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STUDY ON MODIFIED WALSH CODE FOR OPTICAL CODE DIVISION MULTIPLE ACCESS

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Abstract

Optical code division multiple access (OCDMA) networks based on spectral amplitude codes is used widely to remove some kinds of noise and share the bandwidth by sending/receiving multiple subscribers data over a single channel. Our research article describes and simulates low cost-effective model for modified Walsh coding (MWC) to overcome Walsh Hadmarad code limitation with increasing number of subscribers for former works. The MWC is created, simulated and compared using two techniques; optigrating software and uniform fiber Bragg grating (UFBG) with balanced detector. The results revealed that the better system performance quality of the encoding is with optigrating software. The bit error rate (BER) at mid value of -45 dBm electrical received power reduces to 10^{-266} for three users system. Better system performance is obtained when the number of users is decreased to two and one.

Keywords: Bit error rate, Modified Walsh code (MWC), Optigrating, SAC-OCDMA, Uniform fiber Bragg grating.

1. Introduction

OCDMA provides a few interesting lineaments such as asynchronous access, privacy and safety in communication, offer to support burst traffic and varying the bit rate, as well as the network's scalability. Since code division multiple access (CDMA) systems is a sort of multiplexing to support each user unique code, asynchronous burst traffic, protocol transparency, and decentralized operations. Indeed, CDMA systems are appropriate for local area networks (LANs) and metropolitan area networks (MANs).

A series of new coding families including tuneable chirped fiber Bragg gratings were proposed for the transmitter and the receiver of spectral amplitude coding-optical code division multiple access (SAC-CDMA) systems. The effects of the noise such as intensity noise, thermal noise, and phase-induced intensity were all considered in the analysis of the suggested system.

Compared with the former Hadamard-based system, it had been found that these code families can adequately stifle the noise intensity and significantly enhance the characteristics of the system [1, 2]. To attain correlation performance suitable for asynchronous direct sequence (DS-CDMA) applications, an essential aspect of this approach was suggested and adopting a simple but effective method for changing Walsh-Hadamard sequences. OCDMA is a technology which enables many users to take part bandwidth over encoded high-capacity networks [3, 4].

The enhanced double weight (EDW) code had been shown to perform best than the encoded program with modified frequency-hopping (MFH) and Hadamard codes. The BER of a 10 Gbps via a standard optical communication was 10^{-12} [5]. OCDMA enables many users to take part transmission facilities with a satisfactory service quality [6]. A new two-dimensional optical orthogonal coding technique was used with six lasers and the performance increase was achieved by reducing the length of the code and the BER of the optical CDMA system [7].

Since the generation instead of the effectiveness of Walsh codes and gold codes was easy, that has been utilized in CDMA communications as spread spectrum codes [8, 9]. The dual coding of the SAC-OCDMA system, both unipolar and bipolar, was evaluated through the impact of phase-induced intensity noise (PIIN). The unipolar method can be used for low data levels (voice data). Wider openings are visible in the eye diagrams of the bipolar coding scheme and higher BER than those of unipolar coding schemes [10].

A new SAC-OCDMA for 10 users network was tested using a data rate of 15 Gb/s multi diagonal (MD) code with BER of 10^{-9} with multiple access interference (MAI) elimination over 30 km single mode fiber [11]. Single photodiode detection (SPD) technique is used to mitigate the PIIN and MAI effects. BER efficiency and cost-effectiveness benefit of SPD technique was better than other optical access network detection schemes [12]. Research attempts to execute unipolar modified Walsh Code (MWC) had been studied and evaluated to several other types of OCDMA codes, such as MFH code, HD code, and modified Quadratic Congruence (MQC) code [13].

The dense wavelength division multiplexing (DWDM) channels in the designed system were set to wavelength range of (1479-1555) nm [14]. It had been suggested to test the correct output for the actual MWC with regard to beat noise, phase-incoherent strength noise and thermal noise. MWC based OCDMA simulation using Matlab graphical user interface for three users. However the creation of the real MWC graphical user interface software based on the opti-system is achieved [15, 16].

Shift Zero Cross Correlation (ZCC) code is easy development and greater adaptability. It can be found that it had insignificant BER. The extension in the number of users can be achieved without increasing its weight and nature. Also, it was noted that moving ZCC code can serve 60 and 80-100 robust users at 1 Gb/s and 622 Mbps, separately [17, 18]. SAC OCDMA's efficiency was analysed based on the Walsh Hadamard and Free Space Optical (FSO) networks which was so convenient in point-to-point transmission systems. The schemes for the encoder and decoder were based on optical Fiber Bragg grating (FBG) filters. The form of eye diagrams under varying channel gain and transmission distances are used to demonstrate the BER [19].

SAC-OCDMA system utilized (MDW) and EDW code was suggested using a single photodiode with a dispersion compensation fiber to compensate dispersion. The results of the simulation show that the setup involving EDW codes as signature codes provides sufficient performance system for longer transmission distances of more than 1 Gbps [20]. Study of comparison was made between Walsh Hadamard (WH), diagonal double weight, MDW, EDW, and MD codes for the same input parameters. The output results show that EDW codes are better than the other which performed the best performance terms and due to less spectral interference [21]. When the transmission bit speed and distance rise of the DWDM system, the Q-factor was decreased [22]. A simulation of new zero cross-correlation (NZCC) code for SAC-OCDMA network was efficiently developed using the technique of direct detection with minimum weight and zero cross-correlation. The study reported that the proposed code has 10.43 Q-factor and the minimum BER of 9.89×10^{-26} compared to other current SAC-OCDMA codes such as RD [23].

In comparison to traditional previous works, the design and application are new and find the better system operation, where the demonstration of the design and implementation of SAC-OCDMA system based MWC for three users are achieved. The comparison of its BER performance using two techniques (optigrating and UFBG components) is performed. Balanced detection and PIN PD are also implemented at the receiver to be compared in order to decide the lower size and cost system design and choose the better performance.

The article is divided into five sections. Section two describes the modified Walsh code. The system design and description are recorded in section three, which includes the optigrating techniques and UFBG components for encoding implementation. Section four shows the results of the system performance analysis. Lastly, section five deals with the conclusions of the work.

Related Works

Walsh Hadamrd code is utilized to encode the information data of three and seven subscribers in incoherent SAC-OCDMA system and to enhance its performance the use of dispersion compensation fiber Bragg grating (DCFBG) was investigated. The results revealed that the BER values without using DCFBG were 4.7×10^{-9} , 8.1×10^{-8} and 9.2×10^{-34} for each user, respectively [24]. Compared to the above system, the values of BER are too low for our proposed system using MWC only without any type of dispersion compensation fiber (DCF) as will be seen later. Broad band operating at 3 Gb/s SAC-OCDMA utilized MD and WH codes was implemented for 15 subscribers. The MD system contains a small number of users, the BER approximately was within the range of (10^{-34}-10^{-11}) and as a large number of users share the same optical fiber, the range was around 10^{-12} to 10^{-10} [25]. This research shows the limitation of WH codes, where the BER is of higher values even if the users number is few compared to the obtained BER for our proposed work.

Using three distinct dispersion compensating fiber techniques, the characteristics of a SAC-OCDMA system based on two encoding–decoding MD and WH codes for fifteen users was improved. With MD encoding, the lowest value of BER and highest Q-factor value were roughly 10^{-30} and 10.5, respectively. As a result, the BER performance of the MD system was better than of the WH code [26], while our work is simulated using MWC for three users without DCF and obtain better performance. The data of an OCDMA multi-user cross-layer security networks was encoded using a hybrid two dimension modified Walsh (2D-MW) code and an approach encryption technique. Using the proposed MWC, the minimum BER value was 10^{-50} [27], compared to our work which has higher performance using MWC.

SAC-OCDMA system, with a ZC code introduced as double weight multi-diagonal was presented with constant weight or variable weight to enhance the system performance [28]. In extreme weather conditions, the bipolar-OCDMA was used with several well-known SAC codes, including MD code, MQC, MML, and WH code, for two users, both for AWGN and turbulence-induced fading channel. In comparison to other codes, the WH code performed better in simulations [29]. Higher system quality for more users is fulfilled for our system.

2. Modified Walsh Encoding

The system execution of three users was examined using two techniques: optigrating components and UFBG elements. The benefits of the improved technique can be divided into three categories. 1) The weight of the code is fixed 2) the proposed strategy displays lower BER, and 3) A design using MWC is more principled based on the assessment of BER for SAC-OCDMA. As needs be, the proposed MWC will effectively clear out obstruction sway between multi transmitted signals in the data transmission. A drawback of the complexity of the code is the length of the code word for each user which is increased as the number of user is increased. OCDMA codes are addressed by three essential parameters (N, w, λ), as N signifies the length of the code, w is the code weight and measured by the number of once in the code word of each user, and λ means the in-stage cross-correlation (IPCC), the latter is given by

$$\lambda = \sum_{i=1}^{n} x_i y_i \tag{1}$$

The IPCC for two random vectors or sequences of different code words, where $(x = x_1, x_2, \ldots, x_n)$ a certain random code and $(y = y_1, y_2, \ldots, y_n)$ is another one. A central unipolar 2×2 Walsh code with respect to "1 and 0" cross section can be given by:

$$[W_{sh2}] = \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix} \tag{2}$$

Then 4×4 Unipolar Walsh matrix is written [25, 26]:

$$[W_{sh4}] = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

The following steps can be used to explain the MWC:

i. The three fundamental encoding; $W_1 = [010]$, $W_2 = [100]$, $W_3 = [001]$ are confined discarding the principal line similarly as the essential segment of the network.

ii. The code has been updated. Different directions of the aforementioned columns are used to make the M_1matrix, as seen in Eq. (4).

$$[M_1] = \begin{bmatrix} W_1 & W_2 & W_3 \\ W_2 & W_3 & W_1 \\ W_3 & W_1 & W_2 \end{bmatrix} \quad (4)$$

MWC is introduced by K x N matrix. N is denoted the code length and K is denoted the users number.

iii. New MWC codes are generated as shown below:

$$[M_2] = \begin{bmatrix} M_1 & 0 \\ 0 & M_1 \end{bmatrix} \quad (5)$$

A comparative way has been done to get greater number of subscribers. The balanced code has a significant impact on the relationship list and instigates in-stage cross correlation with the value 0, lowering BER. It was moreover noted that the weight in MWC is constantly reliable, continually identical to 3, and N is continually on various occasions of the amount of clients K. The properties of the code

$$\sum_{i=1}^{N} C_k(i)C_j(i) = \begin{cases} W & \text{when } k = j \\ o & \text{otherwise} \end{cases} \quad (6)$$

where C_k express the sequence of kth row of K x N unipolar MWC matrix $C_k\ (i)$= kth row of MWC matrix, where k is active users number.

3. System Design Description

Simulation setup of SAC-OCDMA system based modified Walsh code (MWC) is to compare the data transmission for three users via a single optical link. Figure 1 displays the transmitter's block diagram being implemented. NRZ pulse generator encodes random binary sequences. The incoherent optical signal of white laser source is spectrally amplitude encoded based MWC. Two methods are used to implement MW encoding; uniform FBG (UFBG) component and optigrating component that imports the complex and complement spectrum from Optigrating software version 4.2. The electrical random NRZ pulses externally modulate the spectrally amplitude encoding signal using Mach-Zehender (MZ) modulator. Three user's information is launched simultaneously through a common optical link.

The received signal is divided into three branches, each of which belongs to the data associated with a specific subscriber as shown in the receiver components of Fig. 2. Next, the signal is detected using a balanced detector where each user's signal is split again; the upper part includes the MWC complex spectrum centred on the wavelengths of the FBG decoder array, while the complementary code spectrum is associated in the lower part as shown in Fig. 3. To remove the interfered frequency bins from the desired one, the electrical signal obtained at the output of the upper branch PIN photodiode is subtracted from that of the lower one. The obtained received optical is filtered by cut-off frequency BLPF equal to 0.7 of the signal bit rate to limit a specific subscriber's data to 3 dB bandwidth.

Fundamentally, -3dB is 0.707 units and it is usually utilized with all filters kinds. The output signal is decreased to 50% of the peak signal. The dynamic range of filter operation will be from zero hertz up to f_c. The characteristics of the system such as BER are measured by BER analyser.

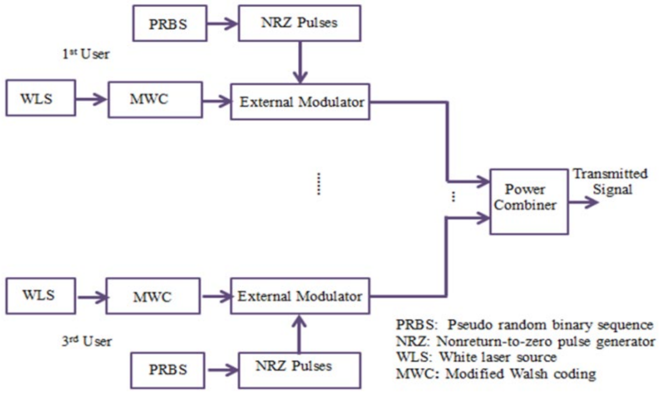


Fig. 1. Block diagram of the transmitter.

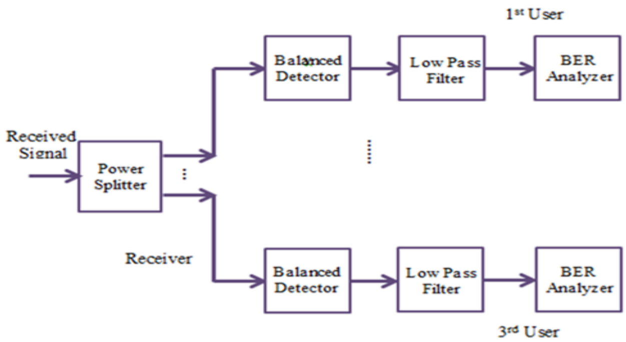


Fig. 2. Block diagram of the receiver.

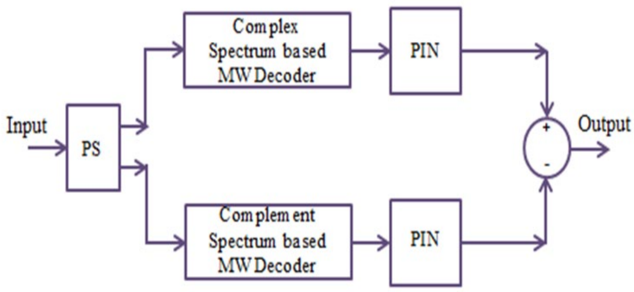


Fig. 3. Block diagram of a balanced detector.

3.1. Design of the modified Walsh codes

The modified Walsh encoding for three subscribers is descried briefly in section 2, their corresponding matrices M_1 and M_2 are given in Eqs. (7) and (8), respectively. The dimension of the matrix M_1 is (3×9), while that of the matrix M_2 is (6×18).

$$[M_1] = \begin{bmatrix} 010 & 100 & 001 \\ 100 & 001 & 010 \\ 001 & 010 & 100 \end{bmatrix} \tag{7}$$

$$[M_2] = \begin{bmatrix} M_1 & M_0 \\ M_0 & M_1 \end{bmatrix} \tag{8}$$

where the matrix M_0 is of all zeros parameters.

The generation of the matrix M_1 for seven subscribers needs to write the (8×8) Unipolar Walsh matrix as given in Eq. (9) [25, 26].

$$[W_{sh8}] = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 1 & 0 & 1 & 1 & 0 \end{bmatrix} \tag{9}$$

Then the W vectors can be found by discarding the first row and the first column from Eq. (9) as written below:

$$[W_1] = [0 \quad 1 \quad 0 \quad 1 \quad 0 \quad 1 \quad 0]$$
$$[W_2] = [1 \quad 0 \quad 0 \quad 1 \quad 1 \quad 0 \quad 0]$$
$$[W_3] = [0 \quad 0 \quad 1 \quad 1 \quad 0 \quad 0 \quad 1]$$
$$[W_4] = [1 \quad 1 \quad 1 \quad 0 \quad 0 \quad 0 \quad 0]$$
$$[W_5] = [0 \quad 1 \quad 0 \quad 0 \quad 1 \quad 0 \quad 1]$$
$$[W_6] = [1 \quad 0 \quad 0 \quad 0 \quad 0 \quad 1 \quad 1]$$
$$[W_7] = [0 \quad 0 \quad 1 \quad 0 \quad 1 \quad 1 \quad 0]$$

The above seven vectors $(W_1, W_2, W_3, W_4, W_5, W_6, W_7)$ each W_i has seven values of once and zeros and $i = 1.2, \cdots, 7$. The matrix M_1 can be written as in Eq. (10) which of dimension (7×7) in term of W_i and of (7×49) in term of once and zeros.

$$[M_1] = \begin{bmatrix} W_1 & W_2 & W_3 & W_4 & W_5 & W_6 & W_7 \\ W_2 & W_3 & W_4 & W_5 & W_6 & W_7 & W_1 \\ W_3 & W_4 & W_5 & W_6 & W_7 & W_1 & W_2 \\ W_4 & W_5 & W_6 & W_7 & W_1 & W_2 & W_3 \\ W_5 & W_6 & W_7 & W_1 & W_2 & W_3 & W_4 \\ W_6 & W_7 & W_1 & W_2 & W_3 & W_4 & W_5 \\ W_7 & W_1 & W_2 & W_3 & W_4 & W_5 & W_6 \end{bmatrix} \tag{10}$$

As explained for the MWC for three users, the encoding for seven subscribers will be extracted from the matrix M_2 which is as in Eq. (8) that means the MWC for each subscriber of the seven users will be represented by one row of the rows of the matrix M_2. The length of MW code will contain a large number of elements per subscriber. Thus to perform the MWC for more than three users it will be so difficult to distinguish the centre wavelength of the complex or complement spectrum (wavelength of FBG). While the number of UFBG component will increase and the size of implemented system will be big with higher than three users and will require special software programs.

3.2. Modified Walsh encoding using UFBG

The modified Walsh encoding is performed using nine UFBG components. The complex spectrum of spectral amplitude encoding for each user is obtained by connecting three UFBG components in series, while six of the UFBG components are needed to get the complement spectrum encoding. Bragg wavelength or the centre wavelength of the grating λ_B for each UFBG is calculated using the formula:

$$\lambda_B = 2n_{eff}\Lambda \quad (11)$$

where n_{eff} is the effective refractive index of fiber core and Λ is the grating pitch. Table 1 display the sequences of UFBG components or the optigrating corresponds to the measured Bragg wavelength as in Eq. (11), The complex spectrum or its complement is generated using UFBG components, it is seen that each UFBG is numbered from 0 to 8 which means that UFBG0 has $\lambda_0 = 1547.8$ nm, UFBG1 has $\lambda_1 = 1548.4\,nm$ and so on, UFBG8 has $\lambda_8 = 1552.6\,nm$. We arrange the sequence of UFBG component for each user as designed according to MWC and written in Table 1 in terms of the numbered UFBG, while in terms of wavelength are displayed in Table 2. As mentioned above, each UFBG's operating wavelength is modified by setting its frequency to the designed MWC as shown in Table 2, while its bandwidth and reflectivity will be 0.6 nm, 0.9998, respectively.

Table 1. The address of MWC in term of the UFBG.

User	UFBG to perform the complex spectrum	UFBG to perform the complement spectrum
1st	UFBG1 UFBG3 UFBG8	UFBG0 UFBG2 UFBG4 UFBG5 UFBG6 UFBG7
2nd	UFBG0 UFBG5 UFBG7	UFBG1 UFBG2 UFBG3 UFBG4 UFBG6 UFBG8
3rd	UFBG2 UFBG4 UFBG6	UFBG0 UFBG1 UFBG3 UFBG5 UFBG7 UFBG8

Table 2. Wavelength of UFBG used to generate MWC.

User	Wavelength in (nm) to generate complex spectrum	Wavelength in (nm) to generate complement spectrum
1st	1548.4, 1549.6, 1552.6	1547.8, 1549, 1550.2, 1550.8, 1551.4, 1552
2nd	1547.8, 1550.8, 1552	1548.4, 1549, 1549.6, 1550.2,1551.4, 1552.6
3rd	1549, 1550.2, 1551.4	1547.8, 1548.4, 1549.6, 1550.8, 1552, 1552.6

3.3. Modified Walsh encoding using optigrating component

The Optigrating software is utilized to simulate the spectral amplitude encoding (SAE) and export the complex and complement spectrum to OptiSystem version 7.0. Integrated and fiber optical grating software which is represented by an optigrating component can be used to load measured data from files. The input file is formatted containing three items per line; the wavelength in microns, a complex value transmission, and a complex value for the reflection. Nine grating parameters are set and adjusted using Opigrating software; three of them are used to produce the complex spectrum and six are used to obtain the complement spectrum. Figure 4 depicts the profile of the grating, the periods in nm are arranged according to the wavelengths of spectral amplitude encoding. The information of other parameters of grating are listed in Table 3.

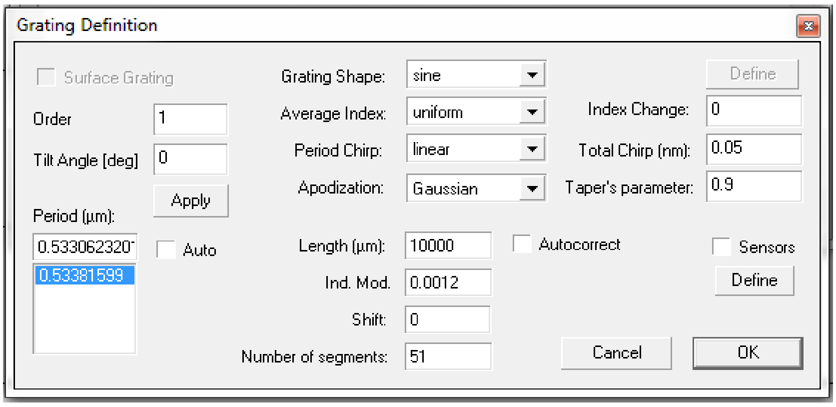


Fig. 4. Grating's profile.

Table 3. Parameters of grating

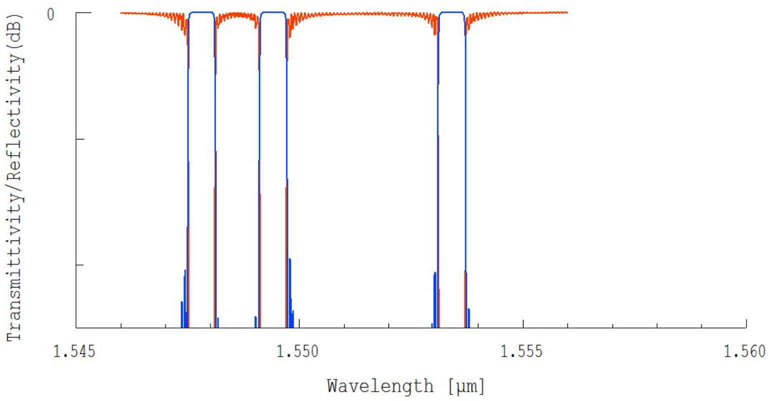
Parameter	Type
Grating Profile	Sinusoidal
Average Index	Uniform
duration Chirp	Linear
Apodization	Gaussian
Length	10000 µm
Ind. Mod.	0.0012
Number of segments	51
Index Change	0
Total Chirp	0.05

4. The System Performance Analysis

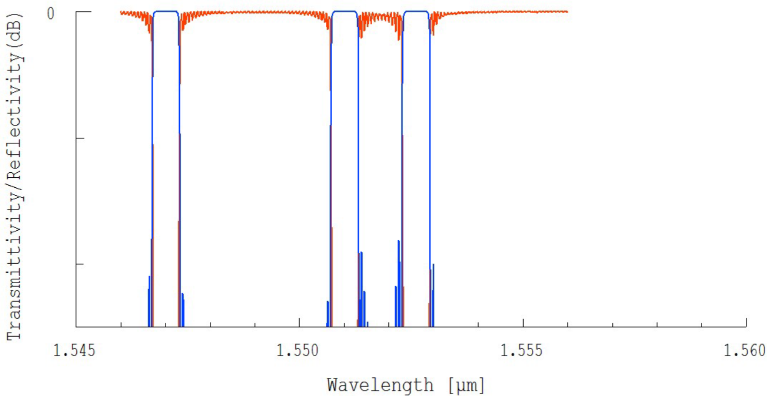
The analysis and the simulation of SAC-OCDMA system based MWC for three users is achieved to obtain best transmission performance over common bandwidth simultaneously. This section demonstrates and discusses the shape of the following topics; complex spectrum and complement spectrum of the modified Walsh encoding, eye diagram and BER performance according the two methods aforementioned.

4.1. Spectrum of modified Walsh code

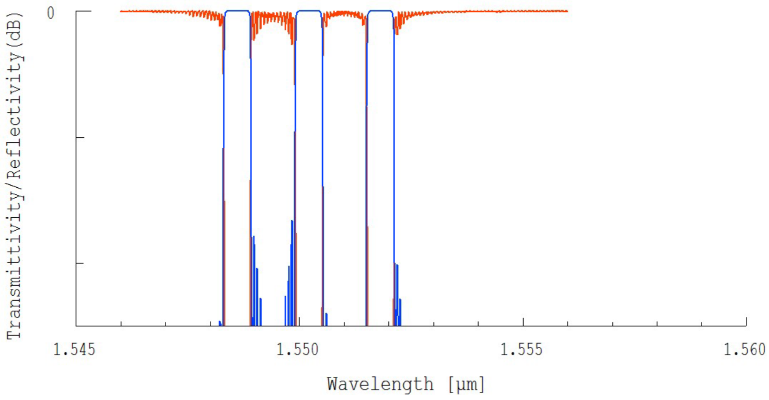
The generation of spectral amplitude encoding based MWC using Optigrating component and UFBG is shown in Figs. 5 and 6, respectively. It is clear that the transmitted and reflected complex spectrum (Fig. 5) and complement spectrum (Fig. 6) which are exported by optigrating software version 4.2, are exactly looking like the originated theoretical one. So their simulation results are more precise that are obtained using UFBG components as illustrated in Figs. 7 and 8 which are for complex spectrum and complement spectrum, serially.



(a) First user.

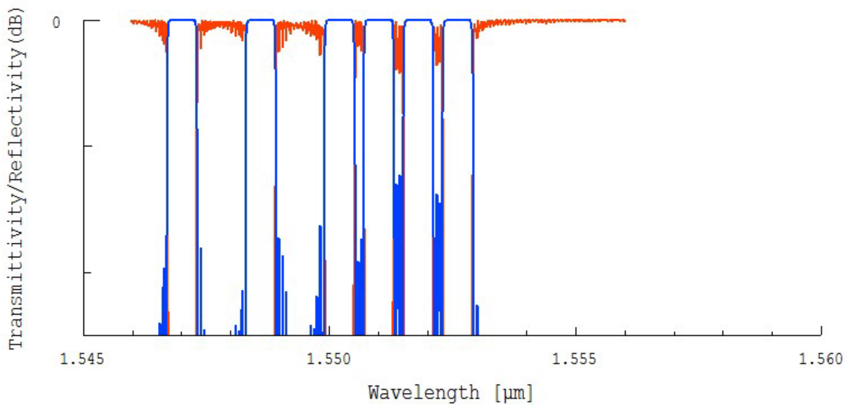


(b) Second user.

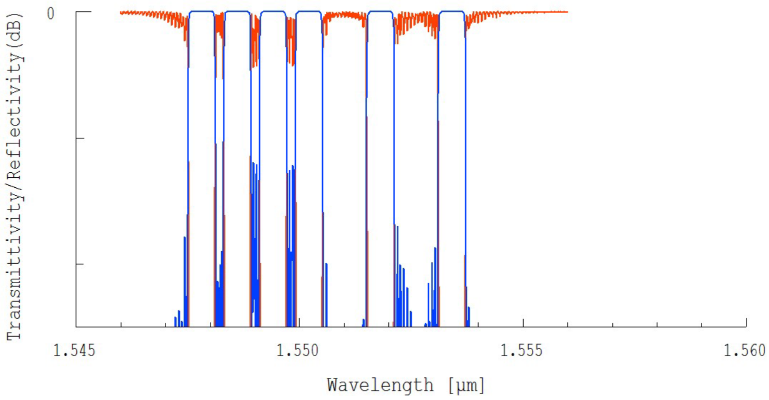


(c) Third user

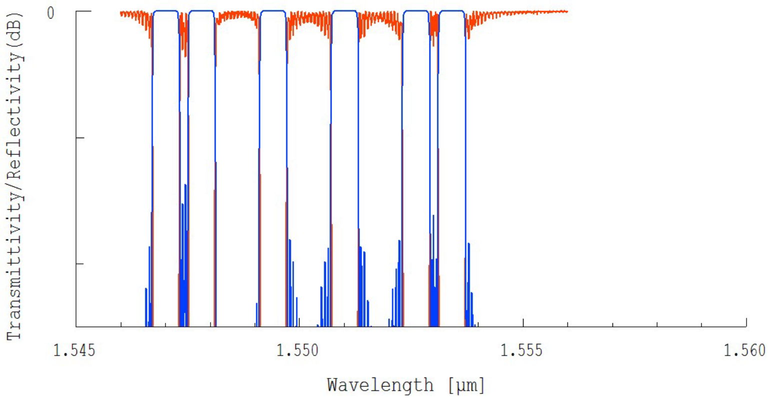
Fig. 5. Transmitted and reflected complex spectrum using optigrating component.



(a) First user.

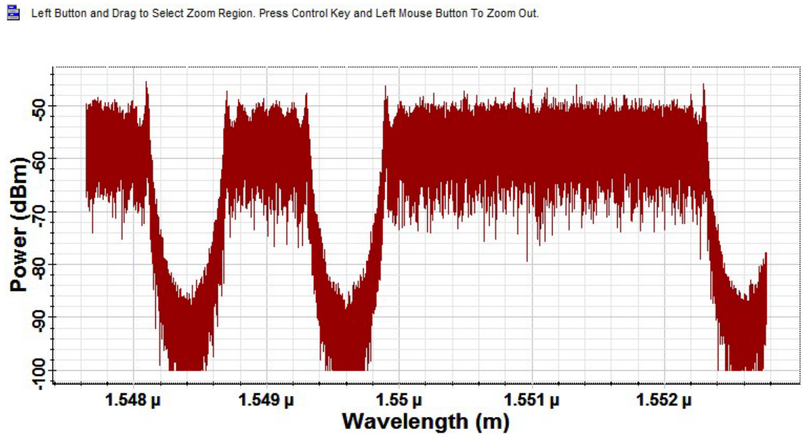


(b) Second user.

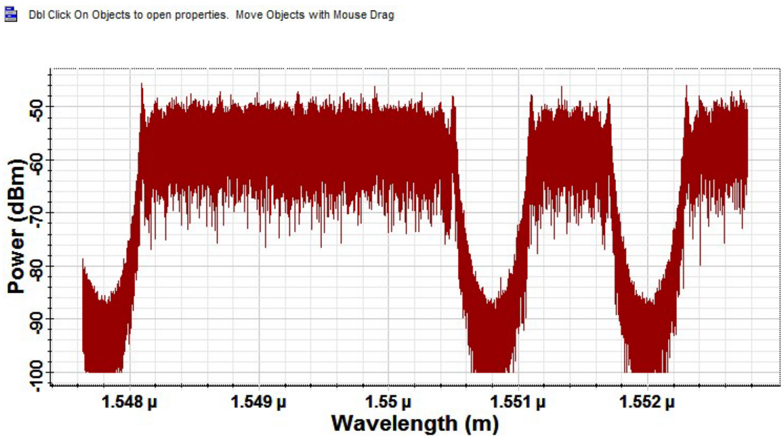


(c) Third user.

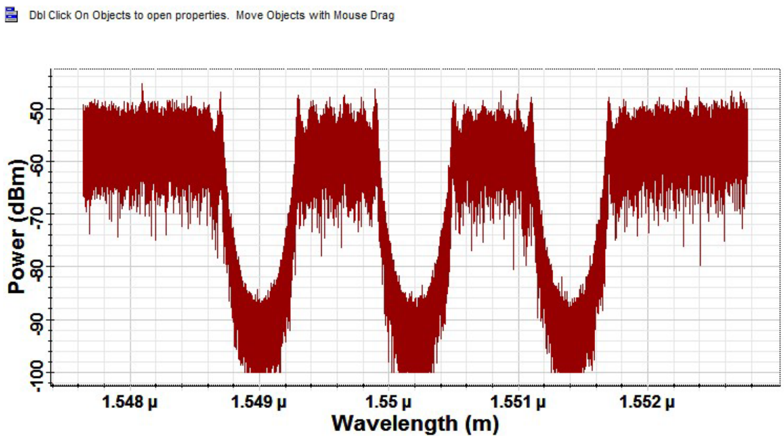
Fig. 6. Transmitted and reflected complementary spectrum using optigrating component.



(a) First user.

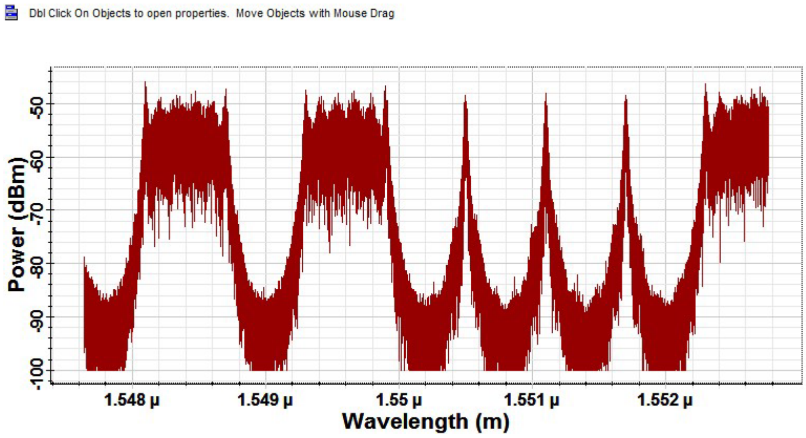


(b) Second user.

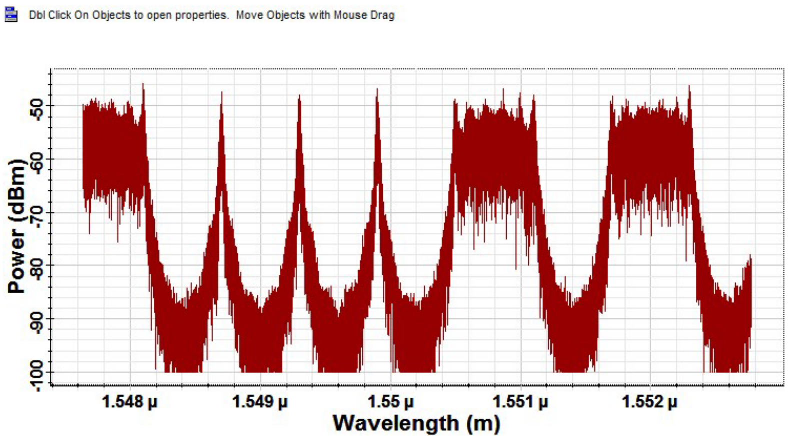


(c) Third user.

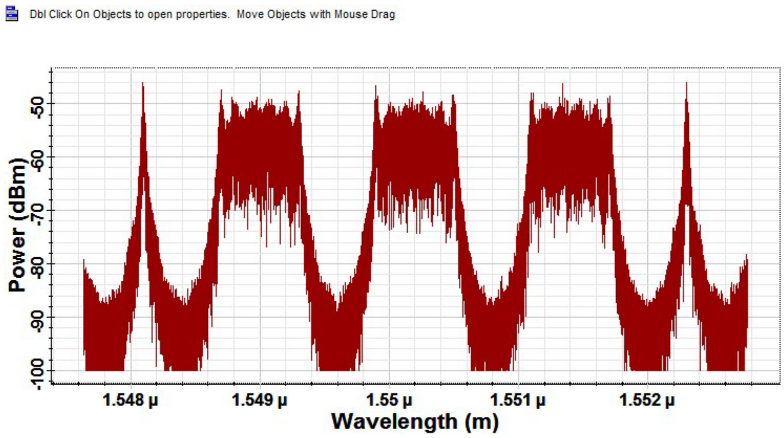
Fig. 7. Transmitted and reflected complex spectrum using UFBG component.



(a) First user.



(b) Second user.

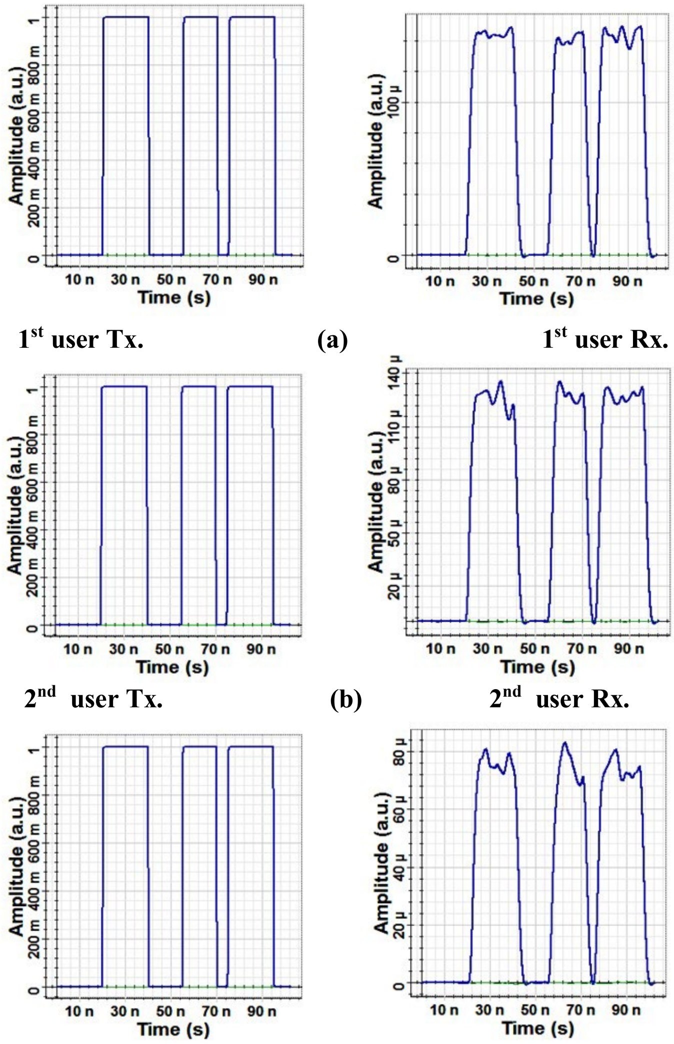


(c) Third user.

Fig. 8. Transmitted and reflected complementary spectrum using UFBG component.

4.2. Transmitted-received signals comparison

To test the information data that sent by each user, the designed system is operated at laser power of 6.221 dBm, while the average power of the received signal equals to -50.855 dBm. Figure 9 displayed the electrical encoding transmitted signal to the right and the corresponding received to the left for three users. The signal for each user is received obviously without any loss, it is evidence how the ability of MWC to recover the sent data.



1st user Tx. **(a)** **1st user Rx.**

2nd user Tx. **(b)** **2nd user Rx.**

3rd user Tx. **(c)** **3rd user Rx.**

Fig. 9. Transmitted and received signal for the users.

4.3. Code system performance

From the SAC-OCDMA system, which is using two techniques for modified Walsh encoding, the influence of increasing the users on the loading on the network will be clarified as displayed in the results in section 4.3.2. In our work, the results demonstrate the BER and Q-factor measuring, and the eye diagram will be displayed to achieve this.

4.3.1. Balanced detector compared to PIN detector

The system is operated with PIN photodiode using the optigrating component and UFBG elements. In spite the PIN PD detector with the system using optigrating component demonstrate better quality than that of using balanced detector, where the zero BER and Q-factor of 55.020, 50.757 and 73.590 for 1st , 2nd , and 3rd user, respectively. However, it does not prefer to be used in the proposed system because it performs so bad with system using UFBG because zero quality factor for 1st and 3rd user and 2.938 for the 2nd user.

4.3.2. Demonstration of performance

As the obtained electric received power in dBm grows at the receiver side, the BER falls slightly. Nonetheless, it is equivalent to 10^{-266} and 10^{-43} as the minimum values using optigrating and UFBG for three users, respectively, as illustrated in Fig. 10. This trend is because, first of all, the optigating system needs two elements, one for complex spectrum and the other for complementary spectrum for each subscriber. While UFBG uses nine components, three components are for complex spectrum, and six connected in series for complement spectrum, and the possibility of an error in getting the spectral encoding may definitely have occurred. Second, perfect encoding accuracy is obtained with optigrating component based optigrating software. On the other hand, for diagnostic purposes, the Quality factor is a function of how noisy a pulse is. Since the Q-Factor indicates the minimal signal-to-noise ratio (SNR) necessary to achieve a particular BER for optical data transmission. Then, the Q-factor is also demonstrated as shown in Fig. 11 which increases to 35 and 14, respectively for optigating and UFBG components.

The research also tests the performance of two and one user to be compared with that of three users. Because network loading decreases for two users, the BER reduces more than that of three users, where for the first user it reaches zero at received power greater than -67.731 dBm, and for the second user it reduces to 10^{-160} by optigrating component, however, the BER hits10^{-62} and10^{-58} for the 1st subscriber and the 2nd subscriber using UFBG, respectively as shown in Fig. 12. Figure 13 gives that the network loading decreases, but in terms of Q-factor, whereby the first user has a stronger Q-factor (42) and the zero BER is ensured. The systems of single-user using two techniques are roughly ideal because the BER equals to zero and the Q-factor approaches 65 and 76.744 (Fig. 14), for optigration and UFBG, respectively, which means that the UFBG is better.

Eventually, the performance verification of the simulated MWC for three subscribers by means of the eye opening in the eye diagram using the UFBG component and the Optigrating component with high (-50.855) dBm and low (-89.302 dBm) received power values are as displayed in Figs. 15 and 16. The BER and eye height values for the eye diagrams of Figs. 15 and 16 are as listed in Table 4. It is clear that the BER values are lower, and the eye height is greater at -50.855 dBm than that at -89.302 dBm. Figures 17 and 18 show the wideness of the eye diagram, which is being wider as the number of users is decreased to two and one, respectively. These results indicate better performance once the load up on the network is relieved. Moreover, a comparison of systems performance has been presented in Table 5, where the received power is equal to -50.855 dBm. However, the quality of the system is enhanced as long as the number of users is decreased. It was noted that the system performs better when the number of users is decreased.

Number of users plays the crucial factor, so, the acceptable limit for the length of the code using MWC which proportional to BER, Q-factor and Eye height. From Figs. 10 and 11 and Table 4, it is clear for 3 users that BER, Q factor and Eye height are 3.416×10^{-266}, 34.618, 8.272×10^{-5} respectively. Furthermore, for two users system, they are 0, 40.978, 1.289×10^{-4} and 0, 61.402, 1.388×10^{-4} for one user system. There are many points that illustrate why the MWC generation has good results when exporting the optigraing spectral amplitude encoding. (1) Good precision in obtaining the sequences of the ones and the zeros. (2) Loading of data files via the optigating component.

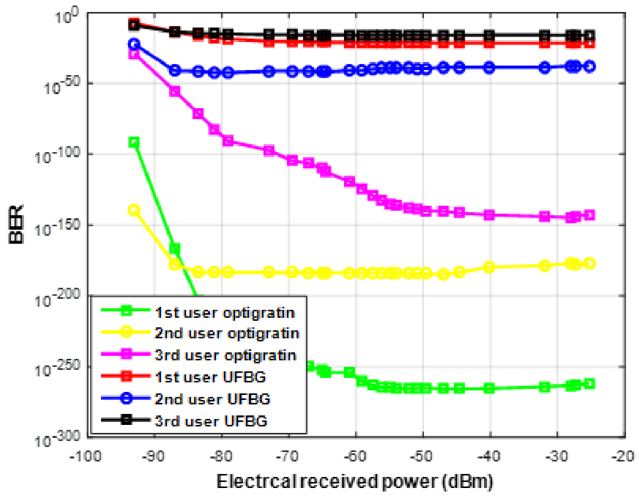


Fig. 10. BER performance for three users using optigrating and UFBG.

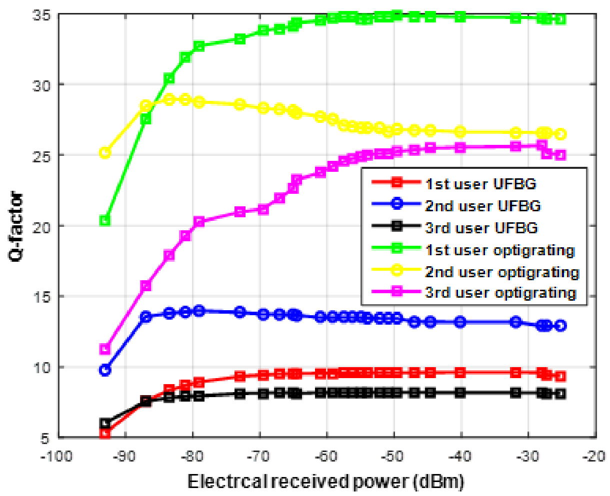


Fig. 11. Q-factor for three users using optigrating and UFBG.

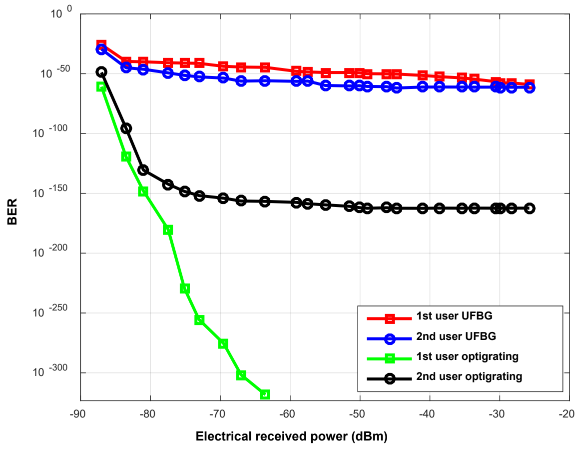


Fig. 12. BER performance for two users using optigrating and UFBG components.

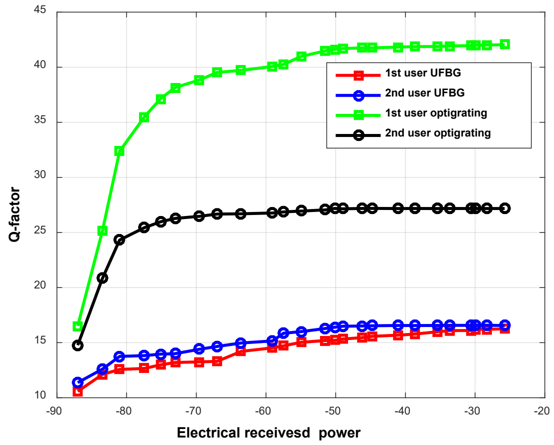


Fig. 13. Q-factor for two users using optigrating and UFBG.

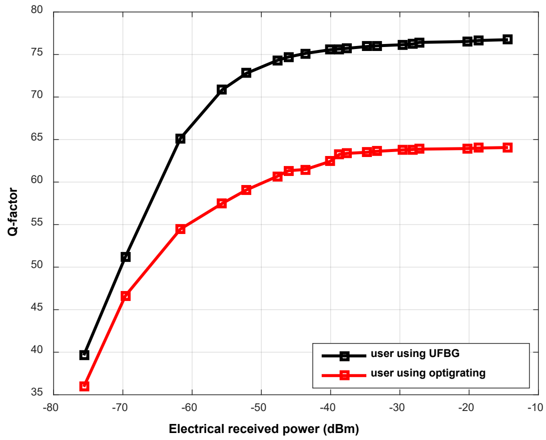
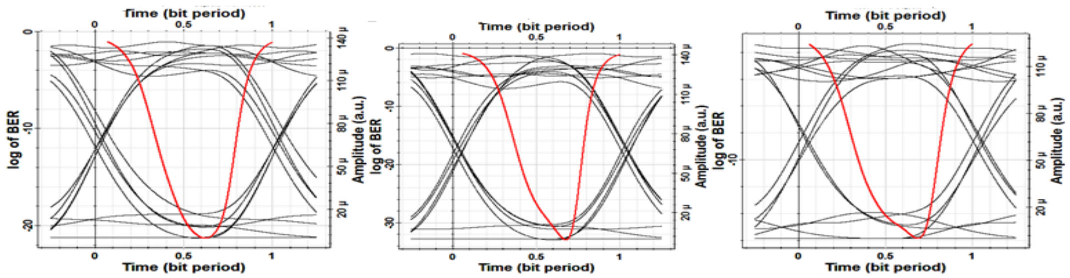
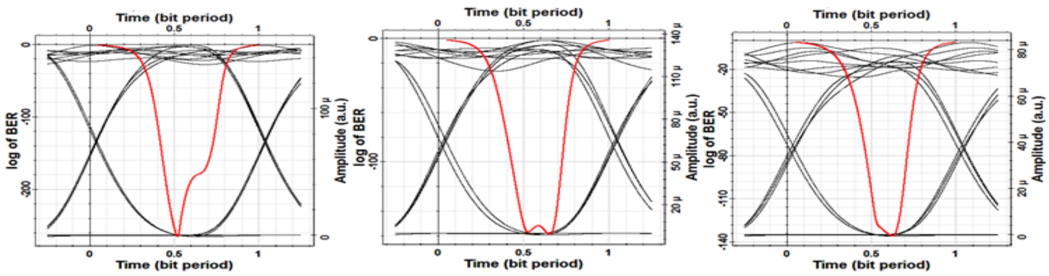


Fig. 14. Q-factor for single user Using optigrating and UFBG.

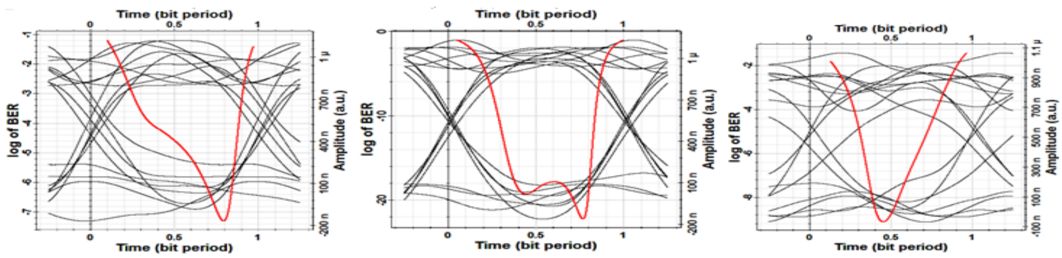


(a) Using UFBG component.

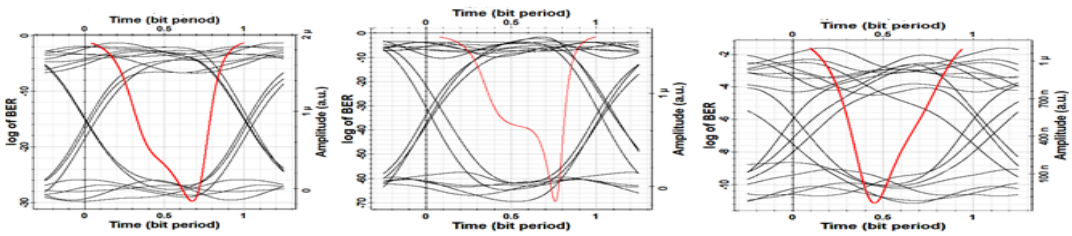


(b) Using optigrating component.

Fig. 15. Eye diagram of three users system at received power (-50.855 dBm).

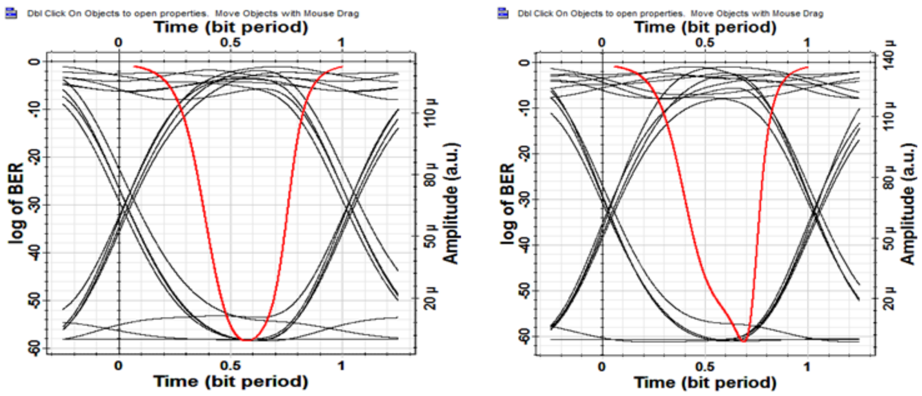


(a) Using UFBG component.

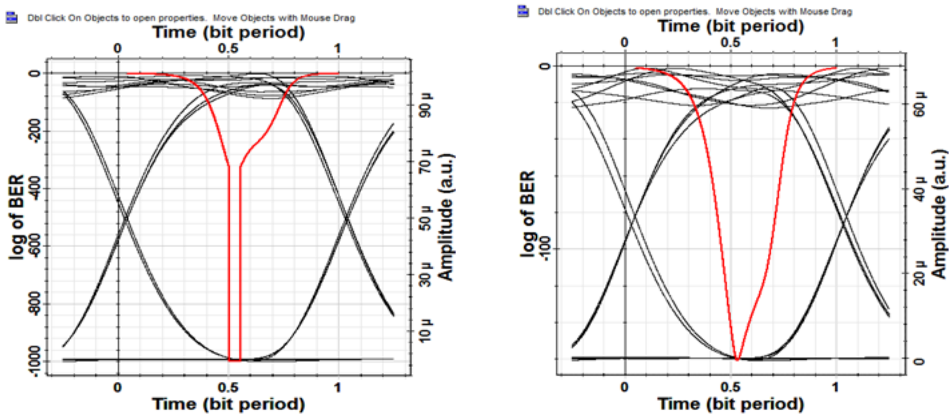


(b) Using optigrating component.

Fig. 16. Eye diagram of three users system at received power (- 89.302 dBm).

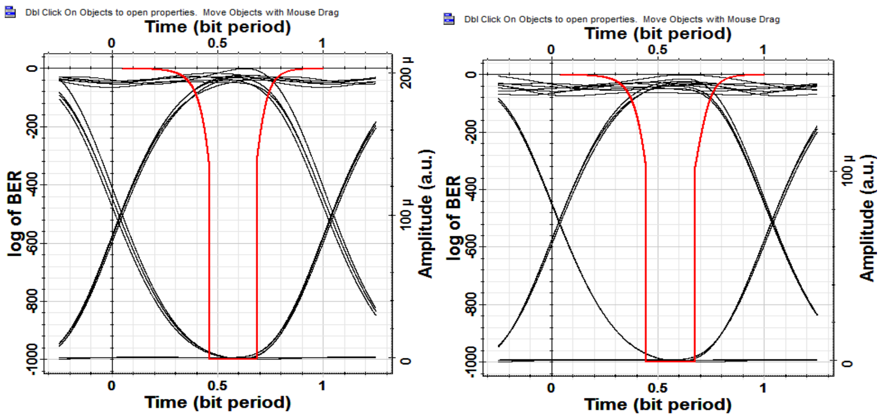


(a) Using UFBG component.



(b) Using optigrating component.

Fig. 17 Eye diagram of two users system at received power (- 50.855 dBm).



(a) Using UFBG component. **(b) Using optigrating component.**

Fig. 18 Eye diagram of one user system at received power (-50.855 dBm).

Table 4. The BER and eye height values of three users for Optigrating and UFBG.

User	Optigrating		UFBG		Received power (dBm)
	BER	Eye Height	BER	Eye Height	
1st	3.416×10^{-266}	1.310×10^{-4}	4.929×10^{-22}	8.272×10^{-5}	
2nd	3.546×10^{-160}	1.146×10^{-4}	1.304×10^{-33}	9.304×10^{-5}	-50.855
3rd	7.447×10^{-137}	6.572×10^{-5}	1.432×10^{-16}	6.674×10^{-5}	
1st	1.499×10^{-30}	1.256×10^{-6}	4.960×10^{-8}	3.502×10^{-7}	
2nd	2.848×10^{-70}	1.196×10^{-6}	5.260×10^{-23}	6.811×10^{-7}	-89.302
3rd	7.196×10^{-12}	4.805×10^{-7}	7.486×10^{-10}	3.935×10^{-7}	

Table 5. Performance comparison of three types of systems.

Users	User	Optigrating		UFBG	
		Q-factor	Eye Height	Q-factor	Eye Height
Three users	1st	34.618	1.31×10^{-4}	09.577	8.272×10^{-5}
	2nd	26,940	1.146×10^{-4}	12.041	9.304×10^{-5}
	3rd	25.024	6.572×10^{-5}	8.176	6.674×10^{-4}
Two users	1st	40.978	1.298×10^{-4}	16.178	1.014×10^{-4}
	2nd	27.04	1.161×10^{-4}	16.558	1.024×10^{-4}
One user	1st	61.402	1.388×10^{-4}	74.710	1.885×10^{-4}

5. Conclusions

A few necessities will be encouraged by a high-speed network, including support for a large number of clients, arbitrary traffic, high transmission speeds, transparent packet structure of protocol, reliable, compatible, and massive bandwidth.

The proposed SAC-OCDMA system trend is to report the performance analysis of multiple subscribers in data transmission by encoding the MWC dependent information. Using optigrating software and UFBG techniques this code is created with spectral amplitude coding. The work also involves the varying the number of users such as three users system, two users system and one user system to test the performance of the system. It is found that the balanced detector is more suitable for system operation than that of utilizing PIN photodiode detection. For optigrating software, the best BER performance and good quality are achieved for three users, where the BER reduced to10^{-266}. For two users, the BER reduces more than that of three, where one of them hits zero. On the other hand, the case is the opposite for single-user system which explained for optigrating and UFBG in terms of quality factor 65 and 76.744, which means the UFBG is stronger.

Finally, it may be confirmed that the acceptable limit for the length of the code using MWC is crucial case for increasing number of users which proportional to BER, Q-factor and Eye height. From our experience in this field, our suggestion for future works to get the proper simulator for SAC-OCDMA based MWC for higher number of subscribers.

Nomenclatures

C_j	Sequence of the jth Row of k×N MWC Matrix
C_k	Sequence of the kth Row of k×N MWC Matrix
f_c	Cut-off Frequency
k	Number of Users

M_1	Matrix of Fundamental Encoding
M_2	Matrix of Walsh Encoding
N	Length of the Code
n_{exff}	Effective Refractive Index of the Fiber Core
W_1	Encoding for User 1
W_{sh2}	2×2 Unipolar Walsh Matrix
W_{sh4}	4×4 Unipolar Walsh Matrix
W_{sh8}	8×8 Unipolar Walsh Matrix
w	Weight of the Code
x	Random Code
y	Another Random Code

Greek Symbols

Λ	Grating pitch.
λ	In-stage Cross-correlation
λ_B	Wavelength of the Grating

Abbreviations

2D-MW	Two Dimension Modified Walsh
AWGN	Additive White Gaussian Noise
BLPF	Bessel Low Pass Filter
CDMA	Code Division Multiple Access
DCF	Dispersion Compensation Fiber
DCFBG	Dispersion Compensation Fiber Bragg Grating
DS-CDMA	Direct Sequence-Code Division Multiple Access
DWDM	Dense Wavelength Division Multiplexing
EDW	Enhanced Double Weight
FBG	Fiber Bragg Code
FSO	Free Space Optical
IPCC	In-stage Cross-correlation
LANs	Local Area Networks
MAI	Multiple Access Interference
MANs	Metropolitan Area Networks
MD	Multi-Diagonal
MFH	Modified Frequency Hoping
MQC	Modified Quadratic Congruence
MWC	Modified Walsh Code
MZ	Mach-Zehender
NRZ	Non-return to Zero
NZCC	New Zero Cross-Correlation
OCDMA	Optical Code Division Multiple Access
PIIN	Phase-Induced Intensity Noise
PIN PD	Positive Intrinsic Negative Photodiode
SAC-CDMA	Spectral Amplitude Coding-Code Division Multiple Access
SPD	Single Photodiode Detection
UFBG	Uniform Fiber Bragg Grating
WH	Walsh Hadmarad
ZCC	Zero Cross Correction

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