CW Laser Combined with LED to Reduce the FWM in SAC-OCDMA Network

Ibrahim F. Alshammari, Haider A. Abdulkarim, Ali Abdulraheem Alwan

***Abstract:** A new technique based on LED combined with CW lasers in Spectral Amplitude Coding (SAC) Optical Code Division Multiple Access (OCDMA) networks, which allow reduction of the four-wave mixing (FWM) effect. In this paper, SAC-OCDMA networks have been developed and analyzed based on Multi Diagonal (MD) and Zero Cross Correlation (ZCC) codes. We simulate and investigate of three users design and concluded that the FWM can be reducing by using the LED source combined with CW lasers for each user in the code's design. Our results show that the MD code gives better performance than the ZCC code by using our technique. In other words, the ratio of reducing the FWM power in the MD code is approximately -20 dBm, while in ZCC is -10 dBm.*

***Keywords:** Optical code division multiple access (OCDMA), Spectral amplitude coding (SAC); Multi diagonal (MD);Zero-Cross Correlation (ZCC); Four-Wave Mixing (FWM; Light Emitting Diode (LED).*

I. INTRODUCTION

Ever since the mid-1980s when single-mode fiber-optic media were swallowed to become the chief highways of future telecommunications networks for transporting high-volume high-quality multipurpose information [1]. The greatest technical challenge for today’s communication network systems is to take more information transporting capacities since the volume of information caused increases rapidly.With the substantial growth in data traffic, the need for higher capacity optical systems increases [2]. Fiber nonlinear effects represent the fundamental limiting on the sum of data that can be transmitted on optical fiber. Nonlinearities of optical fiber can be divided into two sections. The first category encompasses the nonlinear inelastic scattering processes. These are Stimulated Brillouin Scattering (SBS) and Stimulated Raman Scattering (SRS). The second category of nonlinear effects appears from intensity-dependent variations in the refractive index in optical fiber. This produces effects such as Self- Phase Modulation (SPM), Cross Phase Modulation (XPM) and four-wave mixing (FWM) [3]. The FWM occurs when light of two or more different wavelengths is launched into a fiber. Generally speaking FWM occurs when light of three unusual wavelengths is launched into a fiber, giving rise to a new wave (know as an idler), the wavelength of which does not agree with any of the others. FWM is a kind of optical parametric oscillation[4]. In other words, the FWM has been widely studied with various types of optical fibres.

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In particular, FWM has been investigated as a technique of realizing wavelength tunable light sources, and as a means of measuring fibre properties, such as the third-order nonlinearly in a fibre. [5]. The Optical Code Division Multiple Access (OCDMA) systems have experienced increasing research attention in the last decade because they offer many attractive features, such as asynchronous access, privacy and security in transmission, ability to support variable bit rate and bursty traffic, and scalability of the network. The advantages of using Optical Code Division Multiple Access(OCDMA) techniques are to provide moderate security communication and allow multiple users to access optical network with a sharing bandwidth mechanism[6]. In SAC-OCDMA technique, a spectral encoding has been applied on the output of a broad-band source by decomposing it into spectral bins and the intensity of eachbin is modulated such that the bin is either ‘on’ or ‘off’ depending on the user code being applied. Each user has his own unique code, defined by a specific combination of spectral components, which should be orthogonal to all other user codes[7]. In this paper, we made a new technique to reducing the FWM effect in SAC-OCDMA network's design by using LED source combined with the CW lasers for each user. We used the MD and the ZCC codes as examples of SAC codes, our analytical expressions and simulation shows that our technique makes a reduction in FWM effect in the MD code approximately -20 dBm, and for the ZCC code is -10 dBm.

II. FOUR WAVE MIXING

The origin of FWM process lies in the nonlinear response of bound electrons of a material to an applied optical field. In fact, the polarization induced in the medium contains not only linear terms but also the nonlinear terms. The magnitude of these terms is governed by the nonlinear susceptibilities of different orders. The FWM process originates from third order nonlinear susceptibility ($\chi3$). If three optical fields with carrier frequencies f1, f2 and f3, copropagate inside the fiber simultaneously, ($\chi3$) generates a fourth field with frequency f4, which is related to other frequencies by a relation, f4 = f1 ± f2± f3. In quantum-mechanical context, FWM occurs when photons from one or more waves are annihilated and new photons are created at different frequencies such that net energy and momentum are conserved during the interaction. The effect of FWM on optical transmission is signal-to-noise degradation and cross-talk. As the signal input power of f1, f2, and f3 increases, or as the channel spacing decreases, the FWM mixing output term fFWM increases[8, 9 As shown in figures(1, 2), the FWM power versus channel spacing and input power respectively for different values of Dispersion (17, 1, 3.7)

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ps/(nm.km) using the bellow equations:

$$\Delta k = \left(\frac{2\pi\lambda^2}{c}\right) \times \Delta f^2 \left[Dc + \frac{\lambda^2}{2c} \times 2\Delta f \times SD\right] (1)$$

Phase mismatches equation

$SD \rightarrow$ Slope Dispersion

$Dc \rightarrow$ Chromatic Dispersion

$\Delta f \rightarrow$ Channel Spacing

$\lambda \rightarrow$ Wavelength

$$\eta = \frac{\alpha^2}{\alpha^2 + \Delta k^2}\left\{1 + \frac{4\exp(-\alpha L)\sin^2(\frac{\Delta k L}{2})}{[1-\exp(-\alpha L)]^2}\right\} (2)$$

FWM efficiency equation

$\alpha \rightarrow$ Attenuation

$L \rightarrow$ Fiber Length

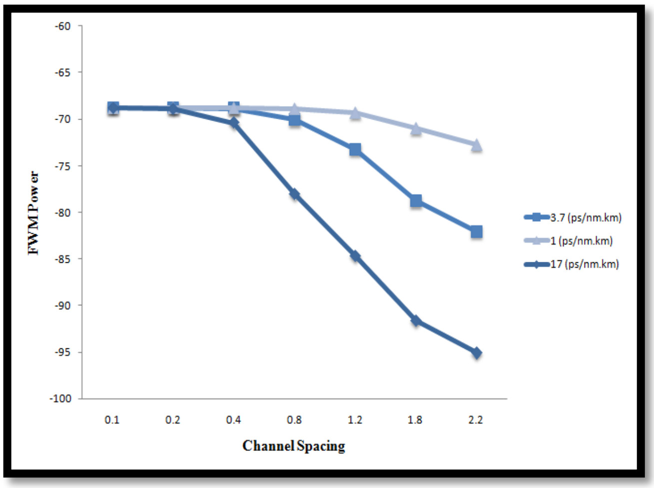
$$P_{FWM} = \frac{1024\pi^6}{n^4\lambda^2c^2}\left(\frac{d \times x_{1111} \times Leff}{Aeff}\right)^2 P_{in} \times \exp(-\alpha L) \times \eta (3)$$

$n \rightarrow$ refractive index

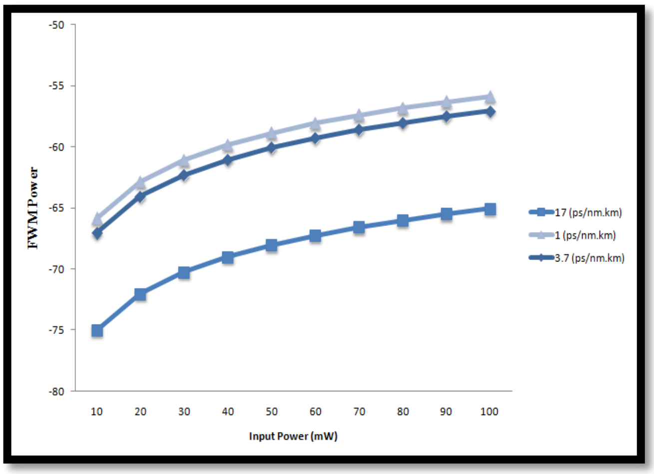
$Leff \rightarrow$ effective Length

$Aeff \rightarrow$ effective Area

$X_{1111} \rightarrow$ third order susceptibility



Figuer 1. The FWM power versus Channel Spacing



Figuer 2. The FWM power versus Input Power (Mw)

III. SAC-OCDMA CODES CONSTRUCTIONS

A- MD Code

The MD code is characterized by the following parameters (N,W, kc) where N is the code length (number of total chips), W is the code weight (chips that have a value of 1), and kc is the inphase cross correlation. The Cross-correlation theorem could be defined as follows: In linear algebra, the identity matrix or unit matrix of size N is the N-by-N square matrix with ones on the main diagonal and zeros elsewhere. It is denoted by IN, or simply by I if the size is immaterial or can be trivially determined by the context.

I=[1],

$I_2 = \begin{vmatrix} 1 & 0 \\ 0 & 1 \end{vmatrix}$, $I_3 = \begin{vmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{vmatrix}$ .... $I_n = \begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ & & \searrow & \\ 0 & 0 & & 0 \\ 0 & 0 & .. & 1 \end{vmatrix}$

The cross-correlation theorem states that cretin sets of complementary sequences have cross-correlation functions that sum to zero by using all pairwise permutations. Here, all cross-correlation function permutations are required in order that their sum be identically equal to zero. For example, if the rows and columns of a (K N) matrix are orthogonal and all the columns except one sum to zero, then the sum of all cross-correlations between nonidentical code words is zero. The matrix of the MD code consists of a K N matrix functionally depending on the value of the number of users (K), and code weight (W). For the MD code the choice of weight value is free, but should be more than 1(W > 1) [6].

B- ZCC Code

The ZCC code is represented in a matrix K × L where K rows represent the number of users and L columns represent minimum code length. The ZCC code has flexibility in number of weight consideration. In order to increase the number of weights, formulation via 'code transformation' is required. In optical ZCC code, the basic code represents weight = 1. To transform the code from w = 1 to w = 2, the general form of transformation is given by.

$Z_T = \begin{array}{c|c} A & B \\ \hline C & D \end{array}$

where [*A*] – consist of (1, *w* (*w*-1)) matrix of zero. [*B*] – consist of *w* replication of matrix $\sum_j^w = 1j(01)$. [*C*] – consist of duplication of matrix from *w*-1. [*D*] – consist of diagonal pattern [*m* × *n*]with alternate column zeros matrix [*m* × *n*]. The transformation code from *w* = 1 → *w* = 2, for example is shown as

$Z_{T=1} = \begin{array}{c|c} 0 & 1 \\ \hline 1 & 0 \end{array}$

$Z_{T=2} = \begin{array}{c|c} 0\,0\,0 & 1\,0\,1 \\ \hline 0\,1\,0 & 0\,1\,0 \\ 1\,0\,1 & 0\,0\,0 \end{array}$

The relationship between the basic number of users *KB*, weight w and basic code length *LB* is given by;

KB = w+ 1

LB = w (w + 1)

When the code weight increases, the code length also increases because the cross correlation has to be maintained at zero. In order to increase the number of users and codes without changing the weight, a mapping technique is used as below:

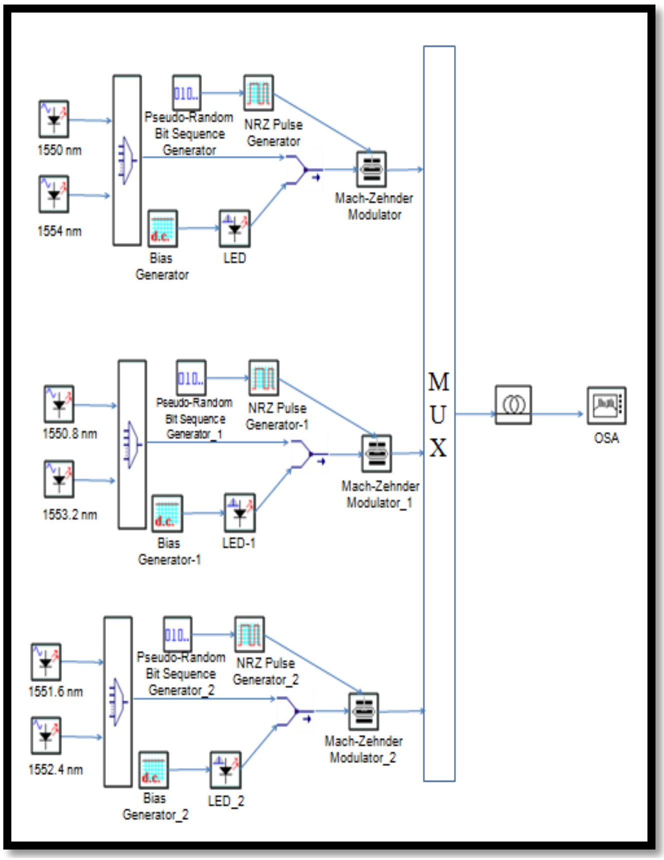
$$Z_2 = \begin{array}{c|c} 0 & Z_{T=1} \\ \hline Z_{T=1} & 0 \end{array}$$

$$Z_3 = \begin{array}{c|c} 0 & Z_2 \\ \hline Z_2 & 0 \end{array}$$

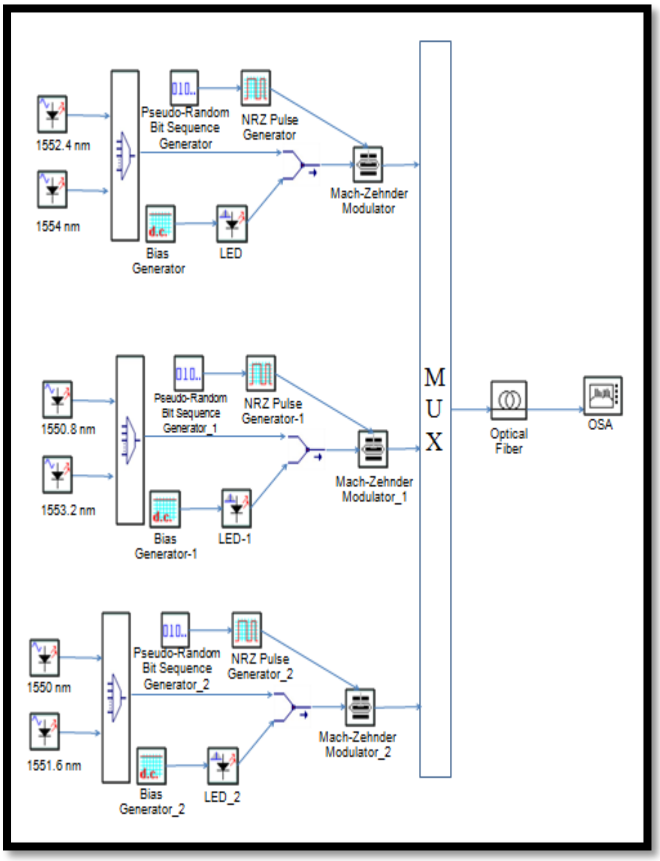
From the mapping, it is noted that as K increases, the code length L also increases but w is unchanged (for this particular example $w = 1$) [10].

IV. SIMULATION ANALYSIS

The performance analysis of the MD and the ZCC codes was simulated by using the simulation software, Optisystem Version 9.0. A simple circuit design consists of three users, as illustrated in Figures (3, 4). Each chip has a spectral width of 0.8 nm. The tests were carried out at a rate of 5 Gb/s for a 40-km distance with the ITU-T G.652 standard single-mode optical fiber (SMF). All the attenuation a (i.e., 0.25 dB/km), dispersion (i.e., 17 ps/nm km), and nonlinear effects were activated and specified according to the typical industry values to simulate the real environment as close as possible [6, 10]. The performances of the FWM in the system were characterized by referring to the Optical Spectrum Analyzer (OSA). As shown in Figures (3, 4), in the transmission we used a CW laser for each user and after this lasers inter the WDM Multiplexer we made combine with the output and the LED to reducing the FWM power in the system.



Figuer 3. MD code schematic block diagram using the LED technique for three users



Figuer 4. ZCC code schematic block diagram using the LED technique for three users

V. RESULTS AND DISCUSSION

We simulate and investigate the FWM in SAC-OCDMA codes using the two codes which are the MD and the ZCC codes. We simulate it and invent a new technique to reduce the FWM in the systems. We will show later the results contains the FWM before and after using the technique.

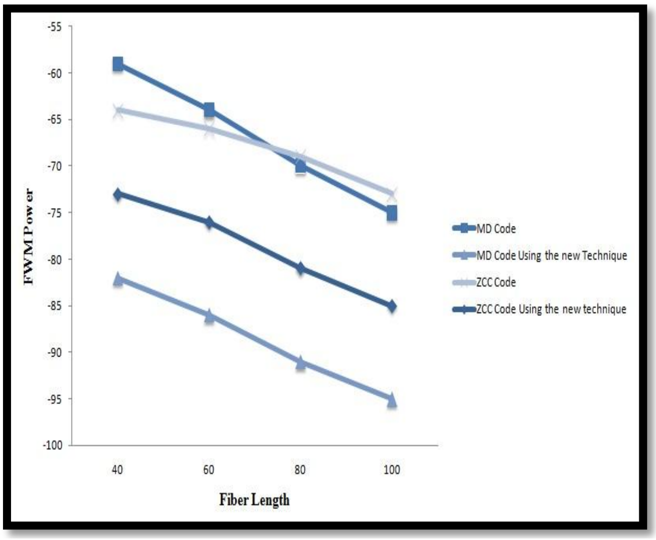


Figure 5. FWM Power Versus Fiber Length

Figure 5, shows the ZCC and the MD codes before and after using the technique. Before using the technique the ZCC code gives better results in short distance (20-60 km), while the MD code gets better performance in extended distance (80-100 km). In

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other words, the MD code in a long distance the FWM power not effects as is the case of the ZCC code, and vice versa for the ZCC code in small distance. In addition, when we use the technique, the MD code gives better performance than the ZCC code as in the case of the FWM effects in the SAC-OCDMA codes. Figures(6, 7, 8, 9), in this figures we show the FWM effects in the MD and the ZCC codes before and after using the LED technique at 60 km. We can show the FWM effects get better after using our technique for both codes. However, in the MD code, the FWM reducing more than the ZCC code because the distance between the one's in the code construction for the MD code further than in the ZCC code. In other words, the wavelengths of the MD code get more distances between each other so the overlapping between the wavelengths is little in the MD as comparing with the ZCC code.

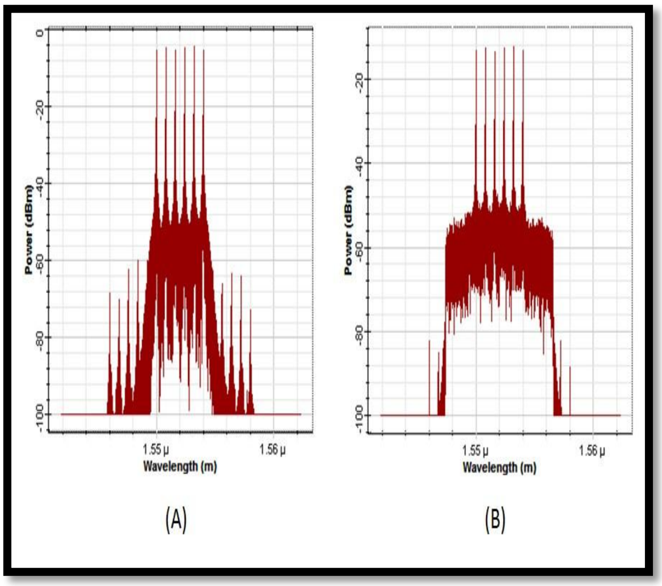

Figure 6. The OSA simulation results for the MD code at 60 km. (A) before using the LED technique. (B) after using the LED technique.

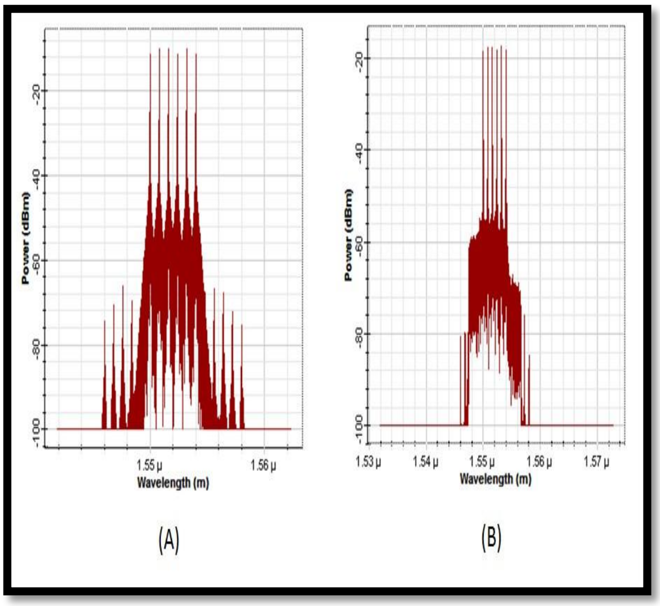

Figure 7. The OSA simulation results for the ZCC code at 60 km. (A) before using the LED technique. (B) after using the LED technique.

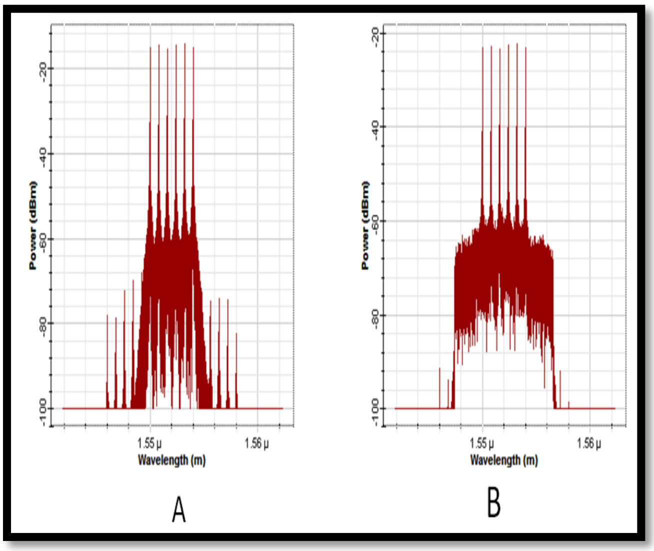

Figure 8. The OSA simulation results for the MD code at 80 km. (A) before using the LED technique. (B) after using the LED technique.

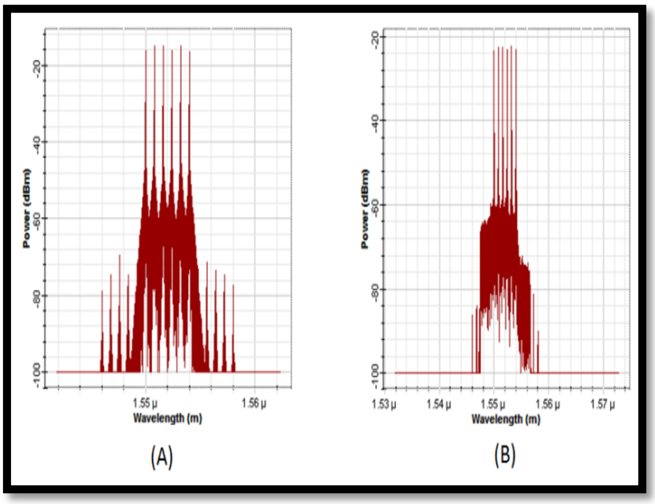

Figure 9. The OSA simulation results for the ZCC code at 80 km. (A) before using the LED technique. (B) after using the LED technique.

VI. CONCLUSION

We have illustrated a new technique based on LED combined with CW lasers in Spectral Amplitude Coding (SAC) Optical Code Division Multiple Access (OCDMA) networks, which allow reduction of the four-wave mixing (FWM) effect. This technique is applied for both SAC codes, the MD and the ZCC codes. The systems give better performance in BER after using the technique comparing with the systems before using the technique. Depending on the results show that the MD code gives better performance than the ZCC code by using our technique. In other words, the ratio of reducing the FWM power in the MD code is approximately -20 dBm, while in ZCC is -10 dBm.

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