applied sciences

MDPI

Article

Enhanced Spectral Amplitude Coding OCDMA System Utilizing a Single Photodiode Detection

Somia A. Abd El-Mottaleb [1], Heba A. Fayed [1], Ahmed Abd El-Aziz [1], Mohamed A. Metawee [2] and Moustafa H. Aly [1,3,*]

1. Arab Academy for Science, Technology and Maritime Transport, Alexandria 1029, Egypt; eng_somaya@hotmail.com (S.A.A.E.-M.); hebam@aast.edu (H.A.F.); ahmedabdelazizyoussef@gmail.com (A.A.E.-A.)
2. College of Engineering, Delta University for Science and Technology, Mansoura 5145, Egypt; drmohmetawee@gmail.com
3. The Optical Society of America (OSA), Washington, DC 20036, USA

* Correspondence: mosaly@gmail.com; Tel.: +20-100-663-9473

Received: 19 September 2018; Accepted: 2 October 2018; Published: 10 October 2018

Abstract: In this paper, the performance of a spectral amplitude coding-optical code division multiple access (SAC-OCDMA) system is investigated utilizing a single photodiode (SPD) detection technique. The proposed system uses enhanced double weight (EDW) codes as signature codes with three simultaneous users to overcome both phase-induced intensity noise (PIIN) and multiple access interference (MAI). In addition, a dispersion compensating fiber (DCF) is used in order to decrease the group velocity dispersion (GVD) caused in the single mode fiber. An erbium-doped fiber amplifier (EDFA) is used to overcome the attenuation. The use of both DCF and EDFA leads to an appreciable enhancement in the system performance. The system performance is evaluated through its bit error rate (BER), Q-factor, and received power. A comparison between the EDW codes and modified double weight (MDW) codes on the SAC-OCDMA system is demonstrated. Simulation is carried out through Optisystem ver. 7. The simulation results show that: (a) using an avalanche photodiode (APD) over PIN photodiode allows data transmission over longer distances; (b) the use of DCF improves the system BER;(c) using MDW codes gives better BER than using EDW codes.

Keywords: bit error rate; codes; computer simulation; photodetectors; dispersion compensating fiber; single photodiode detection; avalanche photodiode; erbium-doped fiber amplifier

1. Introduction

Due to its large bandwidth and low attenuation, the optical code division multiple access (OCDMA) system is used for high-quality video transmission [1]. It is a multiplexing technique in which each user in the communication channel is assigned a distinguishable and unique optical code (rather than a wavelength or time slot) at the transmitter [2]. Using low-cost incoherent broadband light sources and complete cancellation of multiple-access interference (MAI) makes the spectral amplitude coding (SAC) OCDMA a system of special interest among all the OCDMA techniques. The reasons for this are its ability to restrain the negative effects of MAI and its flexibility in phase cross-correlation, which can be utilized as address sequence and balance detection at the receiver side [3] when using a suitable detection approach [4], as well as the availability of cost-effective broadband sources such as light emitting diodes (LEDs) [5].

In a previous work [6], the use of broadband sources results in phase-induced intensity noise (PIIN), which degrades the communication quality. Recently, a single photodiode (SPD) detection technique using a PIN photodiode was implemented to reduce both PIIN and MAI [7], and enhance the performance compared with other detection techniques such asmodified-AND subtraction detection [8]. Many different codes are developed in the literature for the SAC-OCDMA networks, such as a modified frequency-hopping (MFH) code [9], modified quadratic congruence (MQC) code [10], optical orthogonal code [11], prime code [12], Khazani–Syed (KS) code [13], random diagonal (RD) code [14], and dynamic cyclic shift (DCS) code [15].

As some of these codes have limitations in length, code construction is limited by code parameters, as is the case for MQC [9], DCS [15], and MFH [9] codes, and cross-correlation increases with weight number, as is for the prime and RD codes. In addition, some of the SAC-OCDMA codes do not support a large number of simultaneous users or high data rates [9–15]. Modified double weight (MDW) codes and enhanced double weight (EDW) codes are utilized as signature sequences for our SAC-OCDMA systems. They are characterized by unity cross-correlation, which is the ideal cross-correlation value, and can support a large number of users and high data rates [16]. For high-bit-rate long-haul fiber optic communications, the use of avalanche photodiode (APD) is preferred because of its internal gain, which provides a relatively better sensitivity margin than PIN photodiodes. APDs can achieve a sensitivity 5–10-dB higher than PINs, provided that the multiplication noise is low and the gain bandwidth product is sufficiently high [17,18]. For high-speed receivers, researchers used SAC-OCDMA with MDW as signature codes and APD in modified-AND subtraction detection to detect the received signal [19]. The SAC-OCDMA system was compared using EDW codes as signature codes with the SPD detection technique and modified-AND subtraction detection technique using an APD detector at 622 Mbps; the SPD detection technique with an APD was found to improve the performance of the system [8].

In this study, a comparison was performed for a SAC-OCDMA system using EDW codes as signature codes and the SPD detection technique with different detectors (APD and PIN) at different bit rates. The system is simple, as it uses only one photodiode (APD or PIN) in the SPD detection technique to overcome both PIIN and MAI. Furthermore, the effect of adding erbium-doped fiber amplifier (EDFA) and dispersion compensating fiber (DCF) on the system performance was studied. Finally, a comparison was performed for SAC-OCDMA using MDW and EDW codes with different detectors (PIN and APD) at different bit rates and transmission distances in the presence of both EDFA and DCF. The performance evaluation characteristics were investigated, including the quality factor (Q-factor) of the detected signal at the receiver end, bit error rate (BER), optimum received power, and eye opening.

The remainder of the paper is organized as follows. Section 2 provides a detailed explanation of single photodiode detection (SPD). The system performance analysis is introduced in Section 3. The simulation results are presented and discussed in Section 4. Section 5 is devoted to the main conclusions.

2. SPD Detection Technique

The SAC-OCDMA receiver in this technique is shown in Figure 1, which is drawn by Optisystem ver. 7 (Optiwave, Ottawa, ON, Canada). The received signal is decoded by a decoder that has the same spectral response of the intended encoder. The detected output from the decoder is either w for active user or λ for interferers, where the weight w represents the number of occupied frequency bins in the user encoder, and λ is the maximum number of common frequency bins occupied by any two codes of the family [20].

The remainder of the signal from the decoder is then transmitted to the subtractive decoder (s-Decoder) to cancel out signals with mismatched signatures, i.e., interferers. After optical subtraction, the output from the s-Decoder is either zero for active user or λ for interferers.

To decode the received signal, inexpensive uniform fiber Bragg gratings (FBGs) are used. This implies that the interference signals are cancelled in the optical domain before the conversion of the signals to the electrical domain. As a consequence, the new SPD scheme alleviates both PIIN and

MAI in the optical domain. The logical representation of interferences cancellation when using EDW codes is illustrated in Table 1.

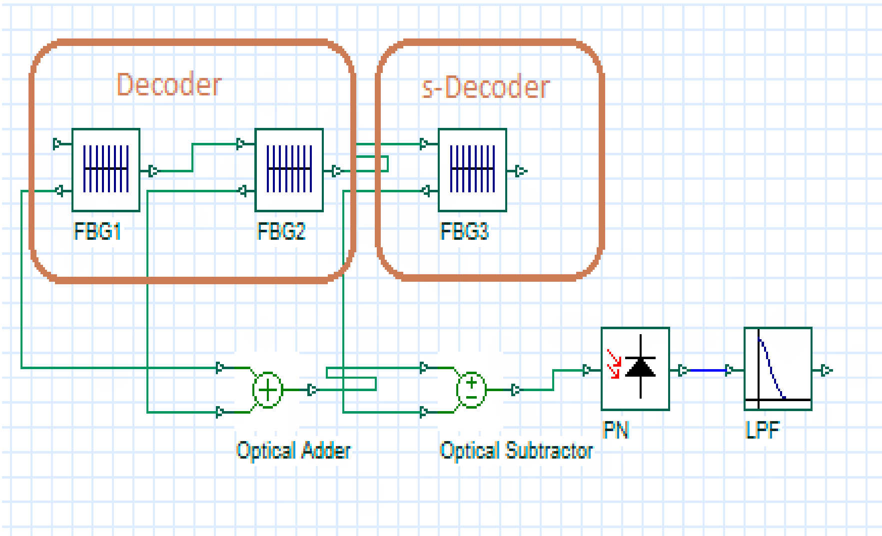


Figure 1. Single photodiode (SPD) detection.

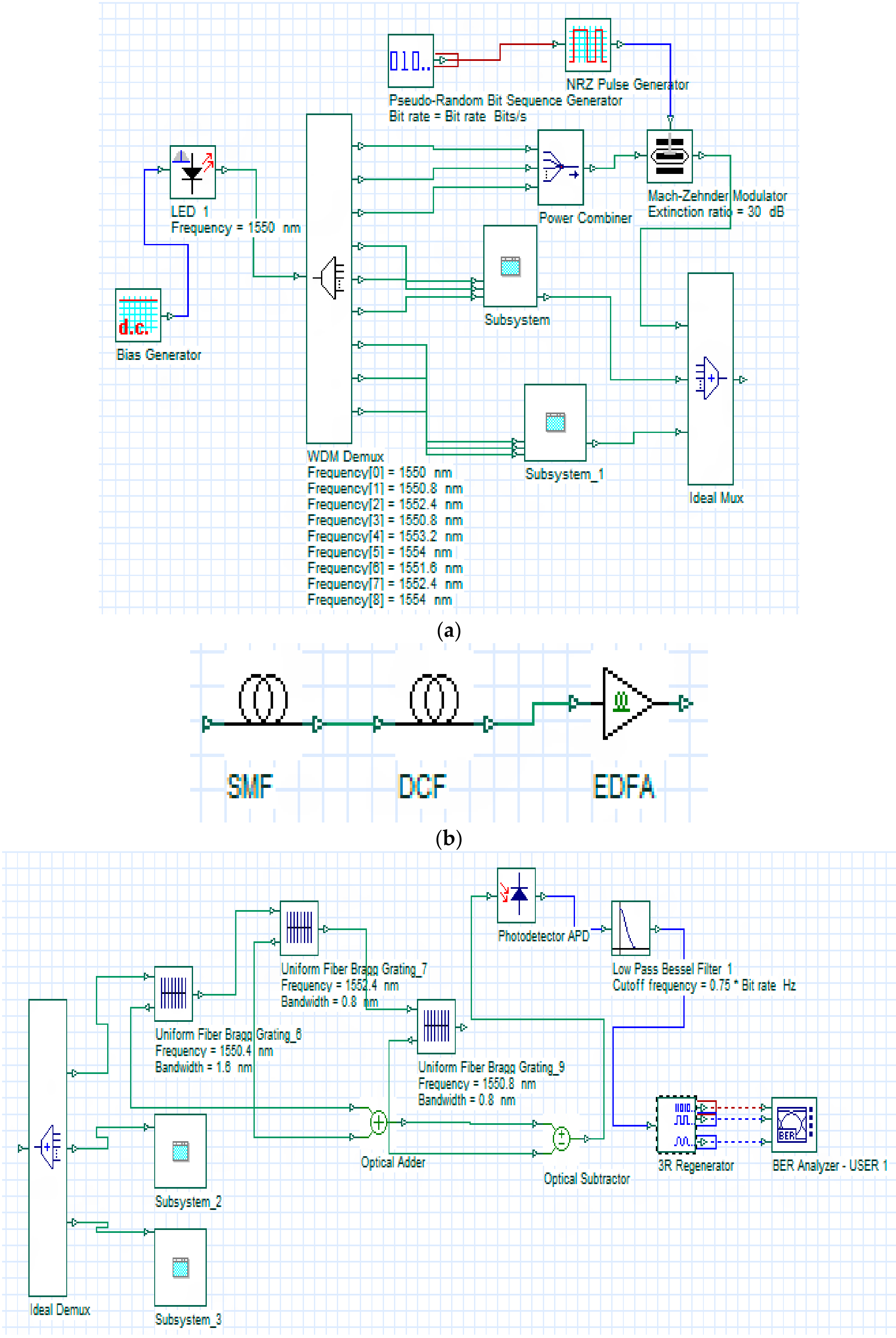
Table 1. Logical interference cancellation.

User One (Decoder)	010011
First interference of user one (X)	110100
Second interference of user one (Y)	001101
(Decoder × X)	010000
∑(X × Decoder)	1
$\overline{\text{Decoder}}$	101100
(X × Y)	000100
S-Decoder = $\overline{\text{Decoder}}$ × (X × Y)	000100
(X × S-Decoder)	000100
∑(X × Decoder) − ∑((X × S-Decoder)	1 − 1 = 0

3. Performance Analysis

3.1. System Description

The block diagram of the proposed system of three users of SAC-OCDMA using EDW code is shown in Figure 2. The transmitter consists of an LED that is sliced into nine wavelengths using wavelength division multiplexing (WDM) to generate the OCDMA codes. The information signals are generated from the pseudorandom bit generator with the non-return-to-zero (NRZ) line coding before being modulated with the codes using an external Mach Zehnder modulator. Then, the signals are combined using an ideal multiplexer before launching to the single mode fiber (SMF). A DCF and an EDFA are connected in series to the SMF. At the receiver, FBGs are used with the same bandwidth but with different Bragg wavelengths to decode the signal. The signal is then converted from the optical domain to the electrical domain through the APD. The resultant signal is filtered by a fourth-order Bessel low pass filter, which is used to reject noise and interference components.



(c)

Figure 2. Block diagram of three users of spectral amplitude coding-optical code division multiple access (SAC-OCDMA): (**a**) transmitter using enhanced double weight (EDW) code, (**b**) channel, and (**c**) receiver using EDW code.

3.2. Analysis

In this section, analytical expressions are presented for the mean optical power and noise in order to get the BER performance of the SAC-OCDMA system based on SPD with APDs. As mentioned earlier, EDW codes, characterized by unity cross-correlation, are utilized as the signature sequences for the proposed SAC-OCDMA system. For a weight of three (w = 3), the code length is as follows [21]:

$$L = 2k + \frac{4}{3}\left[\sin\left(\frac{k\pi}{3}\right)\right]^2 \frac{8}{3}\left[\sin\left(\frac{(k+1)\pi}{3}\right)\right]^2 + \frac{4}{3}\left[\sin\left(\frac{(k+2)\pi}{3}\right)\right]^2, \quad (1)$$

where L is the code length and k is the number of users.

The mean optical power reaching the photodetector when the desired user is active is as follows [20]:

$$P_{User} = S\int_0^B H_E(v)H_D(v)dv = S\frac{B_0}{L}\sum_{i=1,\ E=D}^{L} C_E(i).C_D(i) = \frac{SB_0}{L}w = \frac{3SB_0}{L}, \quad (2)$$

where S is the received power spectral density level at the photodiode; B_0 is the optical bandwidth partitioned into logical frequency bins of width B_0/L; $H_E(\nu)$ and $H_D(\nu)$ are, respectively, the encoder and decoder transfer functions (i.e., they are spectral representations of the filters, both made of bins of a given spectral width that are fully transmissive or fully opaque); $C_E(i)$ and $C_D(i)$ denote the ith element of the encoder and decoder code words, respectively.

For APDs, Equation (2) can be rewritten as

$$P_{User} = \frac{3SGB_0}{L} \quad (3)$$

where G is the average internal gain of APDs.

The PIIN expression for unpolarized thermal light source is expressed as [20]

$$\sigma_{PIIN}{}^2 = S^2B_e\int_0^{B_0}[H_E(v)H_D(v)]^2dv = S^2B_e\frac{B_0}{L}\sum_{i=1,\ E=D}^{L}[C_E(i)]^2.[C_D(i)]^2 = \frac{S^2B_eB_0}{L}w = \frac{3S^2B_eB_0}{L} \quad (4)$$

where B_e is the electrical bandwidth and is assumed to be equal to 0.75 × RB, where RB is the bit rate.

For APDs, Equation (4) can be rewritten as

$$\sigma_{PIIN}{}^2 = \frac{3S^2GB_eB_0}{L}, \quad (5)$$

The signal to noise ratio (SNR) is defined as [6]

$$SNR = \frac{(P_{User})^2}{\sigma_{PIIN}{}^2} = \frac{3GB_0}{B_eL}, \quad (6)$$

Based on the Gaussian distribution, the bit error rate (BER) is given by [6]

$$BER = \frac{1}{2}erfc\left(\frac{\sqrt{SNR}}{2}\right), \quad (7)$$

where *erfc* is the complementary error function.

The parameters that were used in the simulation of the proposed system are given in Tables 2 and 3 [19,20,22].

Table 2. Typical parameters used in numerical analysis.

Symbol	Quantity	Value
RB	Data bit rate	622 Mbps, 1 Gbps and 2 Gbps
Bo	Optical bandwidth	3.75 MHz
Be	Electrical bandwidth	0.75 × RB Hz
S	Received power at photodiode	−10 dBm

Table 3. Parameters used in simulation.

Light Emitting Diode (LED) and Signal Data Parameters	
LED Bandwidth	30 nm
LED Input Power	9 dBm
Signal Data	128 PN sequence
Chip Spectral Width	0.8 nm
Signal Format	NRZ
Optical Modulator Extinction Ratio	30 dB
Bit Rate	622 Mbps, 1 Gbps and 2 Gbps
Fiber Bragg Ratings (FBGs) Reflectivity	0.99
Fiber Parameters	
Wavelength	1550 nm
Single Mode Fiber (SMF)	Dispersion, D = 17 ps/nm/km Dispersion slope, S = 0.075 ps/nm^2/km
Dispersion Compensating Fiber (DCF)	Dispersion, D =−85 ps/nm/km Dispersion slope, S = −0.0375 ps/nm^2/km
Erbium-Doped Fiber Amplifier (EDFA) Parameters	
Pumping technique	Forward
Pumping power	50 mW
Pumping wavelength	980 nm
PIN Parameters	
Dark current	5 nA
Thermal noise coefficient	1.8×10^{-23}
Avalanche Photodiode (APD)Parameters	
Gain	10 dB
Dark current	5 nA
Thermal noise coefficient	1.8×10^{-23} W/Hz
Low Pass Filter	
Receiver filter bandwidth	0.75× Bit Rate

4. Results and Discussion

Based on the described model, the simulation was performed using Optisystem ver. 7. The obtained results are divided into four parts according to the absence or presence of DCF and EDFA as follows.

4.1. Absence of EDFA and DCF

For the sake of comparison, we used three users, but the results can be generalized for any number of users. The comparison of the average BER for three users of the SAC-OCDMA system using EDW codes as signature codes is shown in Figure 3. The different detectors (PIN and APD photodetectors) were investigated at different transmission distances and bit rates of 622 Mbps, 1 Gbps, and 2 Gbps. A better performance was observed when the APD was used. At 622 Mbps, when using the APD, the data of the SAC-OCDMA system could be transmitted over a distance 40 km longer than that when using the PIN detector with a BER less than 10^{-9}, as shown in Figure 3a. As shown in Figure 3b, at 1 Gbps and a transmission distance of 48 km, the average BER of three users is 1.02×10^{-5} and 4.73×10^{-10} for PIN and APD, respectively. While at 2 Gbps and transmission distance of 36 km, the average BER of three users is4.76×10^{-5} and 1.82×10^{-5} for PIN and APD, respectively, as shown in Figure 3c. Therefore, the system using the APD can transmit data for longer distances than that using the PIN detector.

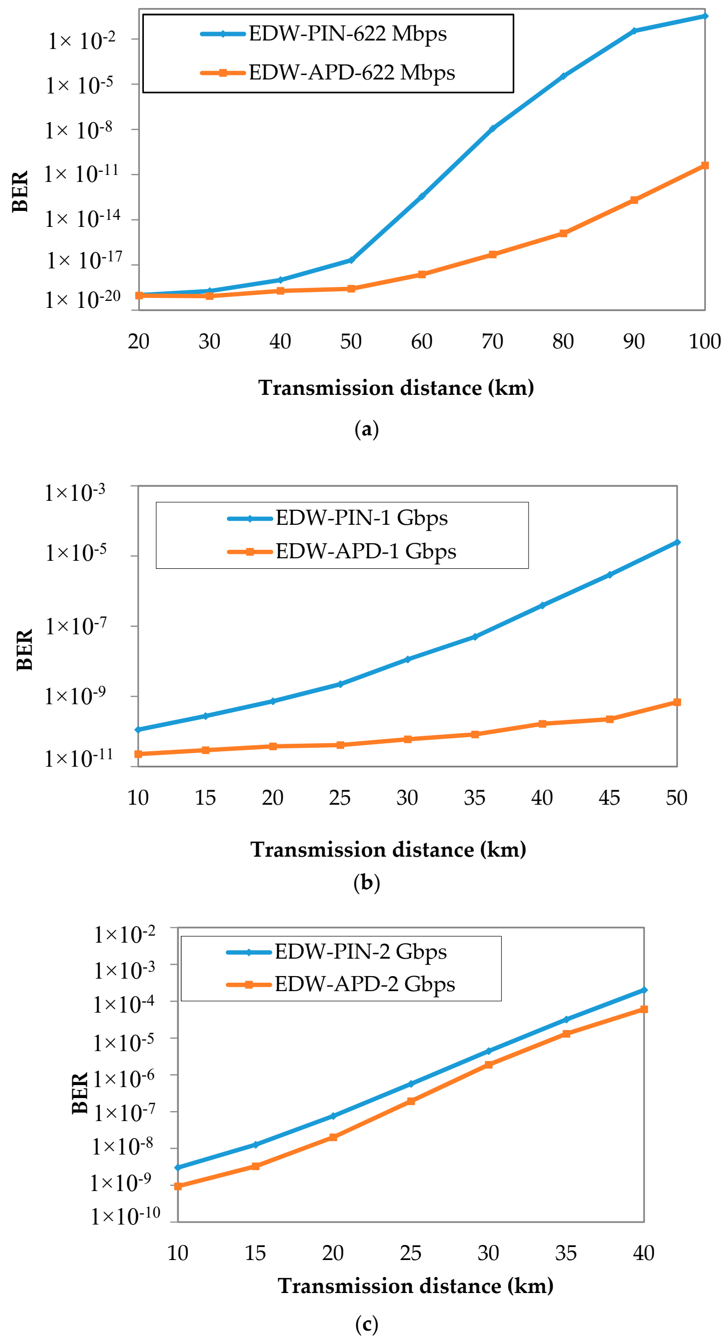


Figure 3. SAC-OCDMA system performance in terms of bit error rate (BER) using EDW codes and two different detectors in the absence of erbium-doped fiber amplifier (EDFA) and dispersion compensating fiber (DCF) at bit rates (**a**) 622 Mbps, (**b**) 1 Gbps, and (**c**) 2 Gbps (PIN detector is indicated by the blue line and avalanche photodiode (APD) by the red line).

As a sample, the eye pattern for one user at a bit rate of 622 Mbps and transmission distance of 100 km is displayed in Figures 4 and 5, where the APD performs better (with a larger eye opening) than the PIN detector. The BER and Q-factor when using the PIN detector are 10^{-8} and 3, respectively. These values are improved when an APD is used and become 10^{-11} and 6, respectively.

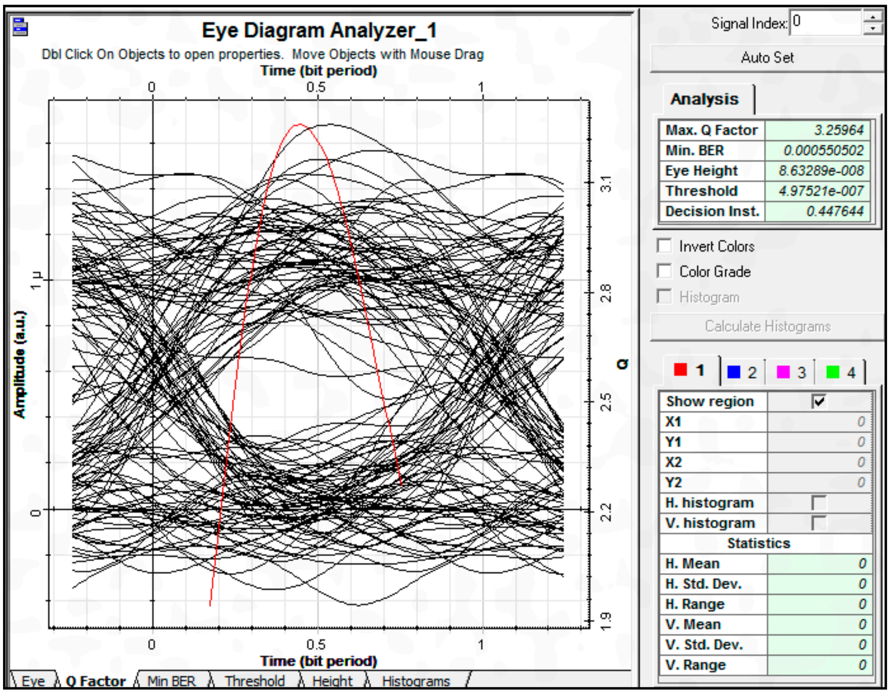


Figure 4. Eye diagram for one user of SAC-OCDMA system using EDW code and PIN photodetector at 622 Mbps and 100 km.

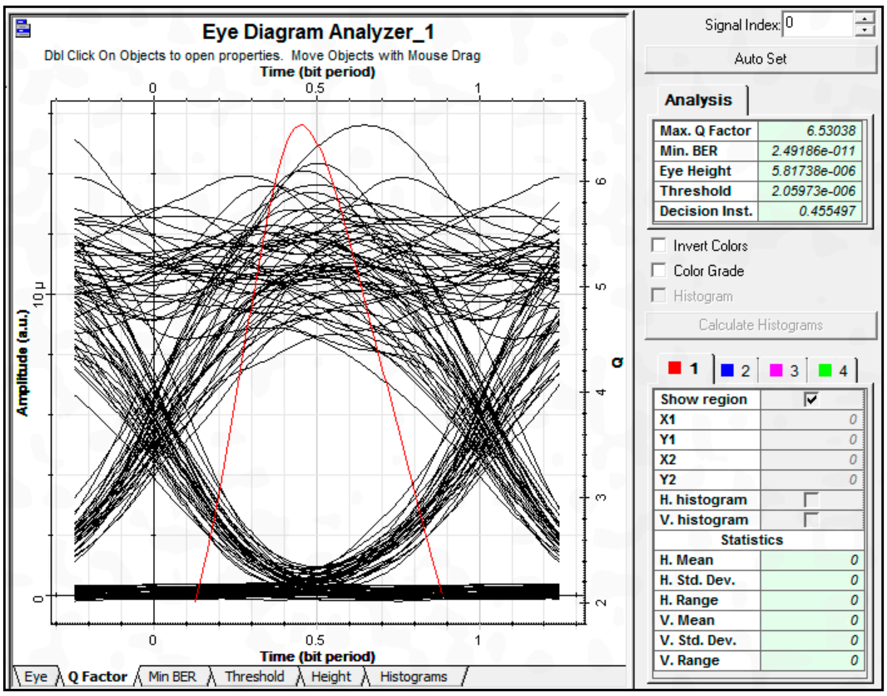


Figure 5. Eye diagram for one user of SAC-OCDMA system using EDW code and APD photodetector at 622 Mbps and 100 km.

4.2. Presence of DCF Only

Nowadays, tens of millions of kilometers of conventional SMFs already exist in the underground ducts and are operating at 1300 nm. Transmission capacity can be increased by operating these fibers at 1550 nm and using optical amplifiers such as EDFA. However, there will be significant residual (positive) dispersion. On the other hand, replacing these fibers with dispersion shifted fibers (DSFs) would incur huge costs. In recent years, considerable work has been done to upgrade the installed 1310-nm optimized optical fiber links to operate at 1550 nm. This is achieved by developing fibers with very large negative dispersion coefficients, a few hundred meters to a kilometer, which can be used to compensate for dispersion over tens of kilometers of the fiber in the link. Compensation of dispersion at a wavelength around 1550 nm in a 1310 nm optimized single-mode fiber can be achieved by using specially designed fibers whose dispersion coefficient (D) is negative and large at 1550 nm to improve performance. These types of fibers are known as dispersion compensating fibers (DCFs). The length of the DCF required for compensation can be reduced by having fibers with very large negative dispersion coefficients. Thus, there has been a considerable research effort to achieve DCFs with very large (negative) dispersion coefficients in order to reduce costs [23].

The DCF could be designed to have a negative GVD value at 1550 nm, and is usually used to compensate the accumulated dispersion of a conventional SMF-based transmission link. The length, L_{DCF}, of the DCF used in the simulation was calculated using [5]

$$L_{DCF} = -\frac{L_{SMF} D_{SMF}}{D_{DCF}}, \tag{8}$$

where L_{SMF} is the original SMF length, and D_{SMF} and D_{DCF} are, respectively, the total dispersion parameters of SMF and DCF.

The total link length, L, is

$$L = L_{SMF} + L_{DCF}, \tag{9}$$

Figure 6 displays the average variation of BER of three users with respect to the fiber length at 622 Mbps when using APD and PIN photodiodes. When compared with Figure 3a, an improvement is achieved in the system BER. As an example, at a distance of 72 km, the SAC-OCDMA system achieves a BER of 2.14×10^{-8} and 5.01×10^{-19} for PIN and APD, respectively, while the corresponding values without DCF are 7.90×10^{-8} and 2.26×10^{-16} at 622 Mbps.

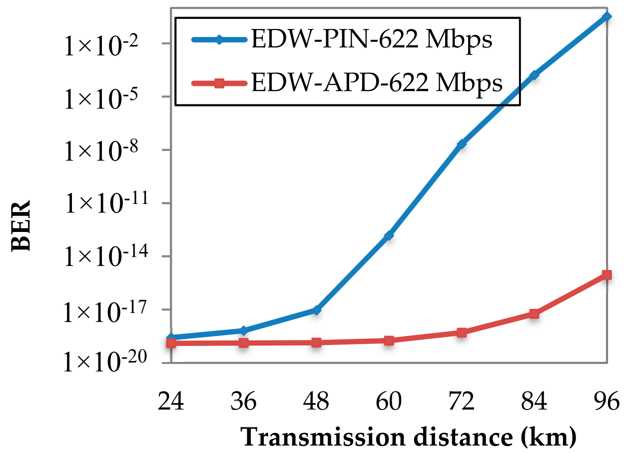


Figure 6. BER with transmission distance of SAC-OCDMA system using EDW codes using two different detectors in presence of DCF.

4.3. Presence of EDFA Only

In all optical communication systems, the transmitted optical power is degraded with the transmission distance, leading to the use of optical amplifiers to overcome this degradation. EDFA is an excellent type of optical amplifier to be used. The SAC-OCDMA system using MDW codes with SPD detection technique with a PIN detector in the presence of EFDA showed improvement in BER [13]. It is shown that the system at a bit rate of 622 Mbps with EDFA can transmit over a distance of 70 km with a BER of approximately 10^{-27}, while the BER is about10^{-24} without EDFA at the same distance [22].

The average BER of three users of the SAC-OCDMA system using EDW codes is displayed in Figure 7 for the APD and PIN without EDFA, and for PIN with EDFA at 622 Mbps and different transmission distances. It is clear that when the PIN is used in the presence of EDFA, and when the APD is used without EDFA, the SAC-OCDMA system has nearly the same BER until50 km. Hence, it is preferable to use the system with the APD instead of the PIN with EDFA for less complexity and lower cost. However, for distances greater than 50 km, it is preferable to use EDFA with the PIN as it provides a better BER than using the APD only.

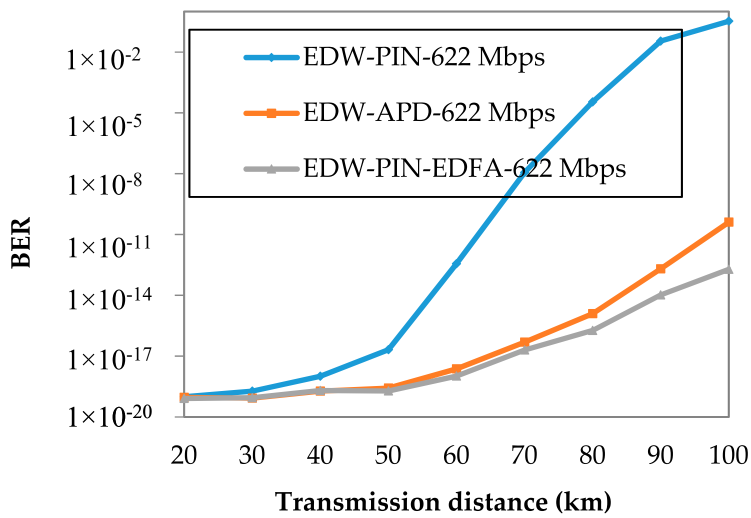


Figure 7. BER with transmission distance of SAC-OCDMA system using EDW codes with APD detector, PIN detector, and PIN detector in the presence of EDFA.

The comparison of the eye pattern for one user as a sample (Figure 8) with those shown in Figures 4 and 5 clearly shows that using the PIN detector in the presence of EDFA results in better performance than using PIN or APD detectors alone, with a larger eye opening at 622 Mbps and 100 km.

4.4. Presence of DCF and EDFA

As discussed, the system performance was improved leading to a better BER in the presence of EDFA only or DCF only in a SAC-OCDMA system using EDW codes as signature codes. Subsequently, we examined performance in terms of BER, Q-factor, and received power for the SAC-OCDMA system using different codes in the presence of both DCF and EDFA with SPD detection techniques (Figure 9). It is clear that using MDW codes gives a better BER than using EDW codes at 622 Mbps and 1 Gbps. At 2 Gbps, the system using MDW codes and that using EDW codes nearly have the same value of BER. In general, as shown, it is preferable to use the system with MDW codes, as it has a better performance at different transmission distances and different bit rates.

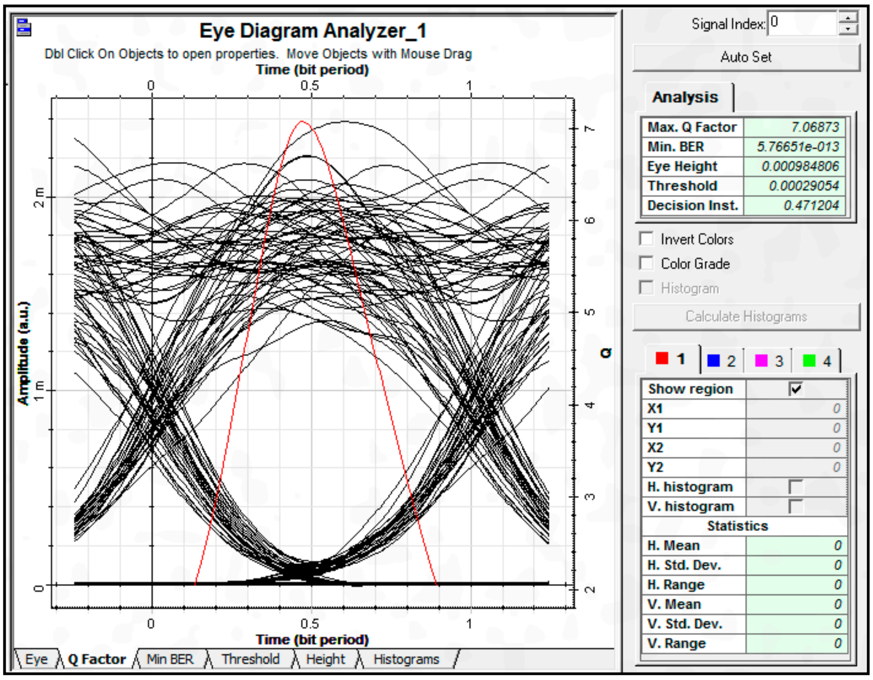


Figure 8. Eye diagram for one user of SAC-OCDMA system using EDW code, sending bit rate of 622 Mbps at 100 km using PIN detector in presence of EDFA.

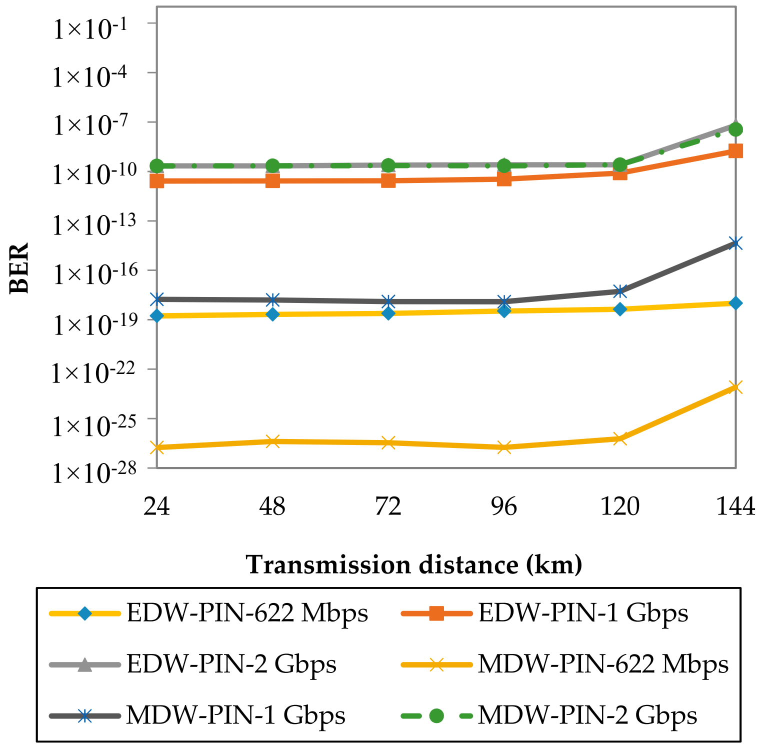


Figure 9. BER with transmission distance for SAC-OCDMA using different codes and SPD detection technique at different bit rates in the presence of DCF and EDFA.

Figure 10 displays a comparison between the received powers of the SAC-OCDMA system using different codes and SPD detection technique at different data rates and different transmission distances in the presence of DCF and EDFA. It is noticed that as the transmission distance increases, the BER increases and the system using MDW code receives greater power than that with EDW codes.

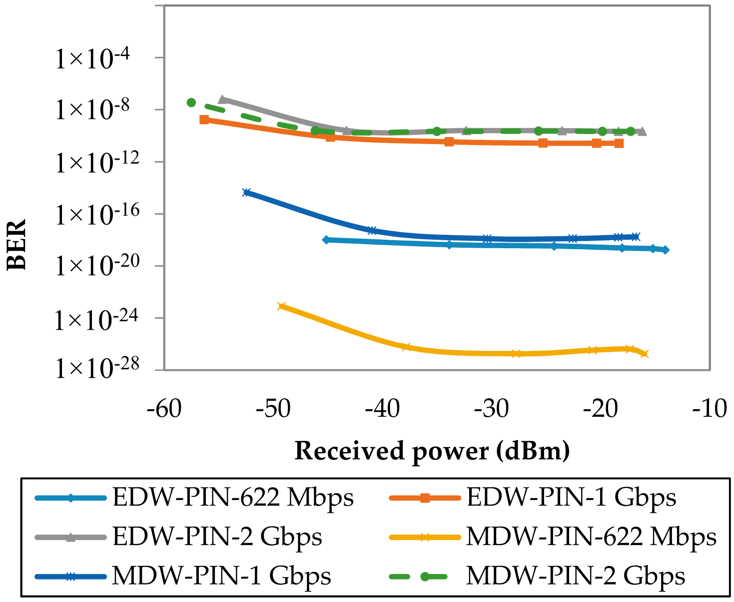


Figure 10. BER versus received power for the SAC-OCDMA system using different codes and SPD detection technique at different bit rates in the presence of both DCF and EDFA.

Table 4 summarizes and compares the present results and previous work, concerning the BER of the SAC-OCDMA system using different signature codes with PIN detector at different transmission distances and different bit rates. A fair agreement is noticed. Moreover, higher bit rates lead to an increase in BER.

Table 4. Bit error rate (BER) summary and comparison.

Spectral Amplitude Coding-optical Code Division Multiple Access (SAC-OCDMA) System Using Different Codes		Transmission Distance (km)		Bit Rate	BER	
		Using Modified Double Weight (MDW) Codes	Using Enhanced Double Weight (EDW) Codes		Using MDW Codes	Using EDW Codes
In absence of EDFA and DCF	Ref. [24]	60 60	NA NA	622 Mbps 1.25 Gbps	1×10^{-20} 1×10^{-15}	NA NA
In presence of EDFA only	Ref. [22]	140	NA	622 Mbps	1×10^{-10}	NA
In presence of EDFA and DCF	Present work	144 144 120	144 144 120	622 Mbps 1 Gbps 2 Gbps	8.2×10^{-24} 4.43×10^{-15} 5.51×10^{-10}	1.01×10^{-18} 1.72×10^{-9} 2.5×10^{-9}

Figure 11 represents a comparison for the Q-factor using different codes and SPD detection technique at different data rates and different transmission distances in the presence of both DCF and EDFA. Clearly, the Q-factor decreases with the transmission distance, and using MDW code yields a higher Q-factor than using EDW code.

Finally, it is worth noting that all the obtained results for the proposed system are designed and simulated using Optisystem ver. 7. The practical implementation for such a system can be also attainable due to the availability of all utilized components and equipments commercially and in laboratories. However, power losses and noise effects should be considered when obtaining experimental results. It is also important to highlight that these results were obtained using transmission speeds up to 2 Gbps and two different codes. Higher speeds will limit the performance of the proposed system, while other codes can change the complexity and hence the limitations of such system.

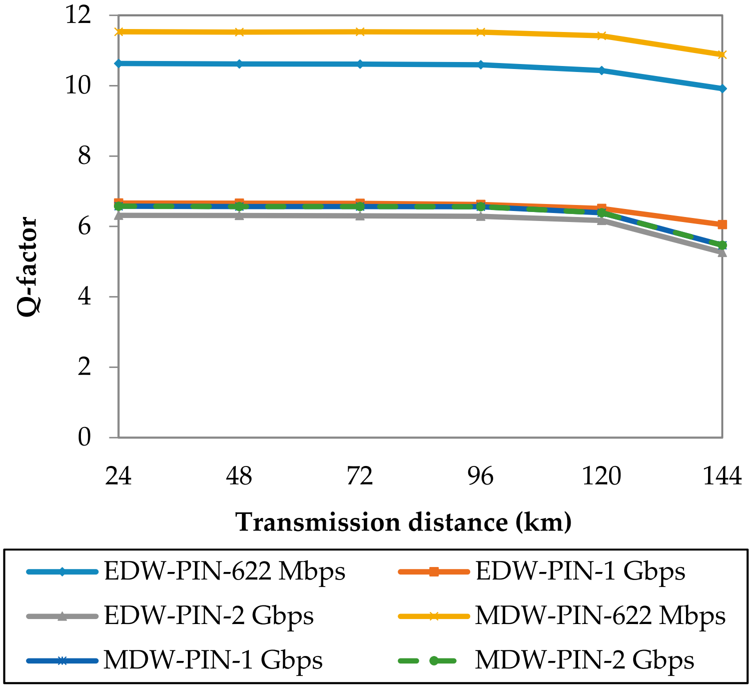


Figure 11. Variation of Q-factor with transmission distance for SAC-OCDMA system using different codes and SPD detection technique at different bit rates in the presence of both DCF and EDFA.

5. Conclusions

A SAC-OCDMA system is proposed including a DCF to compensate dispersion and an EDFA to compensate attenuation in the communication channel. MDW codes and EDW codes were utilized as the signature sequences and a single photodiode was used. The SAC-OCDMA system performance was investigated, and its performance was evaluated in terms of BER, Q-factor, optimum received power, and eye opening, using different codes and detectors at different transmission distances and bit rates.

The obtained results assure that the use of DCF and EDFA allows longer transmission distances with a BER under10^{-9}, especially at bit rates greater than 1 Gbps. This implies the feasibility of the proposed system as a candidate for future optical access network. The simulation results show that the use of an APD in SPD detection in the SAC-OCDMA system with EDW codes as signature codes, yields adequate BER and Q-factor. The system using the APD achieves transmission distances 40 and 30 km longer that that using a PIN detector at data rates of 622 Mbps and 1 Gbps, respectively.

Author Contributions: Conceptualization, H.A.F., A.A.E.-A. and M.H.A.; Data curation, H.A.F. and M.A.M.; Formal analysis, S.A.A.E.-M. and M.H.A.; Investigation, S.A.A.E.-M.; Supervision, H.A.F., A.A.E.-A. and M.H.A.; Validation, M.H.A.; Writing-original draft, S.A.A.E.-M.; Writing-review & editing, A.A.E.-A. and M.H.A.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kaur, N.; Goyal, R.; Rani, M. A review on spectral amplitude coding optical code division multiple access. *J. Opt. Commun.* **2017**, *38*, 77–85. [CrossRef]
2. Abd-rahman, M.S.; Shaarani, S.; Aminuddin, F. The proposal of OCDMA encoder based on optical cross and add-and-drop multiplexer (OXADM)-device characteristic. *Int. J. Comput. Sci. Netw. Secur.* **2008**, *8*, 259–266.
3. Farghal, A.E.A.; Shalaby, H.M.H. Reducing inter-core crosstalk impact via code-interleaving and bipolar 2-PPM for core-multiplexed SAC OCDMA PON. *J. Opt. Commun. Netw.* **2017**, *10*, 35–45. [CrossRef]

4. Al-Khafaji, H.M.R.; Aljunidl, S.A.; Fadhil, H.A. Spectral efficiency analysis of bipolar spectral-amplitude coding optical code-division multiple-access systems using different one-dimensional codes. *J. IET Optoelectron.* **2012**, *6*, 215–222. [CrossRef]
5. Ahmad-Anas, S.B.; Abdullah, M.K.; Mokhtar, M.; Walker, S.D. Multiple access interference elimination with enhanced chromatic dispersion tolerance in SAC OCDMA. *J. IEICE Electron. Express* **2008**, *5*, 617–623. [CrossRef]
6. Al-Khafaji, H.M.R.; Aljunidl, S.A.; Fadhil, H.A. Improved BER based on intensity noise alleviation using developed detection technique for incoherent SAC-OCDMA systems. *J. Mod. Opt.* **2012**, *59*, 878–886. [CrossRef]
7. Kaur, A.; Singh, G. Performance comparison of various detection techniques for SAC-OCDMA system using DW and MDW code. In Proceedings of the IEEE International Conference on Computing and Communication (IEMCON), Vancouver, BC, Canada, 15–17 October 2011; pp. 1–6.
8. Abd El Mottaleb, S.A.; Fayed, H.A.; Abd El Aziz, A.; Aly, M.H. SAC-OCDMA system using different detection. *IOSR J. Electron. Commun. Eng.* **2014**, *9*, 55–60. [CrossRef]
9. Wei, Z.; Ghafouri-Shiraz, H.; Shalaby, H.M.H. New code families for fiber-Bragg-grating-based spectral amplitude-coding optical CDMA systems. *IEEE Photonics Technol. Lett.* **2001**, *13*, 890–892. [CrossRef]
10. Wei, Z.; Shalaby, H.M.H.; Ghafouri-Shiraz, H. Modified quadratic congruence codes for fiber Bragg-grating based spectral-amplitude coding optical CDMA system. *J. Lightwave Technol.* **2001**, *19*, 1274–1281. [CrossRef]
11. Salehi, J.A.; Brackett, C.A. Code division multiple access technique in optical fiber networks. Part II: System performance analysis. *IEEE Trans. Commun.* **1989**, *37*, 834–842. [CrossRef]
12. Aljunid, S.A.; Ismail, M.; Ramli, A.R.; Ali, B.M.; Abdullah, M.K. A new family of optical code sequences for spectral-amplitude-coding optical CDMA systems. *IEEE Photonics Technol. Lett.* **2004**, *16*, 2383–2385. [CrossRef]
13. Ahmad Anas, S.B.; Abdullah, M.K.; Mokhtar, M.; Aljunid, S.A.; Walker, S.D. Optical domain service differentiation using spectral-amplitude-coding. *J. Opt. Fiber Technol.* **2009**, *15*, 26–32. [CrossRef]
14. Fadhil, H.A.; Aljunid, S.A.; Ahmed, R.B. Effect of random diagonal code link parameters on the performance of an OCDMA scheme for high-speed access networks. *J. Opt. Fiber Technol.* **2009**, *15*, 237–241. [CrossRef]
15. Abd, T.H.; Aljunaid, S.A.; Fadhil, H.A. A new technique for reduction of the phase induced intensity noise in SAC-OCDMA system. *J. Opt. Commun.* **2011**, *32*, 263–267. [CrossRef]
16. Al-Khafaji, H.M.R.; Aljunid, S.A.; Amphawan, A.; Fadhil, H.A. SOA/SPD-based incoherent SAC-OCDMA system at 9× 5Gbps. *IEICE Electron. Express* **2013**, *10*. [CrossRef]
17. Campbell, J.C. Recent Advances in Telecommunications Avalanche Photodiodes. *J. Lightwave Technol.* **2009**, *25*, 109–121. [CrossRef]
18. Hasko, D.; Kovac, J.; Uherek, F.; Skriniarova, J.; Jakabovic, J.; Peternai, J.L. Design and Properties of InGaAS, InGaAsP, InP Avalanche photodiode. *J. Electr. Eng.* **2007**, *58*, 173–176.
19. Sun, P.; Hayat, M.M.; Das, A.K. Bit error rates for ultrafast APD based optical receivers: Exact and large deviation based asymptotic approaches. *IEEE Trans. Commun.* **2009**, *57*, 2763–2770. [CrossRef]
20. Rochette, M.; Ayotte, S.; Rusch, L.A. Analysis of the spectral efficiency of frequency-encoded OCDMA systems with incoherent sources. *J. Lightwave Technol.* **2005**, *23*, 1610–1619. [CrossRef]
21. Abdullah, M.K. Construction of a new code for spectral amplitude coding in optical code-division multiple-access systems. *J. Opt. Eng.* **2007**, *46*, 75004. [CrossRef]
22. Abdulqader, S.G.; Aljundi, S.A.; Al-Khafaji, H.M.R.; Fadhil, H.A. Enhanced performance of SAC-OCDMA system based on SPD detection utilizing EDFA for access network. *J. Commun.* **2014**, *9*, 99–106. [CrossRef]
23. Keiser, G. *Optical Fiber Communications*; Wiley: Hoboken, NJ, USA, 2003.
24. Al-Khafaji, H.M.R.; Aljundi, S.A.; Amphawan, A.; Fadhil, H.A.; Safar, A.M. Reducing BER of spectral-amplitude coding optical code division multiple-access systems by single photodiode detection technique. *J. Eur. Opt. Soc.-Rapid Publ.* **2013**, *8*, 13022. [CrossRef]