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Performance enhancement of incoherent spectral amplitude encoding-optical code division multiple access (SAE-OCDMA) by using dispersion compensation fiber Bragg grating (FBG)

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Incoherent spectral amplitude encoding optical code division multiple access (SAE-OCDMA) based on fiber Bragg grating (FBG) is one promising technique aim to improve local area networks to have longer span telecommunication network type. In this study, the performance enhancement incoherent SAE-OCDMA is achieved when a dispersion compensation fiber Bragg grating (DCFBG) and erbium doped fiber amplifier (EDFA) are used in optical link. Though, the results can be obtained, these components give good indicator on system performance. In the design, DCFBG is introduced as the dispersion compensation to eliminate the effect of the positive dispersion. This leads to reduce multiple access interference (MAI). While EDFA, is used to compensate loss in conventional single mode fiber (SMF). As a result, the maximum bit error rate (BER) reaches 10^{-9} and 10^{-6} for 3 and 7 users, respectively without DCFBG and EDFA at 40 km, respectively, but with DCFBG, the maximum BER reaches 10^{-21} and 10^{-10} for 3 and 7 Users, respectively, at the same distance. In this presence case, EDFA and DCFBG are together in optical channel, the maximum BER reaches 10^{-22} and 10^{-12} for 3 and 7 users respectively at the same distance (40 km). So that, the transmission distance is improved to 160 and 140 km for 3 and 7 Users, respectively. Simulation results presented in this study are obtained using Opti system and Opti Grating Softwares.

Key words: Spectral amplitude encoding-optical code division multiple access (SAE-OCDMA), dispersion compensation fiber Bragg grating (DCFBG), multiple access interference (MAI), phase induced intensity noise (PIIN), Walsh hadamard code (WH code).

INTRODUCTION

Recently, interest has increased in spectral-amplitude-encoding optical code-division multiple access (SAE-OCDMA) systems based on fiber Bragg grating due to their ability to assuage multiple access interference (MAI) influence on performance, in addition to their cost savings (Shastri et al., 2008; Al-Khafaji et al., 2012). Where

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Spectral Amplitude encoding (SAE) technique was first demonstrated by Zaccarin and Kavehrad (1995). SAE-OCDMA is one of the competing technologies for future multiple access networks, and it achieved multiplexing transmission and multiple accesses by coding in the optical domain, which supports multiple subscribers in the same time slot and the same frequency (Yin and Richardson, 2007).

SAE-OCDMA systems design is based on encoding the information signal in the time domain by a pseudorandom sequence. Efficient systems for use in local area network (LAN) environments can be obtained. It will always suffer from a basic limitation. As the number of simultaneous active users is increased, the code length has to be increased in order to maintain the same performance. In such systems, that will refer to as SAE-OCDMA systems, the coding is done in the wavelength domain while in the usual CDMA systems, the code multiplies the modulation signal in the time domain (Kavehrad, 1995). To improve the bit error rate of the system multi-fiber, Bragg gratings are used at transmitter and receiver ends with same reflectivity (Ranjan, 2014).

A fiber Bragg grating (FBG) is a type of distributed Bragg reflector constructed in a short segment of optical fiber that reflects particular wavelengths of light and transmits all others. Reflectivities approaching 100% are possible, with the grating bandwidth tailored from typically 0.1 nm to more than tens of nanometers. These characteristics make Bragg gratings suitable for telecommunications, where they are used to reflect, filter or disperse light (Hill et al., 1978). The FBG written by ultraviolet light (UV) into the core of an optical fiber has developed into a critical component for many applications in fiber-optic communication and sensor systems. When ultraviolet light radiates an optical fiber, the refractive index of the fiber is changed permanently; the effect is termed photosensitivity. The change in refractive index is permanent in the sense that it will last for decades (life times of 25 years are predicted) if the optical waveguide after exposure is annealed appropriately, that is by heating for a few hours at a temperature of 50°C above its maximum operating temperature (Erdogan et al., 1994).

Practically, the most commonly used light sources are KrF, ArF excimer lasers and femtosecond laser that generate 248, 193 and 264 nm , respectively, optical pulses (pulse width 10 ns and 260 fs) at pulse repetition rates of 50 to 75 pulses/s and 1- 500 KHZ, respectively. The typical irradiation conditions are an exposure to the laser light for a few minutes at intensities ranging from 100 to 1000 mJ/cm^2. Under these conditions, Δn is positive in germanium doped fiber with a magnitude ranging between 10^{-5} for weak grating to 10^{-3} for strong grating (Erdogan et al., 1994).

Advantages of fiber Bragg gratings over competing technologies include all-fiber geometry, low insertion loss, high return loss or extinction, and potentially low cost. But the most distinguishing feature of fiber gratings is the flexibility they offer for achieving desired spectral characteristics. Multi- physical parameters can be changed, including: induced index change, length, apodization, period chirp, fringe tilt, and whether the grating supports counter-propagating or co-propagating coupling at a desired wavelength (Erdogan et al., 1994). Multi-fiber Bragg gratings (FBGs), having the same bandwidth and different Bragg wavelengths are used to obtain the signature codes in SAE-OCDMA (Tiwari and Singh, 2013). OCDMA supports multiple asynchronous, concurrent users which occupy the same time slots and frequency domain. In addition, OCDMA systems have the advantages of providing multiple users to simultaneously access the same bandwidth with high-level security (Aljunid et al., 2004).

Nonetheless, the OCDMA systems suffer from different noises such as a shot noise, thermal noise, a dark current and a phase-induced intensity noise (PIIN). In addition, multiple access interference (MAI) associated with availability of many users is considered as a dominating system-degradation factor for the OCDMA networks. Therefore, intelligent design of the code sequence is important when reducing contribution of the MAI to the total optical power received (Stok and Sargent, 2000).

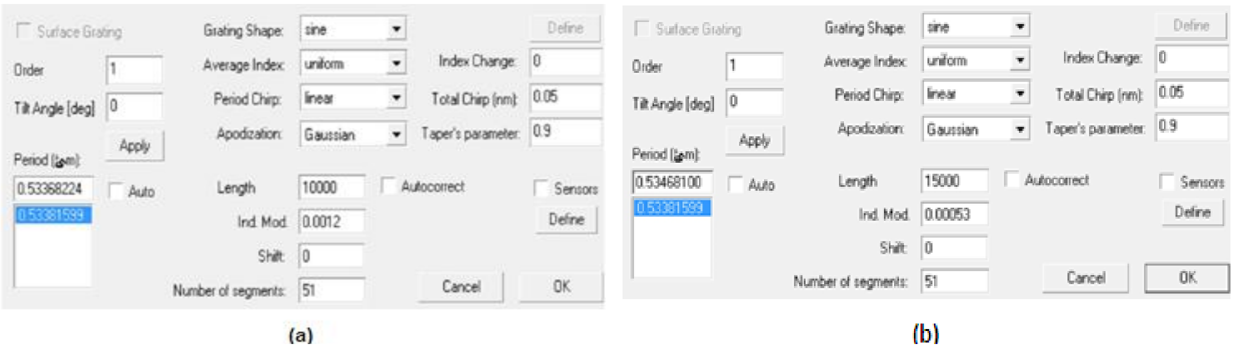
Accordingly, SAE–OCDMA technologies have been introduced, to result in good solutions which have reduced the effect of MAI by utilizing codes with fixed in-phase cross-correlation (Noshad and Jamshidi, 2010). In addition, the balance scheme shows that MAI can be eliminated with Hadamard code (Smith et al., 1998). To support a high-capacity (SAE-OCDMA) transmission, the embedded standard fiber Bragg grating (FBG) should be up rated to overcome the dispersion limit. Dispersion compensating fibers (DCF) have been extremely used to compensate the positive dispersion to improve transmission distance (Raad et al., 2012). But the insertion of DCF increases the aggregate loss, cost of the optical transmission system and nonlinear effects. In addition, the magnitude of compensation is wavelength dependent and can only be quite achieved in a relatively narrow band (Agrawal, 1997). Therefore, dispersion compensation fiber Bragg grating (DCFBG) has also been proposed recently for positive dispersion compensation and is known as a perfect alternative to DCF.

The aim of this study is to obtain the best performance of SAE-OCDMA by using dispersion compensation fiber Bragg grating, multi-FBG and optical amplifier.

MATERIALS AND METHODS

Description of spectral amplitude

With development and ripeness of FBGs, they can be employed as the choosing wavelength filters to implement the Spectral Amplitude



Profile 1. Structure parameters of Array-FBG a- 3 Users b- 7 Users.

Table 1. Bragg wavelengths for 3 user.

Period grating (nm)	Bragg wavelengths (nm)
534.5088001	1552
533.9577601	1550.4
533.6822400	1549.6
533.1312001	1548

Encoding (SAE). The implementation of SAE-OCDMA is to overcome the deficiency of the bulk-optic spectral amplitude encoder/decoder. The spectral amplitude operates where the light pulse from a incoherent light source is modulated by data, and also go through the FBGs with different wavelength to determine the chosen user's address code word (Shalaby et al., 2001). SAE was introduced to eliminate the MAI existing in conventional OCDMA systems.

SAE systems use complementary detection technique to recover the original signals (Smith et al., 1998). The effect of MAI can be eliminated by using subtraction detection technique. The most common subtraction detection technique is the complementary subtraction detection technique, which is also known as balanced detection technique (Kavehrad, 1995). This balance receiver is used as a part of receiver which filters the incoming signals. For unmatched transmitters, half of transmitter spectral components will match the direct filter and the other half will match the complementary filter. The output of the balance receiver represents the difference between the two parts, with unmatched channels being cancelled. It is possible to design codes with the full orthogonality in the incoherent spectral intensity OCDMA system, since there is a subtraction between two photo detectors. In this system, the signature sequence is spread across different wavelength with each chip occupying different wavelength. The advantage of optical spreading CDMA is that; it does not need synchronization as the chip spreads in frequency and not in time (Kavehrad, 1995). Incoherent SAE-OCDMA is a good candidate for optical multiple access networks over other OCDMA techniques. The incoherent source appears as a good indicator for SAE as it is inherently broadband, a necessary characteristic of SAE (Fadhil et al., 2010). The important feature of the SAE-OCDMA systems is that multiple access interference (MAI) can be eliminated by code sequences of a fixed in-phase cross-correlation value. This study uses Walsh-Hadamard codes as signature codes (S-Pin, 2003).

Building of multi-FBG as encoder/decoder

The characteristics response from Bragg Grating can be analyzed as fully described by:

1. The center wavelength of grating λ_B .

2. Peak reflectivity Rmax of grating which occur at λ_B .

3. Physical length of grating L .

Thus, the designed multi -FBG parameters structure can be summarized in Profile 1 for 3 and 7 users.

Thus, parameters set of multi-FBG are shown in Tables 1 and 2 for 3 and 7 users, respectively, depending on the center wavelength of grating which can be expressed as this in Equation 1.

$$\lambda_B = 2.n_{eff} .\Lambda \qquad (1)$$

Where :- n_{eff} : is the effective refractive index of the fiber core; Λ : is the period of FBG.

After setting, these Bragg wavelengths used to implement the SAE in OCDMA (Table 3) show some parameters that are related to multi –FBG for 3 and 7 users by using OptiGrating Software. Thus, the grating spectrum of multi-FBG for 3 and 7 users, respectively can be shown with opti Grating software (Figure 1a to b).

Dispersion compensation FBG

Chromatic dispersion compensation using highly efficient reflective FBGs is fundamentally different from the incumbent technology used for dispersion compensation, namely Dispersion Compensation Fiber (DCF).

Table 2. Bragg wavelengths for 7 user.

Period grating (nm)	Bragg wavelengths (nm)
534.6810001	1552.5
534.5088001	1552
534.3366001	1551.5
534.1644001	1551
533.9922001	1550.5
533.8200001	1550
533.6478001	1549.5
533.4756001	1549

Table 3. Show, peak reflectivity, FWHM, and effective refractive index.

Parameter	3 users	7 users
Reflectivity	0.9999999	0.99994
FWHM	0.6	0.3
n_{eff}	1.451800232	1.451800232

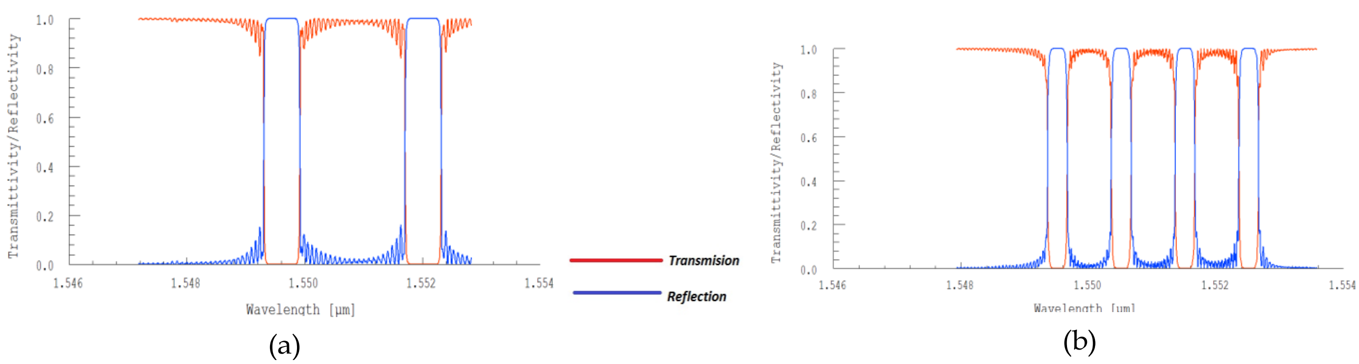


Figure 1a-b. Grating spectrum of multi-FBG a-3 users b-7 users.

After 40 km propagation in SMF, the accumulated dispersion is 670 ps/nm. In order to compensate for this accumulated dispersion, the corresponding option Dispersion in the main tab of the Ideal Dispersion Compensation FBG is fixed as – 670 ps/nm Equation (2).

$$D_T = D_{SMF} \times L_{SMF} \tag{2}$$

Where: D_T : is the accumulated dispersion in optical link; D_{SMF} : is the dispersion of SMF, typically is 16.75 ps/nm-km; L_{SMF} : is the length of optical fiber.

The bandwidth of DCFBG(B_{DCFBG}) used in the simulation calculated from.

$$B_{DCFBG} = \Delta\lambda \tag{3}$$

Where: $\Delta\lambda$: is the line width of incoherent optical source.

Thus, the line width of incoherent optical source can be expressed by Equation 4 (S-Pin Tseng, 2003).

$$\Delta\lambda = \Delta f \; / \; \left(c \; / \; \lambda^2 \right) \tag{4}$$

$$\Delta f = P_{average} \; / \; PSD \tag{5}$$

Where: $P_{average}$: is the average power of incoherent optical source. It can be measured with power meter; PSD : is the average value of the power spectral density of incoherent optical source that can be calculated in Equation 5 (Raad et al., 2012); Δf : is the linewidth of optical source in frequency; λ : is the wavelength of incoherent optical source; c ; is the speed of light in Vacuum.

Finally, how to use an ideal dispersion component in optisystem software for dispersion compensation in SAE-OCDMA is explain.

Table 4. Walsh Hadamard code with length of 4 for 3 user.

Walsh Hadamard codes	Wavelengths
1010	FBG1-FBG3
1100	FBG2-FBG3
1001	FBG1-FBG2

Table 5. Walsh Hadamard code with length of 8 for 7 user.

Walsh Hadamard codes	Wavelengths
10101010	FBG1-FBG3- FBG5-FBG7
11001100	FBG2-FBG3- FBG6-FBG7
10011001	FBG1-FBG2- FBG5-FBG6
11110000	FBG4-FBG5- FBG6-FBG7
10100101	FBG1-FBG3- FBG4-FBG6
11000011	FBG2-FBG3- FBG4-FBG5
10010110	FBG1-FBG2- FBG4-FBG7

Code construction and properties

Walsh-Hadamard consists of the row vector of a Walsh code matrix is arranged according to the order of Hadamard. It is also called Walsh code (Yen et al., 2013). The elements of this Walsh matrix are ±1, which can be rapidly generated from the following recursion relation:

$$A(i+1)=\begin{bmatrix}+A(i)+A(i)\\+A(i)-A(i)\end{bmatrix} \quad (6)$$

For 3 users SAE-OCDMA network, the code word of A(2) is used. Why, for 7 users SAE-OCDMA network, the code word of A(3) is used. A(2) is a 4×4 Walsh matrix; while A(3) is a 8×8 Walsh Matrix. But the 1st line of the code from both matrixes is consisting of a group of logic “1”. The row of logic “1” is not in use, as though the decoding processing, the data will be extracted out by using multi-FBGs (Tables 4 and 5).

Incoherent SAE-OCDMA system model

In OCDMA System, SAE is most effective because of assigning unique code to each user. SAE technique which is operated on bit rate is a cost effective technique for end users. SAE-OCDMA systems use cheap incoherent white Light sources for SAE, but also affected by Phase Induced Intensity Noise (PIIN). PIIN noise largely limits the performance of SAE-OCDMA systems. PIIN arises due to the incoherent light mixing and incident on a photo-detector, less cross-correlation values between signature codes, and reduces the MAI and PIIN effectively; hence increase the SAE-OCDMA system performance. In addition, dispersion in SMF-28(GVD) is also an important system limitation for long transmission distance which must be reduced. Thus, DCFBG is reducing the effect of dispersion in network.

The adopted block diagram of incoherent SAE-OCDMA for 3-users based on DCFBG is presented in Figure 2.

SAE-OCDMA for 3-users and 7 users

In this design, Incoherent White light source used in the transmitter section and number of FBGs is specified with respect to the code weight. SAE uses Walsh-Hadamard code with weight 2 for 3 user and weight 4 for 7 user. The electric data of each user is modulated by Mach–Zehnder modulator (MZ) on a White light source to obtain intensity modulated signal. Then the modulated pulse goes through the multi-FBG with different wavelengths (as encoders and decoders for the incoherent optical signal). Finally, before transmitting signal by the optical channel, all users are collected by a Power combiner and transmitted through the channel. The receiver is comprised of a spectral filter and a photo detector connected in a balanced configuration which performs the decoding with a low-pass filter and a BER analyzer.

RESULTS AND DISCUSSION

The simulation parameters in Optisystem software are chosen for 3 and 7 users SAE-OCDMA as shown in Table 6. The Incoherent SAE-OCDMA for computing BER tester, eye diagram analyzer and quality factor values for different methods use BER analyzer.

Effect of the transmitted power on BER with and without DCFBG

Many parameters influence this system performance which are formerly available as transmitted power, the required input power at the receiver to obtain the desired bit error rate (BER), the overall system loss and bandwidth are shown in Figure 3a and b, the BER as a function of input power for 3 and 7 users respectively use DCFBG. When the average power of incoherent optical source is increased, BER is decreased, but when the input power reaches approximately 2 and 6 mW for 3 and 7 users, respectively, after that the BER value remain stable. Due to this, each of the system has optimum power, so that the

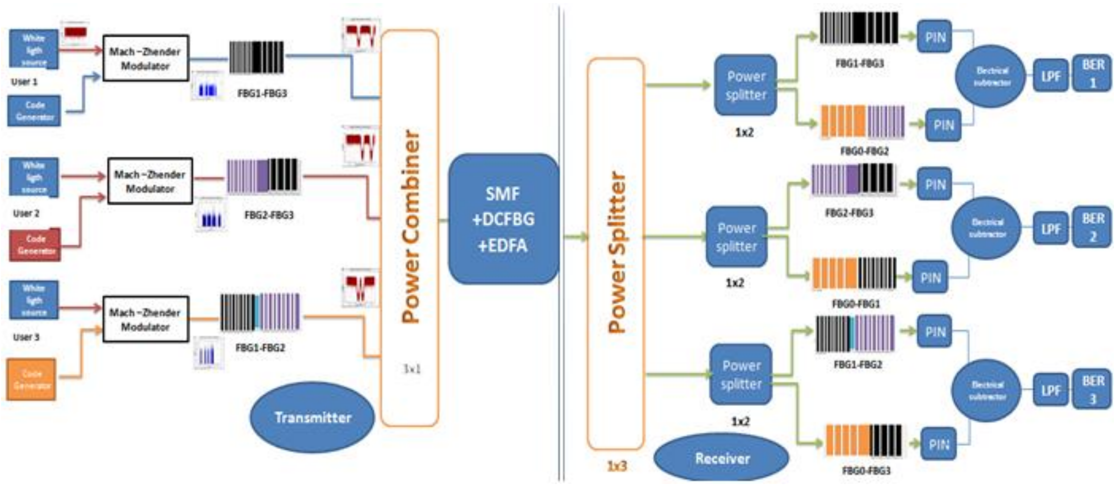


Figure 2. Block digram of 3 user Incoherent SAE-OCDMA.

Table 6. Incoherent SAE-OCDMA simulation parameters.

Parameter	7 Users	3 Users
Operating wavelength	1550.75 nm	1550 nm
Power spectral density	$9.6\text{x}10^{-15}$ W/HZ	$3.2\text{x}10^{-15}$ W/HZ
Fiber length	40 km	40 km
Extinction ratio (MZ)	60 dB	60 dB
Fiber attenuation	0.2 dB/km	0.2 dB/km
Dark current	5 nA	5nA
Responsivity	1 A/W	1 A/W
Receiver filter bandwidth	140 MHZ	140 MHZ
Erbium doped fiber amplifier (EDFA) Gain	20 dB	20 dB
Signal bit rate	200 Mbps	200 Mbps
Bit rate	10 Gchip/s	10G chip/s
Sequence length	1024 bit	1024 bit
Samples per bit	64 sample	64 sample

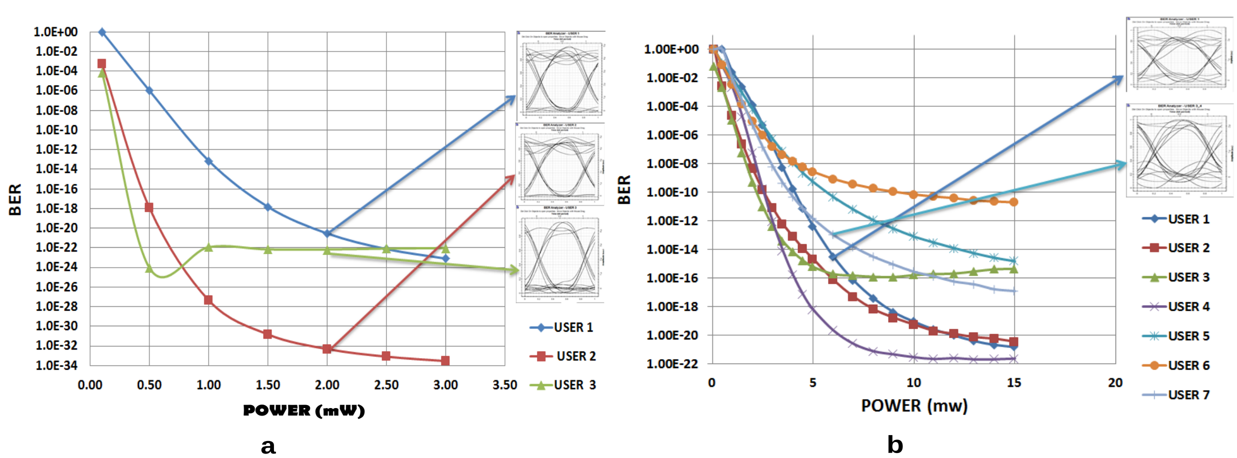


Figure 3. (a). Plotting of input power versa BER presence DCFBG for 3 Users. (b) Plotting of input power versa BER presence DCFBG for 7 Users.

Table 7. BER for 3 and 7 users at 40 km.

Users	3 User
	DCFBG is present
BER1	2.9×10^{-21}
BER2	4.9×10^{-33}
BER3	6.8×10^{-23}
Users	**7 User**
	DCFBG is present
BER1	3.35×10^{-15}
BER2	7.67×10^{-17}
BER3	1.95×10^{-16}
BER4	2.25×10^{-20}
BER5	4.78×10^{-11}
BER6	8.74×10^{-10}
BER7	1.07×10^{-13}

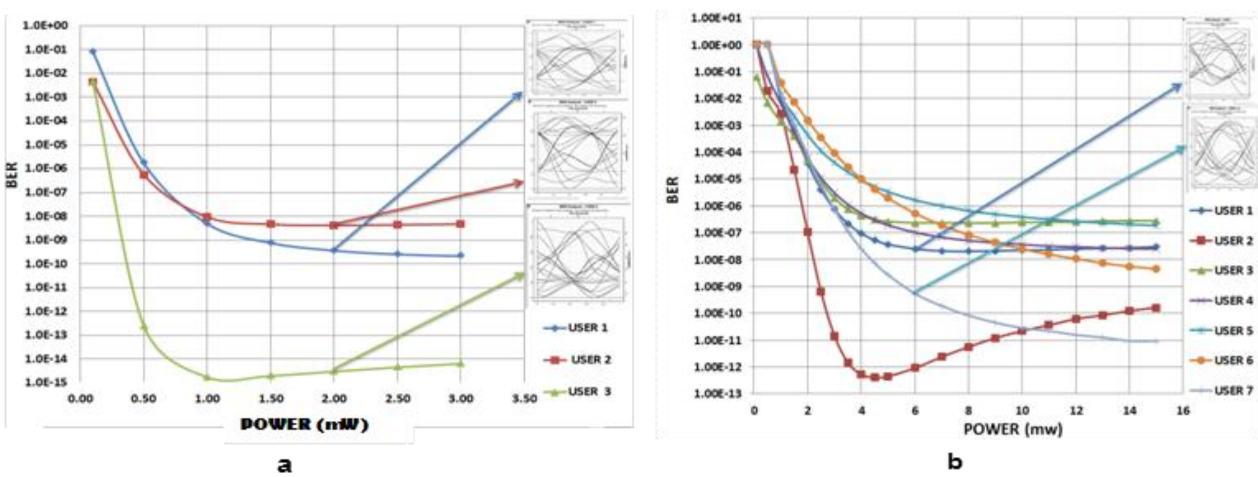
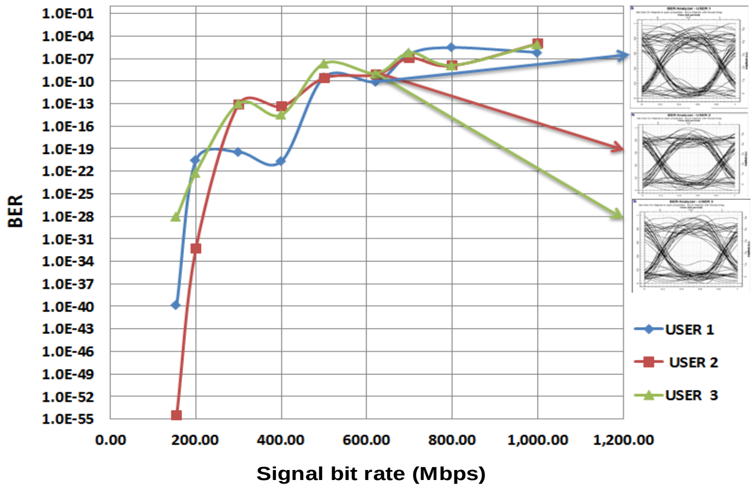


Figure 4. (a) Plotting of input power versa BER absence DCFBG for 3 Users. (b) Plotting of input power versa BER absence DCFBG for 7 Users.

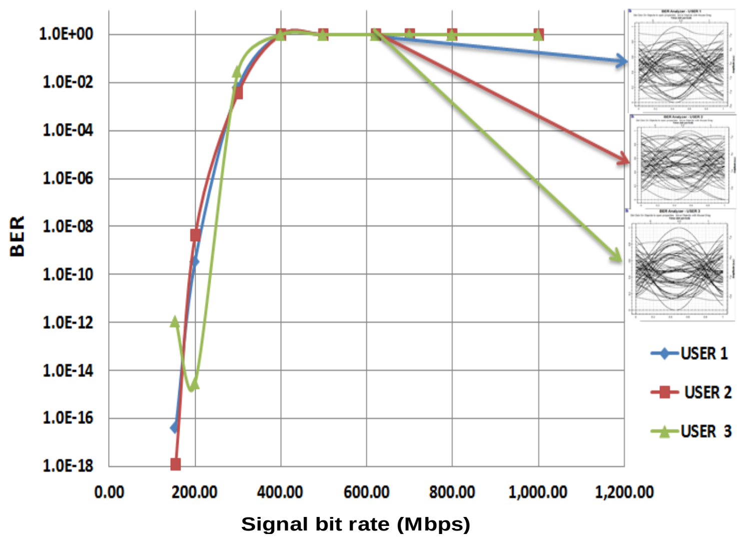
optimum power for 3 and 7 users are 2 and 6 mW respectively in SAE-OCDMA. When the transmitted power increases until it reaches the optimal values, a signal to noise ratio (SNR) is increased, the BER leads is reduced. In addition, the BER value is reduced with the presence of DCFGB at 40 km optical link (Table 7). DCFBG allows the long wavelength (red wavelength) travels fast than the short wavelength (blue wavelength). This mechanism operates to reduce the pulse broadening, to prevent crosstalk between pulses. This process leads to enhance the signal power. Therefore, BER is improved.

When DCFBG is neglected, the BER reaches 3.6×10^{-10}, 4.18×10^{-9}, and 3.02×10^{-15} for User 1, 2 and 3, respectively, at 40 km as shown in Figure 4(a). The BER value is increased compared with the BER value (Figure 3a), due to a single mode fiber G-652 used between the transmission and receiver sides in SAE-OCDMA contains the material dispersion. The value of the material dispersion is increased, when the length of a SMF becomes bigger than 40 km. Thus, the transmitted power increases in this case, which does not affect the BER value, because of the effect of the material dispersion. The material dispersion cause the pulse broadening, so that, this effect appears on the BER value (Figure 4b).

The BER becomes large than 10^{-9} for 7 users. Due to this increase, a number of users can be affected on the performance of system although input power increased. In addition, the effect of material dispersion on the system performance, where BER value oscillate between (10^{-6} ~10^{-13}) at the same distance (40 km), where incoherent



a



b

Figure 5. (a) Plotting of signal bit rate versa BER presence DCFBG for 3 Users. **(b)** Plotting of signal bit rate versa BER absence DCFBG for 3 Users.

SAE-OCDMA suffers from phase induced intensity noise, especially when the number of active users are increasing with low power. But an incoherent optical source prefers SAE-OCDMA because it is producing same power on the overall bandwidth of pulse. Therefore, DCFBG, MAI and PIIN are increased in this case, and Q-factor value and eye diagram opening are reduced.

Effect of signal bit rate on BER with and without DCFBG

Figure 5(a) shows the BER at the receiver side increased with increasing signal bit rate, where BER becomes 9.2×10^{-9}, 7.3×10^{-10} and 1.12×10^{-9} for User 1, 2 and 3, respectively, at 40 km with 622 Mbps a presence DCFBG. While BER becomes large than 10^{-9} without DCFBG after 200 Mbps as shown in Figure 5(b). Due to, the effect of positive dispersion in SMF becomes more with a high signal bit rate. So, when a signal bit rate changes from 200 Mbps into 622 Mbps without DCFBG, in this case, the MAI effect is increased, therefore, the BER value is also increased. Thereby, a DCFBG plays important role to reduced the effect of a positive dispersion to reduce MAI effect when a signal bit rate was increased in an incoherent SAE-OCDMA for 3 user.

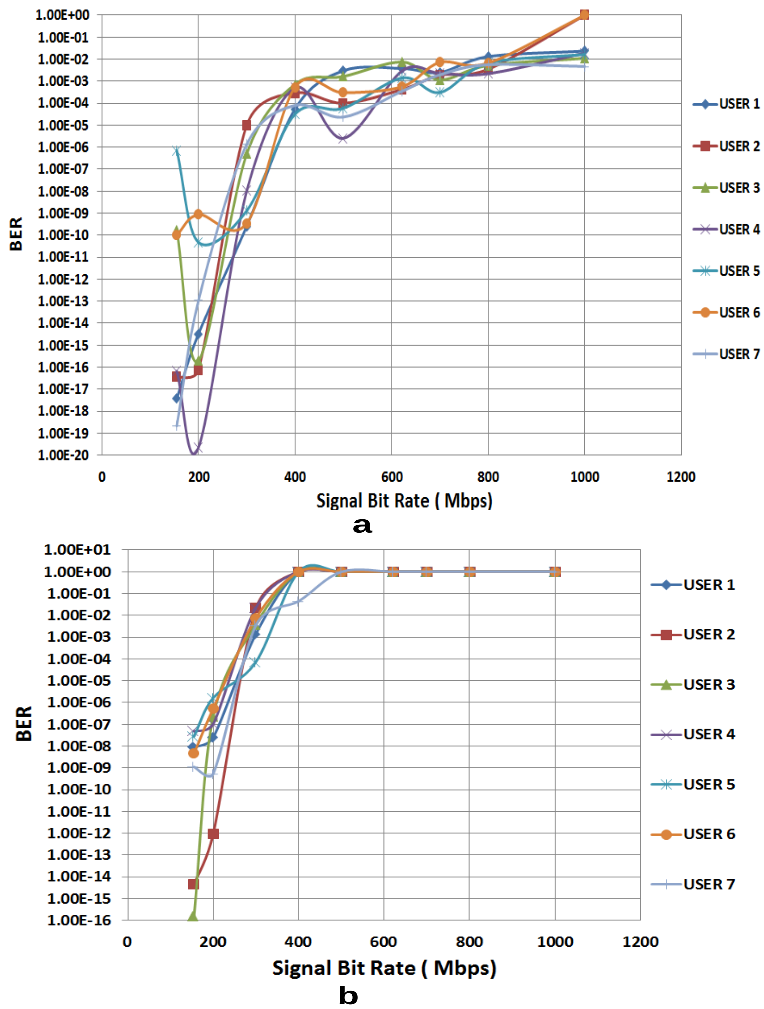


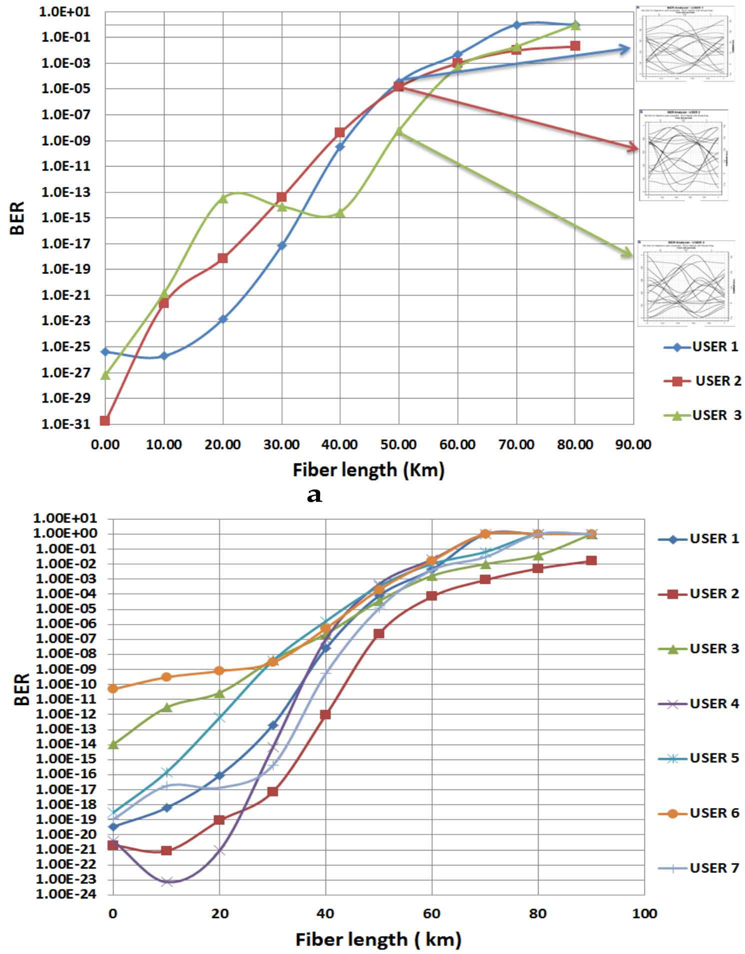
Figure 6. (a) Plotting of signal bit rate versa BER presence DCFBG for 7 Users. (b) Plotting of signal bit rate versa BER absence DCFBG for 7 Users.

In the case of the 7th user, the BER value appears larger than 10^{-9}, the presence or absence of DCFBG at 622 Mbps are shown in Figure 6 (a and b). With the number of simultaneous active users, data rate and the positive dispersion effect are increased, inter symbol interference is also increased, this leads the performance of system deteriorates. In addition, an incoherent optical source can be consider more suitable with the low data rate, not suitable with a high data rate. But, an incoherent white light source prefers to use SAE rather than the coherent optical source because, the coherent source is not able to transmit more user data, due to the line width of a coherent source is very narrow. In addition, the coherent source suffers from optical beat noise (OBN). So, a high data rate in an incoherent SAE-OCDMA for 7 users, aim to increase the MAI effect, an effect for the material dispersion will appear on the system performance until, if the effect of material dispersion is little. Therefore, the BER values appears to be bad with DCFBG as show in Figure 6 (a), but, absence of DCFBG in the BER values appear to be very bad as show in Figure 6 (b).

Effect of fiber length on BER with and without DCFBG

Figures 7 and 8 display the variation of BER for each user with different fiber length in the absence and presence of dispersion compensation FBG. The BER can be explain with Table 8 for absence and presence of DCFBG at 50 km.

Note from results in Table 8, the BER improves with DCFBG. When the fiber length is increased, the



b

Figure 7. (a) Plotting of fiber length versa BER without DCFBG for 3 Users. (b) Plotting of fiber length versa BER without DCFBG for 7 Users.

dispersion of optical fiber will be increased to 16.75 ps/nm for each kilometer. This dispersion produced broadening pulses, thereby, a MAI appears. To prevent it, DCFBG solves these problems. Therefore, DCFBG improves transmission distance, thereby, to enhance local area network to longer span telecommunication network. Where the transmission distance may up to 40 km, 30 km for 3 and 7 users, respectively, in the case of absence of DCFBG, where the BER value at these distances are less than 10^{-9} are shown in Figure 7a and b. While it may up to 70 and 50 km for 3 and 7 users, respectively, the presence of DCFBG are shown in Figure 8 a and b. The BER value is also enhanced by using DCFBG.

Effect of fiber length on BER with DCFBG and EDFA

When DCFBG and EDFA both are used in optical link, the BER value for each user becomes good value. From Figure 9(a), the BER value for user 1, 2 and 3 are 1.25×10^{-9}, 1.57×10^{-16}, and 1.619×10^{-12}, respectively at 160 km. There are two important factors affected on the system performance. The first factor is the attenuation in a SMF. Where the fiber attenuation are equal to 0.2dB/km. Another factor is the chromatic dispersion. The gain in the main tab of the erbium doped fiber amplifier (EDFA) is fixed as 20 dB. This value suffices to compensate a fiber losses, especially, when the fiber length is equal to 100 km. Thus, the gain in optical amplifier (EDFA) depend on a fiber attenuation for each kilometer and fiber length in this system. In addition, splice and connector losses. EDFA can be used to compensate a fiber loss in an optical channel, therefore, EDFA is very important in the large distance. Also, a DCFBG has recently had a lot of attention as a mean of increasing the transmission capacity and the transmission distance. Where the dispersion coefficient in SMF is

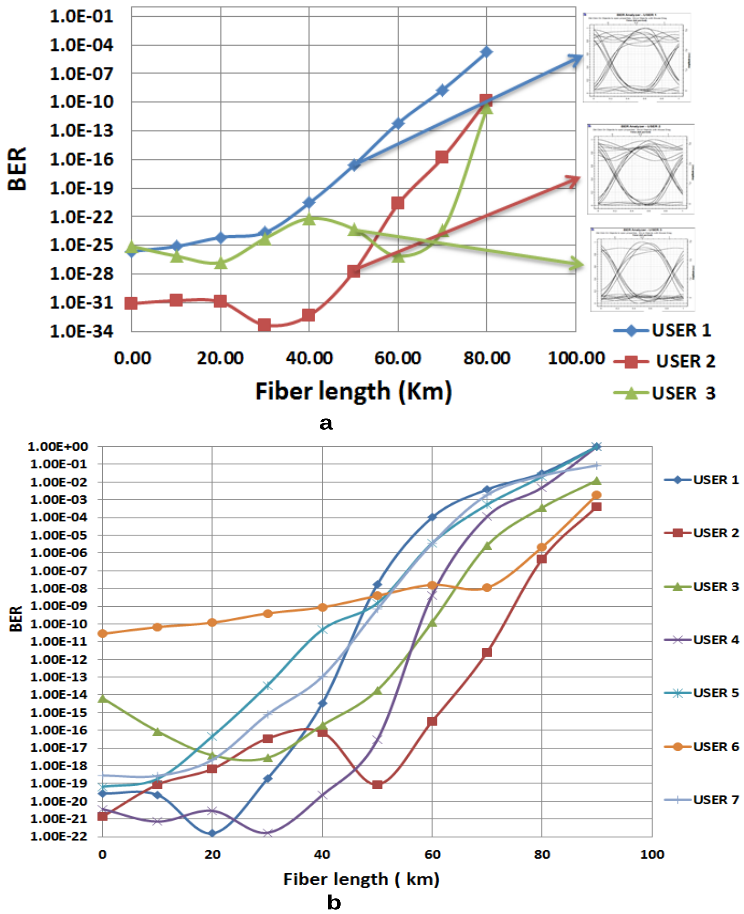


Figure 8. (a) Plotting of fiber length versa BER with DCFBG for 3 Users. (b) Plotting of fiber length versa BER with DCFBG for 7 Users.

Table 8. BERs for 3 and 7 users at 50 km.

Users	3 User	
	Without DCFBG	With DCFBG
BER1	$3.55x10^{-5}$	$2.5x10^{-17}$
BER2	$1.40x10^{-5}$	$1.79x10^{-28}$
BER3	$6.6x10^{-9}$	$5.46x10^{-24}$
Users	7 User	
	Without DCFBG	With DCFBG
BER1	$8.02x10^{-5}$	$1.68x10^{-8}$
BER2	$2.4x10^{-7}$	$8.68x10^{-20}$
BER3	$3.58x10^{-5}$	$1.83x10^{-14}$
BER4	$4.74x10^{-4}$	$2.87x10^{-17}$
BER5	$3.38x10^{-4}$	$1.49x10^{-9}$
BER6	$2x10^{-4}$	$3.88x10^{-9}$
BER7	$1.16x10^{-5}$	$6.74x10^{-10}$

16.75 ps/nm-km, and the fiber length is 100 km, the positive dispersion value becomes 1675 ps/nm. So, the dispersion in the main tab of DCFBG is fixed as -1675ps/nm. This value suffices to compensate a positive

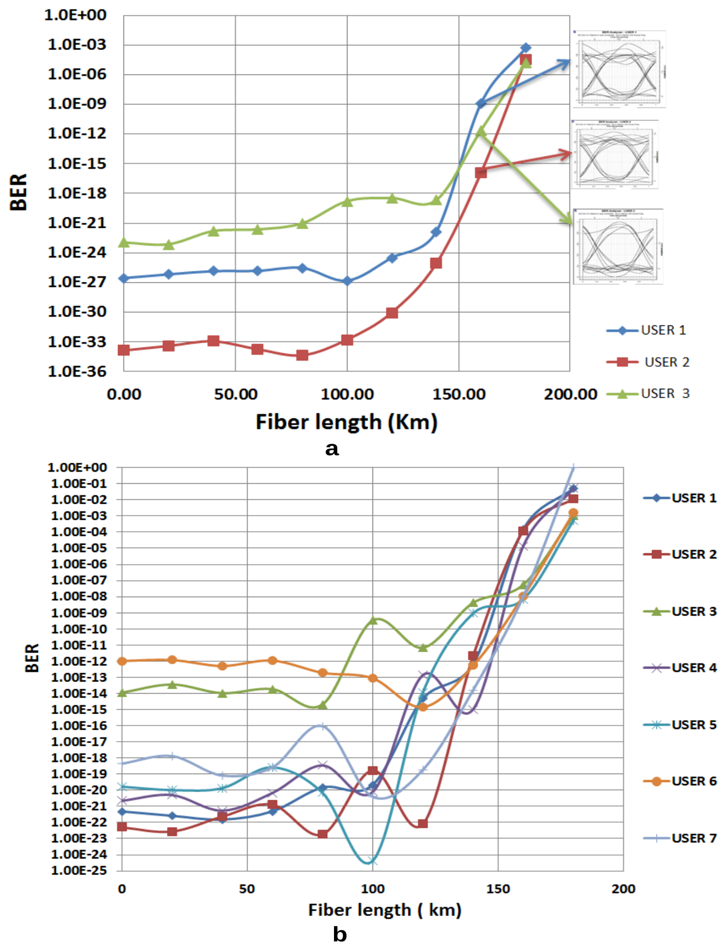


Figure 9. (a) Plotting of fiber length versa BER with DCFBG and EDFA for 3 Users. (b) Plotting of fiber length versa BER with DCFBG and EDFA for 7 Users.

Table 9. Explain Q-factor for 3 users at 160 km.

Q-factor	Absence EDFA+DCFBG	Presence EDFA+DCFBG
User 1	0.00	5.95
User 2	0.00	8.16
User 3	0.00	6.94

dispersion.

Therefore, an optical transmission distance improved to 160 km and 140 km for 3 and 7 user, respectively by using DCFBG and EDFA together. when the number of users increases to 7 users, the BER, presence EDFA and DCFBG together, can obtain less than 10^{-9} at 140 km as shown in Figure 9(b). Note, DCFBG and EDFA together are used to overcome losses in optical link such as attenuation and group velocity dispersion (GVD) to obtain the best signal to noise ratio, eye opening and quality factor as shown in Table 9. Also, note from Figure 9(b), shows BER values for the most user become less at 100 km. Due to this, there is gain effect in EDFA. Also, note from all results can be explain in all figures, the BER value is different from one user to another. Due to non ideal FBG, there is an incoherent light source (amplified spontaneous emission) and a positive/a negative dispersion in SMF.

Conclusion

In this study, the performance enhancement of Incoherent SAE-OCDMA using dispersion compensation fiber Bragg grating and erbium doped fiber amplifier were studied. The proposed SAE-OCDMA system implemented using DCFBG were used to achieve low bit error rate, large transmission distance and large data capacity. These results are valuable for improving system performance by using DCFBG, where the BER is reduce twice by using DCFBG and EDFA together. As seen from results, Single mode fiber (SMF) with DCFBG and EDFA, improve the fiber length and BER compare with absence DCFBG. When the effects of dispersion and attenuation in SMF are compensated, the optical link becomes 160 km, 140 km for 3 and 7 users, respectively, where the BER attain less than 10-9. In addition, Q-factor and eye opening are enhanced.

Conflict of Interest

The authors have not declared any conflict of interest.

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