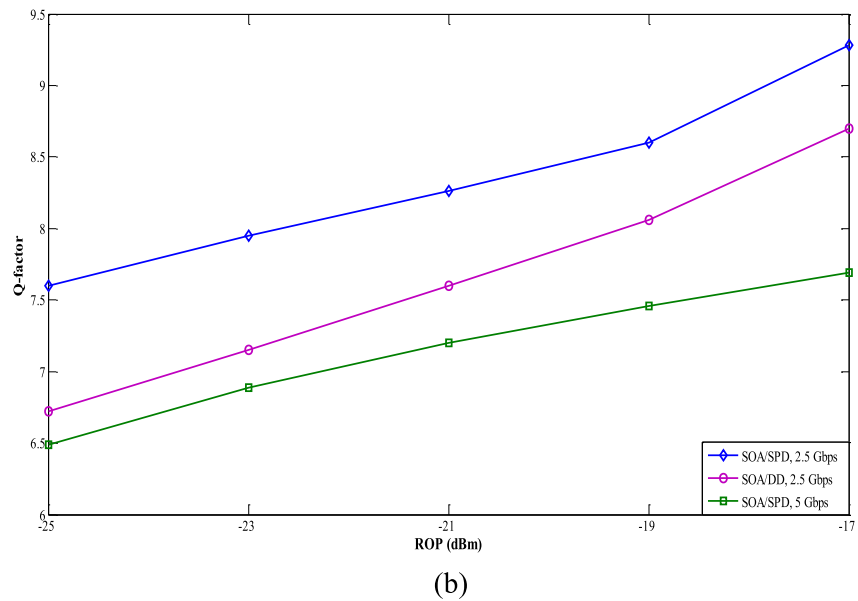
Fig. 2. Performance plot for different PIIN suppression schemes; (a) BER against fiber length, and (b) Q-factor against ROP.

(a)

(b)

(c)
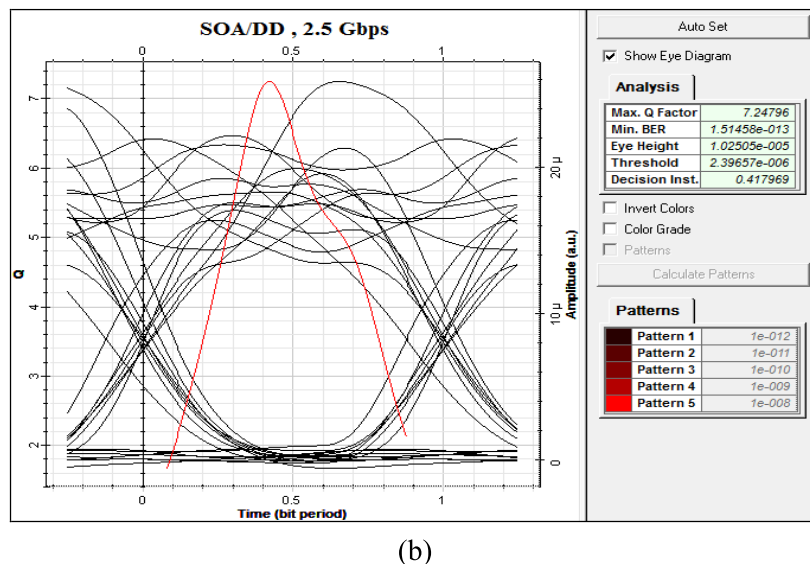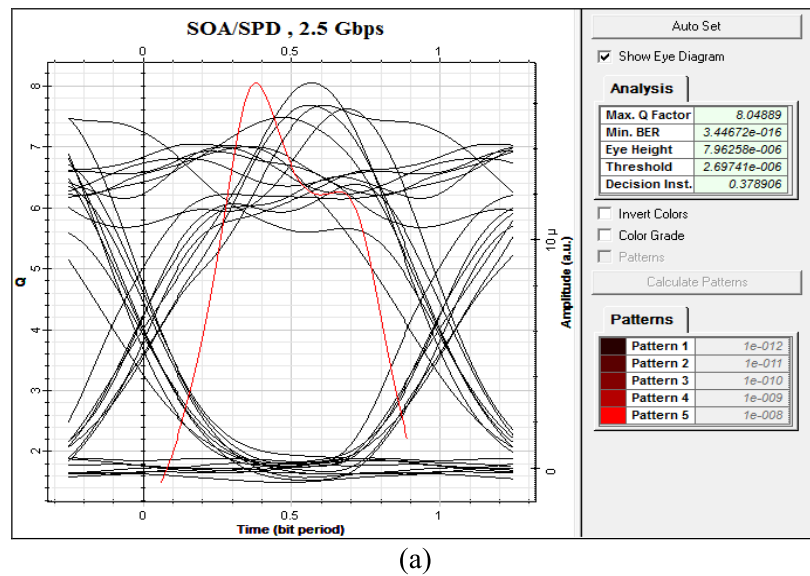
Fig. 3. Eye diagrams for MDW code at 60 km transmission distance using (a) SOA/SPD at 2.5 Gbps, (b) SOA/DD at 2.5 Gbps, and (c) SOA/SPD at 5 Gbps.

from the eye diagrams that the hybrid SOA/SPD configuration at 2.5 Gbps gives better performance, where the eye diagram having a large opening and less vertical distance between the top of the eye opening and maximum signal level, i.e., the PIIN has greatly diminished.

Fig. 2 (b) illustrates the variation of the Q-factor versus the received optical power (ROP) at 20 km transmission distance. Note that the ROP is adjusted by varying the VOA attenuation at the transmitter. At a data rate of 2.5 Gbps, the SOA/DD is unable to achieve a high Q-factor compared to the SOA/SPD. Moreover, when the data rate is doubled to 5 Gbps, the SOA/SPD still gives acceptable Q-factor values for different ROP.

4 Conclusions

In this letter, the feasibility of combining two PIIN cleaning techniques for incoherent SAC-OCDMA system is investigated. The hybrid SOA/SPD scheme is proven to be an efficient solution to tackle the impact of PIIN. BER and Q-factor performances at different bit rates are used to validate the effectiveness of SOA/SPD scheme. An acceptable BER is achieved for nine active users with a maximum fiber length of 60 km and transmission rate of 5 Gbps/user.