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Novel OCDMA Detection Technique based on Modified Double Weight Code for Optical Access Network

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***Abstract*— In this paper a new detection technique known as NAND subtraction scheme based on Modified Double Weight (MDW) code for spectral-amplitude coding OCDMA (SAC-OCDMA) is proposed. The MDW code is the modified version of double weight (DW) code family. The theoretical and simulation results show that the new detection technique can have more better BER performance than other conventional techniques such as the AND and Complimentary subtraction techniques. The system performance was characterized by the signal to noise ratio (SNR), bit error rate (BER), and different P_{sr} (-10 dBm). This study also shows that the new detection scheme can be achieved when the number of users are high and maintain the standard acceptable BER value ((≤10^{-9}).**

***Index Terms*—AND and complimentary subtraction detection, fiber-bragg-grating, modified double weight code, NAND subtraction detection.**

I. INTRODUCTION

In all optical OCDMA systems, the detection is one of the important processes to design the system transmitter and receivers. In general, there are two basic known detection techniques, namely coherent and incoherent [1]. The knowledge of the phase information of the carriers keeps big impact when coherent detection send detection signal. On the other hand, incoherent detection has no such kinds of information. Alternatively, the incoherent OCDMA is performed in a unipolar approach and coherent is performed in a biopolar behavior with the coding operation. The less hardware complexity of incoherent detection makes a popular candidate compared to coherent detection. Moreover, the incoherent detection does not need phase synchronization. The application of coherent technique will be more difficult than that of incoherent technique. Therefore, we have chosen incoherent detection technique based on SAC for this research.

The cross correlation function is always generated in the incoherent code words and Multiple Access Interference (MAI) is generated in the system due to this cross correlation. This MAI can be reduced by using detection schemes for a SAC-OCDMA system. Therefore, a number of detection techniques are proposed by many researchers [2]–[10]. The well known detection techniques are complimentary subtraction technique [3], [4], AND subtraction technique [5], the spectral direct detection technique (SDD) [6] and XOR subtraction detection [7]. However, all these detection schemes suffer from various limitations. Though some of these detection techniques have successfully reduced MAI but still suffer from the better signal. This is considered as a big limitation of the existing detection techniques. The Modified Double Weight (MDW) [5] code is used in this study. The MDW code is successfully applied in complimentary and AND-subtraction techniques but the signals are not very good. In order to have better signals, we proposed a new detection technique called the NAND subtraction detection in this paper. The proposed technique was compared with

Complimentary and AND-subtraction technique. It was found that the NAND-subtraction scheme can reduce MAI completely, and provide better signal quality compared to other conventional existing techniques. Moreover, this new detection technique is applicable to other codes as well.

II. NAND SUBTRACTION TECHNIQUE

The mobility of the digital electrons in NAND gate is three times higher than AND/NOR gates [7]. This statement refers to the digital logic gates (AND, OR, NAND). However, in our proposed system the idea of NAND is used as an operation, not as a digital gate. Considering this point of view, the authors brought the concept of the NAND subtraction technique in our study. In the NAND subtraction detection technique, the cross-correlation $\theta_{\widetilde{XY}}(K)$ is substituted by $\theta_{(\widetilde{XY})}$, where $\theta_{(\widetilde{XY})}$ represents the NAND operation between X and Y sequences. For example, let $X = 1100$ and $Y = 0110$ therefore the NAND is $(\widetilde{XY}) = 1011$. Fig. 1 shows the implementation of NAND subtraction detection technique and Table 1 shows the comparisons between complementary and NAND subtraction detection technique using MDW codes.

Note that λ_i (where i is 1, 2…..N) is the column number

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of the codes which also represents the spectral position of the chips. Therefore, MAI can be cancelled using both techniques. However, NAND subtraction detection technique can generate extra weight as shown in Table I. This is due to the fact that when the code weight is increased, the signal power increases as well; hence, increases the signal-to-noise ratio. Therefore, The SAC-OCDMA performance is improved significantly using the NAND subtraction detection technique.

TABLE I. COMPARISON OF COMPLEMENTARY AND NAND SUBTRACTION DETECTION TECHNIQUE

	Complementary Subtraction				**NAND Subtraction**				**AND Subtraction**			
	λ_1	λ_2	λ_3	λ_4	λ_1	λ_2	λ_3	λ_4	λ_1	λ_2	λ_3	λ_4
X	1	1	0	0	1	1	0	0	0	0	1	1
Y	0	1	1	0	0	1	1	0	0	1	1	0
	$\theta_{XY} = 1$				$\theta_{XY} = 1$				$\theta_{XY} = 1$			
	$\theta_{\overline{XY}} = 0011$				$\theta_{\widetilde{XY}} = 1011$				$X\&Y = 0010$			
	$\theta_{\overline{\overline{XY}}} = 1$				$\theta_{(\widetilde{XY})Y} = 1$				$\theta_{(X\&Y)} = 1$			
Z	$Z = \theta_{XY} - \theta_{\overline{XY}} = 0$				$Z_{NAND} = \theta_{XY} - \theta_{(\widetilde{XY})Y} = 0$				$Z_{AND} = \theta_{XY} - \theta_{(X\&Y)Y} = 0$			

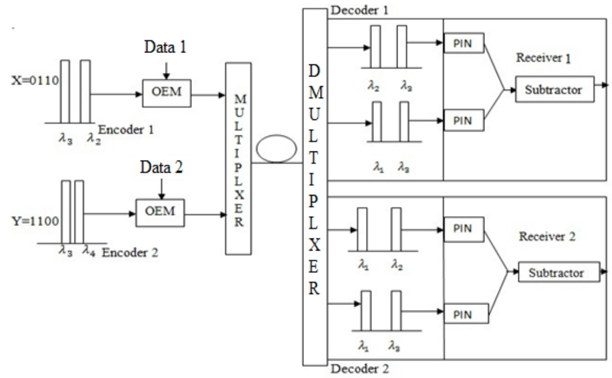

Fig. 1. Implementation of NAND subtraction detection technique.

III. SYSTEM PERFORMANCE ANALYSIS

In our proposed system, we have considered the effect of incoherent intensity noise $\langle i_{PIIN} \rangle$, shot noise $\langle i_{shot} \rangle$ and thermal noise $\langle i_{thermal} \rangle$ as well. The proposed NAND detection scheme is based on MDW code using Fibre Bragg Grating (FBG) followed by photo-detector. Gaussian approximation has been used for the calculation of BER [4]. When incoherent light fields are mixed and incident upon a photo-detector, the phase noise of the fields causes an intensity noise term in the photo-detector output [9]. The source coherence time τ_c is expressed as [10]

$$\tau_C = \frac{\int_0^\infty G^2(v)dv}{\left[\int_0^\infty G(v)dv\right]^2}, \tag{1}$$

where *G (v)* denotes the single sideband power spectral density (PSD) of the thermal source. The Q-factor performance provides the qualitative description of the optical receiver performance. The performance of an optical receiver depends on the signal-to-noise ratio (SNR). The Q-factor suggests the minimum SNR requirement to obtain a specific BER for a given signal [10]. The SNR of an electrical signal is defined as the average signal to noise power, $SNR = \left[I^2 / \sigma^2\right]$, where σ^2 is the variance of noise source (note: the effect of the receiver's dark current and amplification noises are neglected in the analysis of the proposed system), given by

$$\sigma^2 = \langle i_{shot}^2 \rangle + \langle i_{PIIN}^2 \rangle + \langle i_{thermal}^2 \rangle . \tag{2}$$

The (2) can be expressed as

$$\sigma^2 \quad = 2eBI + I^2 B\tau_C + \frac{4K_b T_n B}{R_L}, \tag{3}$$

where the symbols used in (3) bear the following meaning. *e* Electron charge; *I* Average photocurrent; I^2 The power spectral density for *I*; *B* Electrical bandwidth; *Kb* Boltzmann Constant; T_n Absolute receiver noise temperature; R_L Receiver load resistor.

The code cross-correlation properties of MDW codes using NAND operation of the detection part differs from Complementary and AND-Subtraction technique. In this technique, the system carried out better performance in terms of PIIN noise, shot noise, signal to noise ratio and bit error rate. The new detection scheme based on MDW code properties has been explained in (4) and (5). If $C_k\,(i)$ denotes the ith element of the Kth MDW code sequence, the code properties for NAND can be written as shown in (5):

$$\sum_{i=l}^{N} C_K(i)\, C_l(i) = \begin{cases} \mathrm{W}, & For\ \ K = l, \\ 1, & For\ \ K \neq l, \\ 0, & \text{Else}, \end{cases} = \begin{cases} \mathrm{K} + 1, if\ K < l, \\ K - 1, if\ K > l, \end{cases} \tag{4}$$

$$\sum_{i=l}^{N} C_K \widetilde{(\imath) C_l}(\imath) \cdot C_l(i) = \begin{cases} \mathrm{W}, & For\ \ K = l, \\ \mathrm{W} - 1, & For\ \ K \neq l, \\ 0, & \text{Else}, \end{cases} = \begin{cases} \mathrm{K} + 1, if\ K < l, \\ K - 1, if\ K > l. \end{cases} \tag{5}$$

The system transmitter and receiver is analyzed according to the [9], [10] analysis. All the assumptions considered in [9] are important for mathematical simplicity. Therefore, the following assumption is taken into account for the analysis of the system:

- Each light source is ideally not polarized and its spectrum is flat over the bandwidth [v_o-Δv/2, v_o+Δv/2], where v_o is the central optical frequency and Δv is the optical source bandwidth expressed in Hertz.
- Each power spectral component has an identical spectral width.
- Each user has equal power at the receiver.
- Each bit stream from each user is synchronized.

The power spectral density of the received optical signals can be written as [8], [10]

$$r(v) = \frac{P_{sr}}{\Delta v} \sum_{K=1}^{K} d_K \sum_{i=1}^{N} c_K(i) rect(i), \tag{6}$$

where P_{sr} is the effective power of a broadband source at the receiver, *K* is the active users and *N* is the MDW code length, d_K is the data bit of the *K*th user that is "1" or "0". The $rect(i)$ is given by

$$rect(i) = u\left[v - v_0 - \frac{\Delta v}{2N}(-N+2i-2)\right] - u\left[v - v_0 - \right.$$
$$\left. - \frac{\Delta v}{2n}(-N+2i)\right] = u\left[\frac{\Delta v}{N}\right], \quad (7)$$

where $u(v)$ is the unit step function and can be expressed as

$$u(v) = \begin{cases} 1, & v \geq 0, \\ 0, & v < 0. \end{cases} \quad (8)$$

The total incident power at the input of PIN 1 and PIN 2 of Fig. 1 is given by

$$\int_0^\infty G_1(v)\,dv = \int_0^\infty \left[\frac{P_{sr}}{\Delta v}\sum_{K=1}^{K} d_k \sum_{i=l}^{N} C_K(i)\, C_l(i) \times \right.$$
$$\left. \times \left\{u\left[\frac{\Delta v}{N}\right]\right\}\right] dv = \frac{P_{sr}}{N}\sum_{K=1\,K=l}^{K} d_K\,. \quad (9)$$

Now, power spectral density for photodetector 2 is given by:

$$\int_0^\infty G_2(v)dv = \int_0^\infty \left[\frac{P_{sr}}{\Delta v}\ \sum_{K=1}^{K} d_k \sum_{i=l}^{N}\left(C_K\widetilde{(i)C}_l(i) \times \right.\right.$$
$$\left.\left. \times\, C_K(i)\right)\left\{u\ \left[\frac{\Delta v}{N}\right]\right\}\right] dv\,, \quad (10)$$

$$\int_0^\infty G_2(v)dv = \frac{P_{sr}}{N}\ [W + (W-1)\sum d_K]. \quad (11)$$

Now the photodiode current *I* can be expressed as

$$I = I_2 - I_1. \quad (12)$$

In the above equations, d_K is the data bit of the ***K***th user that carries the value of either “1” or “0”. Consequently, the photocurrent *I* can be expressed as combining the (9) and (10)

$$I = I_2 - I_1 = \Re\int_0^\infty G_2\,(v)dv - \Re\int_0^\infty G_1\,(v)dv =$$
$$= \frac{\Re P_{sr}(2W-2)}{N}, \quad (13)$$

where $\Re$ is the responsivity of the photo-detectors and given by ($\Re = {}^{\eta e}\!/_{hv_c}$). Here, η is the quantum efficiency, ***e*** is the electron charge, *h* is the Planck’s constant, and v_c is the central frequency of the original broadband optical pulse.

The noise power of shot noise can be written as:

$$\langle I_{shot}^2\rangle = 2eB\,(I_1 + I_2)\ , \quad (14)$$

$$\langle I_{shot}^2\rangle = 2eB\Re\left[\int_0^\infty G_1(v)dv\ + \int_0^\infty G_2(v)dv\right], \quad (15)$$

$$\langle I_{shot}^2\rangle = 2eB\Re\ \left[\frac{\Delta v}{N}\right]\ \left[\frac{P_{sr}}{N}\sum_{K=1\,K\neq l}^{K} d_k + \ \frac{P_{sr}}{N}\ \left(W + \right.\right.$$
$$\left.\left. +(W-1)\right)\sum_{K=1\,K\neq l}^{K} d_k\right], \quad (16)$$

$$\langle I_{shot}^2\rangle = \frac{2eB\Re P_{sr}}{N}\left[\frac{4W+W^2}{2}\right]. \quad (17)$$

By using the similar methodology in [1] and approximating the summation $\sum_{K=1}^{K} c_K \approx \frac{KW}{N}$ and $\sum_{K=1}^{K} c_{KT} \approx \frac{KW}{N}$ the noise power can be written as:

$$\langle I_{PIIN}^2\rangle = BI_1^2\tau c_1 + BI_2^2\tau c_2\ , \quad (18)$$

$$\langle I_{PIIN}^2\rangle = B\Re^2\left[\int_0^\infty G_1(v)dv + \int_0^\infty G_2(v)dv\right], \quad (19)$$

$$\langle I_{PIIN}^2\rangle = \frac{B\Re^2 P_{sr}^2}{N\Delta v}\ \left[\frac{KW}{N}\right]\sum_{K=1}^{K}\left[\sum_{i=l}^{N} C_K(i)C_l(i)\right] +$$
$$+\frac{B\Re^2 P_{sr}^2}{N\Delta v}\left[\frac{KW}{N}\right]\sum_{K=1}^{K}\left[\sum_{i=l}^{N} C_K\widetilde{(\iota)C}_l(\iota)\,.\,C_K(i)\right], \quad (20)$$

$$\langle I_{PIIN}^2\rangle = \frac{B\Re^2 P_{sr}^2 KW}{N^2\Delta v}\left[\frac{4W+W^2}{2}\right]. \quad (21)$$

The thermal noise is given as [1], [4]

$$\langle i_{thermal}^2\rangle = \frac{4K_bT_nB}{R_L}\ . \quad (22)$$

Noting that the probability of sending bit ‘1’ at any time for each user is ½ [10] so that the SNR of the NAND detection system can be written as

$$SNR = \frac{I^2}{\tau^2} == \frac{\frac{\Re^2 P_{sr}^2(2W-2)^2}{N^2}}{\frac{eB\Re P_{sr}W\left(\frac{4W+W^2}{2}\right)}{N} + \frac{B\Re^2 P_{sr}^2 KW\left(\frac{4W+W^2}{2}\right)}{N^2\Delta v} + \frac{4K_bT_nB}{R_L}}. \quad (23)$$

(16) is the general equation used to calculate the signal to noise ratio for the MDW code families. Using Gaussian approximation, the bit-error-rate (BER) can be expressed as [9], [10]

$$BER = P_e = \frac{1}{2}\,erfc\left(\sqrt{\frac{SNR}{8}}\right). \quad (24)$$

Fig. 2 shows the BER versus number of simultaneous user for NAND-subtraction, AND-subtraction and Complementary technique [6], [9]. The numerical results according to the system parameter are listed in Table I. It is seen from Fig. 2 that the NAND subtraction detection technique in SAC-OCDMA system using MDW codes suppressed MAI completely and the received power (detected 1’st user) is higher than Complementary and AND-subtraction technique. It also shows very clearly that the NAND subtraction technique supports more number of users (users 140 at 10^{-28}) compared to Complimentary and AND subtraction technique. The reason of the better performance of NAND subtraction detection is that the MAI is completely suppressed in the receiver side.

TABLE. I. THE SYSTEM PARAMETERS.

PD quantum efficiency	$\eta = 0.6$
Line width of the thermal source	$\Delta v = 3.75 THz$
Operation wavelength	$\lambda = 1.55\mu m$
Electrical bandwidth	$B = 311\ MHz$
Receiver noise temperature	$T_r = 300\ K$
Receiver load resistor	$R_L = 1030\Omega$

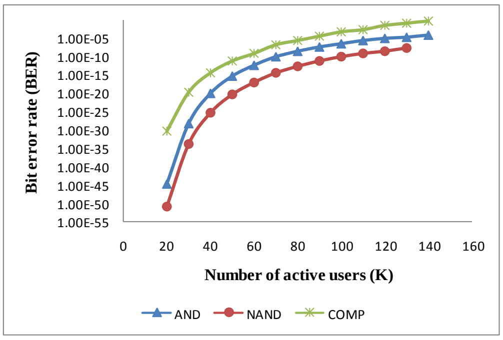

Fig. 2. BER versus number of simultaneous user when $P_{sr} = -10\ dBm$.

Fig. 3 shows the signal to noise ratio (SNR) against the number of simultaneous user. It is seen that the MDW codes give a much higher SNR value using NAND subtraction technique compared to Complimentary and AND detection techniques when the effective power is high (when $P_{sr} < -25\ dBm$).

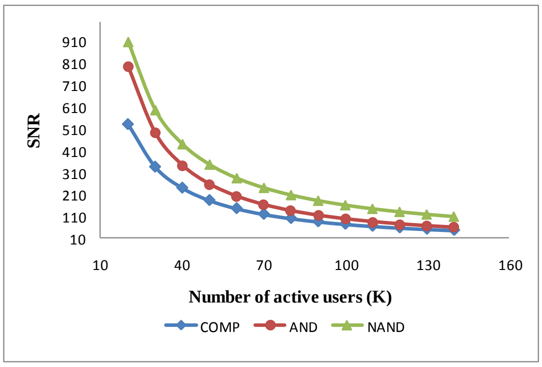

Fig. 3. SNR versus number of simultaneous user when $P_{sr} = -10\ dBm$.

Fig. 4 shows the performance of the system using AND, NAND and Complementary subtraction technique at various values of received power P_{sr}. The numbers of active users in the system are fixed at 40. The performance of the system using NAND subtraction technique is better than other two techniques. Although the BER is go down but the value is very negligible (for example 1^{-55}). This does not oppose the objective of the study in comparing the performance of three detection schemes.

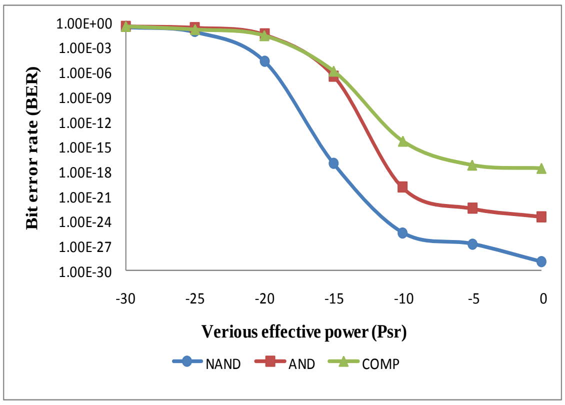

Fig. 4. BER versus P_{sr} when number of simultaneous users is 40.

In numerical analysis, we do not consider any parameters such as optical fiber non-linear effects namely Four Wave Mixing (FWM), Self Phase Modulation (SPM), Cross Phase Modulation (XPM) and also the dispersions namely Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD). However, all this parameters will not affect the comparative analysis between the three techniques, because all the transmission conditions are same. Moreover, all these parameters are taken in to the account in the simulation. The results are shown bellow in the section 4.

IV. SIMULATION RESULTS

The system is designed and simulated at 622 Mb/s bit rates using OptiSystem Ver. 9.0. Each chip has a spectral width of 0.8-nm. The insertion loss of multiplexer/demultiplexer is taken in the account of 0.25 dBm and 2 dBm respectively. The ITU-T G.652 standard single-mode optical fiber (SMF) is used for transmitting signal. The used fiber parameters values are taken from the data which are based on the G.652 Non Dispersion Shifted Fiber (NDSF) standard. This include all fiber parameter such as group delay, group velocity, attenuation α (i.e., 0.25 dB/km), polarization mode dispersion (PMD, i.e.,18 ps/nm km), non linear effects such as four wave mixing (FWM) and self phase modulation (SPM), which were all wavelength dependent. All these parameters were activated during simulation. The dark current values was 5 nA and the thermal noise co-efficient was 1.8×10^{-23} W/Hz for each of the photo detectors. The generated noises at the receivers were set to be random and totally uncorrelated. The system performance is carried out by referring to the bit error rate. The whole simulation is specified according to the typical industrial values to simulate the real environment as close as possible. The data are plotted in Fig. 5 where the simulated fiber distance is taken account for maximum 50 km. It is shown that as the distance are increasing the BER decreases. The simulation results are compared same like analytical method where the NAND is compared between AND and complementary technique. Significantly, the NAND technique always transmits the better signal because the MAI is fully suppressed with extra one filter in the decoder side. The error-free transmission ($BER<10^{-9}$) is always maintain until 50 km for NAND technique. Significantly, the complementary technique cannot maintain standard error free transmission at 50 km distance. Though AND can maintain the value but lower than NAND. It can point out that the very low BER values are just measure the quality of the signals. Although, in real experiment it may not be meaningful.

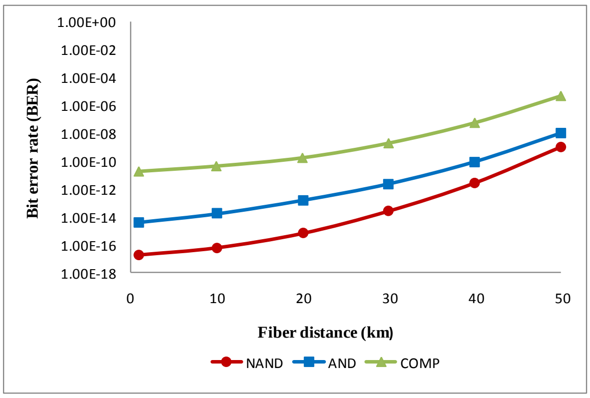

Fig. 5. BER against distance of OCDMA system using NAND subtraction at transmission rates at 50 km.

V. CONCLUSIONS

In this paper, we have successfully developed a novel OCDMA detection technique referred to as the NAND subtraction technique to improve the system performance. The performance of the system was carried out by using Modified Double Weight (MDW) code.

The Bit-Error-Rate (BER) performance of OCDMA system using NAND subtraction technique has been evaluated extensively. The evaluation results for the NAND subtraction technique were compared with AND and Complementary subtraction technique. Based on the comparison, we found that the NAND subtraction technique can support some extra active users and offer better performance as compared to other two conventional detection techniques.

It was also found that the the NAND subtraction technique can significantly reduce the effect of MAI and PIIN noise. Since the overall performance of OCDMA system is greatly improved by NAND subtraction technique then the proposed system can be better choice for future OCDMA technology.

REFERENCES

[1] W. Huang, “Coherent Optical CDMA (OCDMA) Systems Used for High Capacity Optical Fiber Networks System Description, OTDMA Comparison, and OCDMA/WDMA Networking”, *Lightwave Technology,* vol. 18, no. 6, pp. 765–778, 2000. [Online]. Available: http://dx.doi.org/10.1109/50.848384

[2] L. Nguyen, B. Aazhang, J. F. Young, “All-Optical CDMA with Bipolar Codes”, *IEEE Electronic. Letters,* vol. 31, no. 6, pp. 469–470, 1995. [Online]. Available: http://dx.doi.org/10.1049/el:19950296

[3] E. D. J. Smith, R. J. Blaikie, D. P. Taylor, “Performance Enhancement of Spectral Amplitude Coding Optical CDMA using Pulse Position Modulation”, *IEEE Transection on Communication,* vol. 46, no. 9, pp. 1176–1185, 1998. [Online]. Available: http://dx.doi.org/10.1109/26.718559

[4] S. A. Aljunid, M. Ismail, A. R. Ramli, M. Ali. Borhanuddin, M. K. Abdullah, “A New Family of Optical Code Sequences for Spectral Amplitude Coding Optical CDMA Systems”, *IEEE Photonics Technology Letters,* vol. 16, no. 10, pp. 2383–2385. [Online]. Available: http://dx.doi.org/10.1109/LPT.2004.833859

[5] M. K. Abdullah, N. H. Feras, S. A. Aljunid, S. Sahbudin, “Performance of OCDMA Systems with new Spectral Direct Detection (SDD) Technique using Enhanced Double Weight (EDW) Code”, *Optics Communnication,* no. 18, pp. 4658–4662, 2008.

[6] Y. A. Hassan, F. Ibrahima, M. S. Naufal, S. A. Aljunid, “OCDMA System: New Detection Scheme and Encoder-Decoder Structure Based on Fiber Bragg Gratings (FBGS) for Vcc Code”, *Computer and Applications,* no. 4, pp. 2021–2881, 2010.

[7] H. Brain, R. Cilve, Digital Logic Design. Elsevier Science, 2002.

[8] R. K. Z. Sahbudin, M. K. Abdullah, M. Mokhtar, “Performance Improvement Of Hybrid Subcarrier Multiplexing System using Code For Ocdma Systems using Spectral Direct Decoding Detection Technique”, *Optical Fiber Technology,* vol. 15, no. 3, pp. 266–273, 2009. [Online]. Available: http://dx.doi.org/10.1016/j.yofte.2008.12.003

[9] Z. H. Wei, Ghafouri-Shiraz, “Codes for Spectral-Amplitude-Coding Optical CDMA Systems”, *Lightwave Technology,* vol. 50, no. 8, pp. 1209–1212, 2002,

[10] A. F. Hillal, S. A. Aljunid, R. B. Ahmaad, “Effect of Random Diagonal Code Link of OCDMA Scheme for High-Speed Access Networks”, *Optical Fiber Technology,* vol. 15, no. 5, pp. 237–241, 2009.