Single Photodiode Detection for Interference Elimination in SAC-OCDMA Systems

Hamza M. R. Al-Khafaji [*], S. A. Aljunid, and Hilal A. Fadhil
School of Computer and Communication Engineering,
University Malaysia Perlis (UniMAP),
Perlis, Malaysia
[*] Corresponding author. E-mail: eng.hamza.alkhafaji@gmail.com

***Abstract*—A single photodiode detection (SPD) technique for interference suppression in spectral-amplitude coding optical code-division multiple-access (SAC-OCDMA) systems is investigated in this paper. Its benefits to eliminate multiple-access interference (MAI) and phase-induced intensity noise (PIIN) which are the major noises in incoherent SAC-OCDMA systems. We show the feasibility of SPD technique; however, appreciable performance enhancements can be realized by utilizing an optical hard limiter.**

***Keywords*—SAC-OCDMA; SPD technique; MAI; PIIN.**

I. INTRODUCTION

The recent growth of broadband access services and the need for high speed and large capacity access networks have driven the development of OCDMA for next-generation broadband access networks. OCDMA is an optical-based multiple-access technique that assigns every user a specific code to efficiently and securely share network resources among users [1, 2]. At the same time multiple-access interference (MAI) problem is an important indicator to impact the performance of conventional OCDMA systems [3]. Mitigating MAI impacts has been a hot issue of domestic and international OCDMA arena. Various schemes have dealt with MAI suppression in different methods ranging from simple passive approaches to highly complex coherent procedures. SAC-OCDMA is a simple and low-cost OCDMA scheme that eliminates MAI via subtraction detection techniques. SAC-OCDMA systems require broadband optical sources owing to their spectral encoding. Most of the literature have considered low-priced broadband incoherent sources, such as light-emitting diodes (LEDs), as SAC sources [4]. However, these sources suffer from PIIN which limits their performance to support systems up to hundreds of Mbps [5, 6]. PIIN depends on the number of interfering users, and the performance is not improved by increasing the transmitted power [7, 8]. Of late, the SPD technique is proposed for eliminating the effects of PIIN and MAI in SAC-OCDMA systems through cancelling the interfering signals in the optical domain [9-11]. Both theoretical and simulation results showed SPD technique can not only improves the performance, but also reduces the cost of the SAC-OCDMA receiver and the generated shot noise. Therefore, the research about SPD technique is of great significance.

In this study, modified double-weight (MDW) codes are utilized as the signature sequences for SAC-OCDMA systems. MDW codes are characterized by unity cross-correlation ($\lambda = 1$), which is the ideal cross-correlation value. For a weight of four ($w = 4$), the code length is [12]:

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

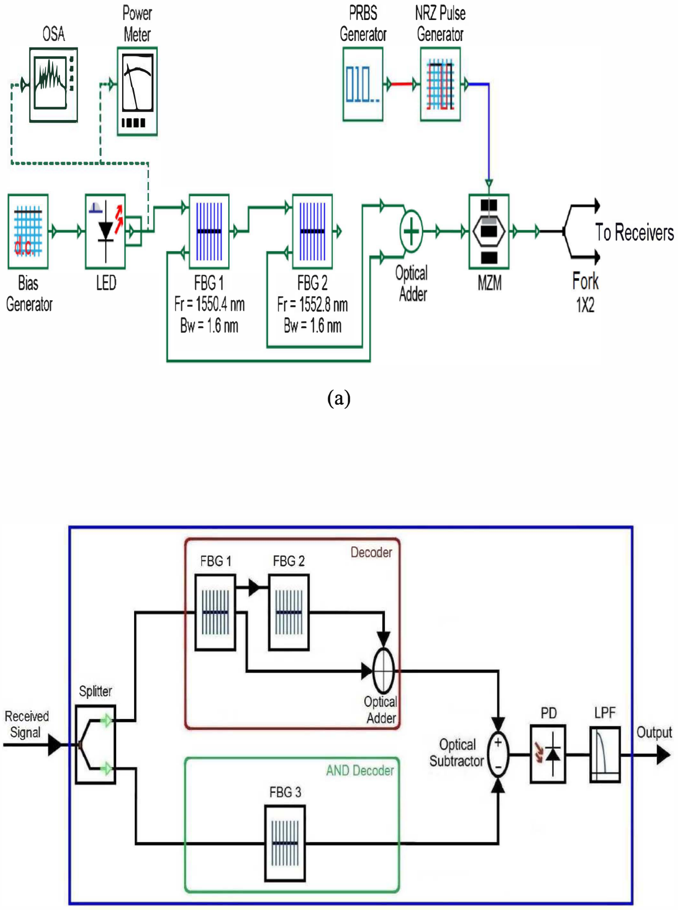
where L is the code length, and K is the number of users.

Following the Introduction, Section II describes the simulation setup. Based on the simulation results in Section III, the conclusions are drawn in Section IV.

II. SAC-OCDMA SIMULATION SETUP

The simulations of SAC-OCDMA systems have been conducted by using OptiSystem software (Version 9.0). OptiSystem is a software simulation kit from *optiwave*^{TM} that analyzes the performance of optical systems and networks. Fig. 1 shows the simulation setup of SAC-OCDMA system based on SPD. There is one transmitter in this simulation system connected to two receivers that employing SPD. We consider the first one to be the desired user and the second one in the interferer. The transmitter using one LED with optical bandwidth of 20 nm. For encoders and decoders, fiber Bragg-gratings (FBGs) filters with uniform apodization functions and 0.99 reflectivity were used to encode/decode the optical signals given their low-price, low insertion losses, high long-term stability, small size, and light weight. Each chip has a spectral width of 0.8 nm. The information signals are generated by using 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) with 30 dB extinction ratio. The output of MZM is connected to the fork which is a component used to duplicate the number of output ports so that each of the signals coming out from the fork's output has the same value with the output signal from MZM. Back-to-back data transmission has been used between the transmitter and the two receivers to exclude the effect of the optical medium. The incoming optical signal is split between the decoder and the AND decoder, and it is decoded by the upper decoder using the same spectral response as that which is intended for the encoder. The detected output from the decoder is either w power units (P.U.)

for an active user or λ P.U. for interferers. While the output of the AND decoder is either zero P.U. for an active user or λ P.U. for interferers. After optical subtraction, the output is either *w* P.U. for an active user or zero P.U. for interferers. This shows that the interfering signals are eradicated in the optical domain before their conversion to the electrical domain. As a consequence, the SPD technique mitigates both PIIN and MAI in the optical domain. Eliminating interfering signals in the optical domain enable a single photodiode to be utilized rather than two as in other detection techniques. All photodiodes are standard positive-intrinsic-negative (PIN) photodiodes with all activated noises. The noises generated at the receivers are random and totally uncorrelated. The dark current value is set to 5 nA, and the thermal noise coefficient is 1.8×10^{-23} W/Hz for each photodiode (PD) at the detection part. After the user signal is detected, the transmitted data are restored and filtered by the low-pass filter (LPF). The electrical LPFs are fourth-order Bessel filters with cut-off frequency of 0.75 of the data rate. Gaussian algorithm is used for bit-error rate (BER) estimation. The performance of the system is evaluated by referring to BER and eye patterns.



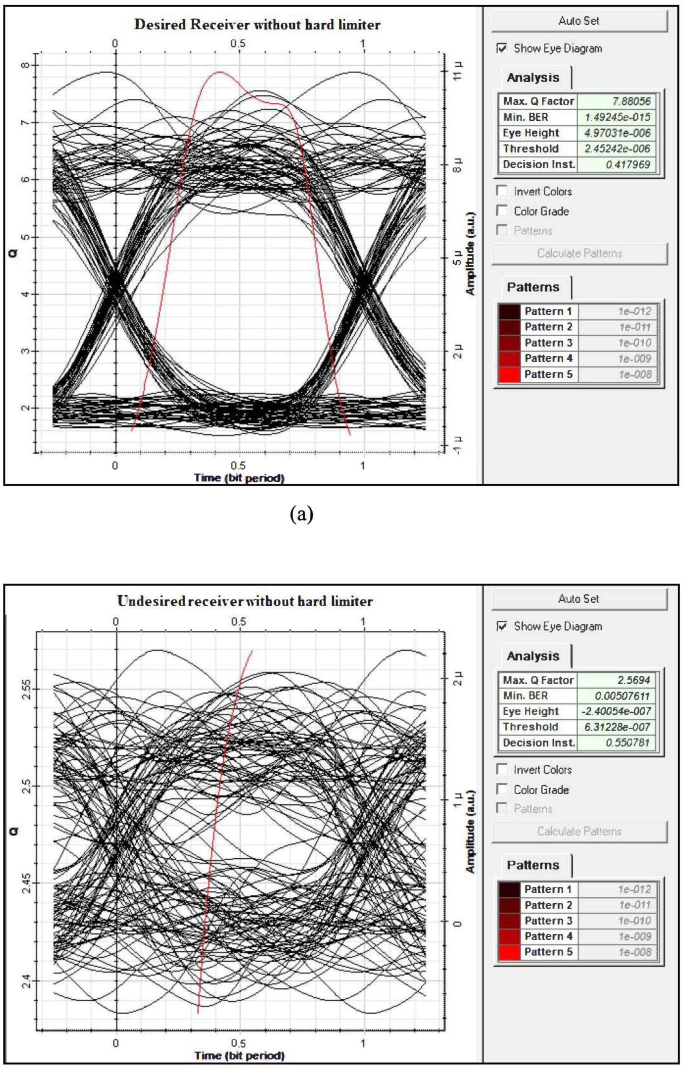
(a)

(b)

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

III. RESULTS AND DISCUSSIONS

Fig. 2 shows the eye diagrams for the desired user and the interferer at 2.5 Gbps. It can be observed from the eye diagrams that the signal of the first receiver has better noise tolerance with acceptable BER, while the BER of the interferer is high.



(a)

☑ Show Eye Diagram

Analysis	
Max. Q Factor	7.88056
Min. BER	1.49245e-015
Eye Height	4.97031e-006
Threshold	2.45242e-006
Decision Inst.	0.417969

☐ Invert Colors
☐ Color Grade
☐ Patterns

Patterns	
Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

(b)

☑ Show Eye Diagram

Analysis	
Max. Q Factor	2.5694
Min. BER	0.00507611
Eye Height	-2.40054e-007
Threshold	6.31228e-007
Decision Inst.	0.550781

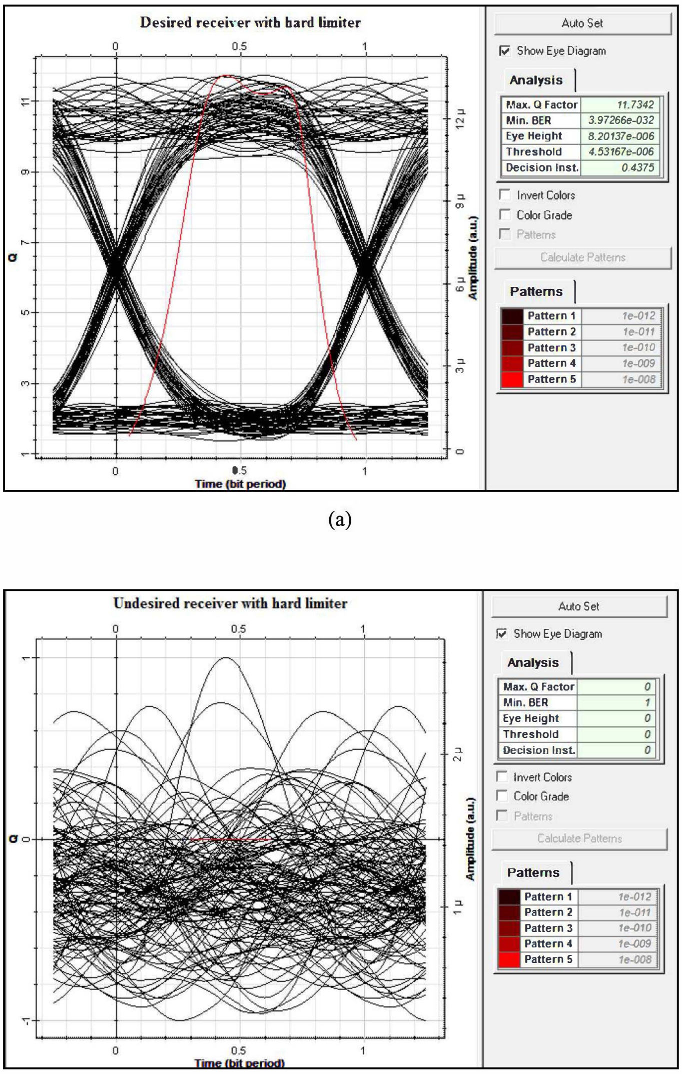
☐ Invert Colors
☐ Color Grade
☐ Patterns

Patterns	
Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

Fig. 2. The eye diagrams without hard limiter; (a) desired receiver, and (b) interferer receiver.

In practice, the two interfering signals differ slightly at the optical subtractor because of the non-rectangular response of the filters, such that some form of distortion will exist. Therefore, appreciable performance enhancements can be realized by utilizing an optical hard limiter (power threshold = −24 dBm; lower output level = −30 dBm; upper output level = −18 dBm) inserted between the optical subtractor and PD to cancel the small amount of optical power reaching the PD.

Fig. 3 shows the eye diagrams for the case of using an optical hard limiter in each receiver at 2.5 Gbps. The interferer receiver has a maximum BER while the BER of the desired user is improved.



☑ Show Eye Diagram

Analysis

Max. Q Factor	11.7342
Min. BER	3.97266e-032
Eye Height	8.20137e-006
Threshold	4.53167e-006
Decision Inst.	0.4375

☐ Invert Colors
☐ Color Grade
☐ Patterns

Patterns

■	Pattern 1	1e-012
■	Pattern 2	1e-011
■	Pattern 3	1e-010
■	Pattern 4	1e-009
■	Pattern 5	1e-008

(a)

☑ Show Eye Diagram

Analysis

Max. Q Factor	0
Min. BER	1
Eye Height	0
Threshold	0
Decision Inst.	0

☐ Invert Colors
☐ Color Grade
☐ Patterns

Patterns

■	Pattern 1	1e-012
■	Pattern 2	1e-011
■	Pattern 3	1e-010
■	Pattern 4	1e-009
■	Pattern 5	1e-008

(b)

Fig. 3. The eye diagrams without hard limiter; (a) desired receiver, and (b) interferer receiver.

IV. CONCLUSIONS

Superior performance and cost-effectiveness have been made the SPD technique of interest for more investigation. The viability of SPD technique is shown for interference suppression in spectral-amplitude coding optical code-division multiple-access (SAC-OCDMA) systems. Appreciable performance enhancements can be realized by utilizing an optical hard limiter with SPD.

REFERENCES

[1] M.H. Zoualfaghari, and H. Ghafouri-Shiraz , “Uniform cross-correlation modified prime code for applications in synchronous optical CDMA communication systems,” J. Lightwave Technol., vol. 30, pp. 2955-2963, 2012.

[2] H.M.R. Al-Khafaji, S.A. Aljunid, A. Amphawan, H.A. Fadhil, and A.M. Safar “Phase-induced intensity noise reduction with improved group velocity dispersion tolerance in SAC-OCDMA systems,” International Journal of Engineering and Technology (IJET), vol. 5, pp. 95-100, 2013.

[3] H. Ghafouri-Shiraz, and M.M. Karbassian “Optical CDMA networks: principles, analysis and applications,”John Wiley & Sons, 1st ed., 2012.

[4] 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. of Modern Optics, vol. 59, pp. 878-886, 2012.

[5] C.-T. Yen, “Optical code-division multiple-access embedded with a polarisation diversity scheme for radio-over-fibre transmissions,” IET Optoelectronics, vol. 6, pp. 131-139, 2012.

[6] M. Noshad, and K. Jamshidi, “Code family for modified spectral-amplitude-coding OCDMA systems and performance analysis,” J. Opt. Commun. Netw., vol. 2, pp. 344-354, 2010.

[7] S. Ayotte, M. Rochette, J. Magne, L.A. Rusch, and S. LaRochelle, “Experimental verification and capacity prediction of FE-OCDMA using superimposed FBG,” J. Lightwave Technol., vol. 23, pp. 724-731, 2005.

[8] M. Abtahi, S. Ayotte, J. Penon, and L.A. Rusch, “Balanced detection of correlated incoherent signals: a statistical analysis of intensity noise with experimental validation,” J. Lightwave Technol., vol. 26, pp. 1330-1338, 2008.

[9] 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, pp. 1829-1834, 2012.

[10] H.M.R. Al-Khafaji, S.A. Aljunid, A. Amphawan, H.A. Fadhil, and A.M. Safar, “Reducing BER of spectral-amplitude coding optical code-division multiple-access systems by single photodiode detection technique,” J. Europ. Opt. Soc. Rap. Public., vol. 8, 13022, 2013.

[11] H.M.R. Al-Khafaji, S.A. Aljunid, A. Amphawan, and H.A. Fadhil, “SOA/SPD-based incoherent SAC-OCDMA system at 9 × 5 Gbps,” IEICE Electron. Express, vol. 10, 20130044, 2013.

[12] S.A. Aljunid, M. Ismail, A.R. Ramli, B.M. Ali, and M.K. Abdullah, “A new family of optical code sequences for spectral-amplitude-coding optical CDMA systems,” IEEE Photon. Technol. Lett., vol. 16, pp. 2383-2385, 2004.