# Study of Optical Spectral CDMA Zero Cross-correlation Code

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**Summary** - This paper concentrates on Double Weight code family as a proposed code for the optical spectrum code division multiple access (OSCDMA) which has one cross correlation value. By eliminating the intersection columns of this code, the cross correlation value will be zero instead of one. This new derived code is called Zero Cross-Correlation Code (ZCC). It is called zero cross correlation code because the cross correlation value between any two codes sequence equals to zero. Therefore, the Multiple Access Interference (MAI) should be reduced. In addition, general new equations are obtained for ZCC code instead of basic matrix and mapping technique.

***Keywords***: *Code Division Multiple Access (CDMA), Optical Spectrum Code Division Multiple Access (OSCDMA), Multiple Access Interference (MAI), Zero Cross Correlation (ZCC) code.*

## 1. Introduction

The major three multiple access techniques are Time Division Multiple Access (TDMA), Wave Length Division Multiple Access (WDMA), and Code Division Multiple Access (CDMA). TDMA and WDMA are used in the fiber optic communication by dividing a bandwidth among multiple users.

TDMA is a technology that allows multiple users to access a channel by allocating time slots to each user within each channel .WDMA is a technology allowing multiple users to access a channel by allocating wave-length or frequency to each user within each channel. TDMA and WDMA have a limited bandwidth for every user. CDMA is an attractive technique invented for wireless communication and it offers better performance if compared to other existing multiple access technique. Also, the main advantages of CDMA are it is random, offer simultaneous protocol (no need for strict timing synchronization), no need for strict wave length control, no need for centralized network, simple protocol, self routing by code sequence, Tolerance to the noise, inherent security and low cost device. We have shown CDMA has become very popular in cellular radio network. In addition, optical communication system in optical fiber acts as the major part of digital communication because it can accommodate high speed LAN, MAN and FTTH. As a result, it has motivated a number of studies if the benefits of CDMA can also be used in optical communication system. Optical CDMA is an attractive multiplexing technique [1]-[4] because it allows multiple users to utilize the available frequency at the same time with no delay. A user is distinguished from the others by a unique code. However, the performance of OCDMA degrades when the number of simultaneous users increases which is in turn increases the multiple access interference (MAI).

The OCDMA suffers from various types of noise like MAI, photo detector, shot noise, dark current and thermal noise. The dominant source of noise is MAI, thus the cancellation or suppression of MAI is a big problem in OCDMA [2] [9].

The primary objective in code design in OCDMA is to construct code sequence with:

(i) High auto-correlation in order to maximize the intended signal with respect to the interfering (noise).
(ii) Low cross correlation to easily distinguish the intended signal from the interfering signal.

To send information from any transmitter to any receiver, the signature code of the specific receiver should be impressed up on the data by encoder at the transmitter.

Various solutions have been proposed especially in the coding techniques. One of the codes studied recently is the Zero Cross-correlation Code [1]. This paper will explain in detail another construction technique of this code.

## 2.OPTICAL SPECTRUM CODE DIVISION MULTIPLE ACCESS (OSCDMA)

OSCDMA is an incoherent broadband light source which contains N user with optical transmitters and receivers [4] [5]. OSCDMA system contains encoders and decoders which can be designed by using any kind of optical filtering technology. In this system, the signature sequence is spread across different wavelength with each chip occupying different wavelength [4] [5].

The advantage of OSCDMA is it does not need synchronization as the chip spreads in frequency and not in time.

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## 3. DOUBLE WEIGHT CODE (DW)

The DW code is represented in [4] by using a KxN matrix, K represents the rows as the number of user and N represents the columns as the minimum code length. A basic DW is given by 2x3 matrix is illustrated in equation .1

$$H_{M=1} = \begin{bmatrix} 0 & 1 & 1 \\ 1 & 1 & 0 \end{bmatrix}$$

(1)

For every three column the combination sequence is 1,2,1 to keep the maximum cross correlation one . The combination sequence is summation of the value of corresponding elements in every two rows. For basic matrix, the number of users is 2 and the length is 3. In order to increase the number of users and the length a mapping technique is proposed in [4] and in this technique the number of rows and columns should be doubled.

$$H_{M=2} = \left[\begin{array}{ccc|ccc} 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 0 \\ \hline 0 & 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 \end{array}\right] = \begin{bmatrix} 0 & H_1 \\ H_1 & 0 \end{bmatrix}$$

The DW code has the following properties:

1. The code weight is two.
2. The cross-correlation is as most one.
3. The weighted chips are in pairs.
4. The chips combination is maintained 1,2,1 for every three columns.

## IV. MODIFIED DOUBLE WEIGHT CODE (MDW)

The MDW is a type of DW family. The properties of DW and MDW are the same except the MDW has a weight more than two (multiple of two) to increase the signal to noise ratio (SNR).The fig.2 shows the basic matrix construction of MDW.

$$\left[\begin{array}{c|c} [A] & [B] \\ \hline [C] & [D] \end{array}\right]$$

Figure1: General form for MDW basic matrix construction

Since A,B,C and D are obtained as :

[A] Consists of a $1 \times 3\sum_{j=1}^{\frac{W}{2}-1} j$ matrix of zeros.

[B] Consists of a 1 x 3***n*** matrix of [ $X_2$ ] for every 3 column. (I.e. a 1 x 3***n*** matrix with ***n*** times repetition of [ $X_2$ ]), where $n = \frac{W}{2}$.

[C] Is the basic code matrix for the next smaller weight, (W = 2(***n***-1)).

[D] Is an ***n*** x ***n*** matrix of [ $X_3$ ] as shown in equation (2)

$$[D] = [X_3] = \begin{bmatrix} 000 & 000 & [X_3] \\ 000 & [X_3] & 000 \\ [X_3] & 000 & 000 \end{bmatrix}$$

(2)

Where:

$$X_1 = \begin{bmatrix} 0 & 0 & 0 \end{bmatrix} \quad (3)$$

$$X_2 = \begin{bmatrix} 0 & 1 & 1 \end{bmatrix} \quad (4)$$

$$X_3 = \begin{bmatrix} 1 & 1 & 0 \end{bmatrix} \quad (5)$$

The two basic components in the basic matrix of MDW code are:-

Basic Code Length:

$$N_B = 3\sum_{m=1}^{\frac{W}{2}} m$$

(6)

Basic number of users:

$$K_B = \frac{W}{2} + 1$$

(7)

After studying the matrix construction of MDW code, we found the cross correlation is one. To obtain specific code for unique user you must construct the entire matrix to get different users by the form matrix construction above. It is important to reduce the cross correlation from one to zero which will reduce the multiple access interference and this enhances the system performance.

## 4. ZERO CROSS-CORRELATION CODE (ZCC)

The example of matrix of MDW code with the weight is equal to 4 (w=4) is given in TABE I.

To get the cross correlation equal to zero the intersection columns should be eliminated ,which contain the cross correlation value equal to one and after this removing the zero cross correlation value can be obtained as shows in Table II. The basic component construction of TABEL II which has cross correlation value equal to zero can be changed as Basic code length as shown in equation (8) which it determines the number of bits in each code sequence.

From equation (8) below we noticed the basic code length depend on the weight

$$N_{B1} = 2\sum_{m=1}^{W\ 1} m$$

(8)

Basic number of user as shown in equation (9) which is determine the number of user in each basic matrix. Also the number of user can be determined by the value of the weight.

$$K_{B1} = W1 + 1$$

(9)

W1 is the weight of the code in TABEL II with zero cross correlation value.

OCDMA is attractive communication technology but it suffers from MAI which impress on the bit error rate (BER). In order to obtain a better performance in OCDMA, the cross correlation value must be in a small value. However, when the cross correlation value increases, the MAI increases. The main goal of these studies is to reduce the MAI of MDW code from one to zero in order to get a good result.

Table I : The basic matrix MDW of weight equal four (W=4) and one cross correlation value with rectangles showing the different groups.

| $k_B$ | C9 | C8 | C7 | C6 | C5 | C4 | C3 | C2 | C1 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 |
| 2 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| 3 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |

| $k_{B1}$ | C6 | C5 | C4 | C3 | C2 | C1 |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| 2 | 0 | 1 | 0 | 0 | 1 | 0 |
| 3 | 1 | 0 | 1 | 0 | 0 | 0 |

Table II : The basic matrix of ZCC code of weight equal two (W=2) and zero cross correlation value with rectangles showing the different groups

## 5. The Mapping Technique

The mapping technique is used to increase the number of users when we obtain the basic matrix [3] with the specific users depends on the weight. This technique increase number of users by repeating the basic matrix diagonally for any number of times and put in the empty space zero.

For very large number of users, the construction of the basic matrix and mapping technique is so difficult. There for a general equation is derived to obtain any number of users. These studies concentrate to find the general equations of ZCC code so we can obtain cross correlation value equal to zero.

Table III: ZCC code mapping technique of basic matrix in Table II with weight equal two (W1=2) and zero cross correlation value. The rectangles showing the different groups

| k | C12 | C11 | C10 | C9 | C8 | C7 | C6 | C5 | C4 | C3 | C2 | C1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## 6. The Equation Based Code Construction

In table .II this is an example of basic matrix after we removed the intersection columns in order to obtain zero cross correlation, hence the weight is changed from 4 in table.1 to two in table. II. In table .II there are two groups where the first group (black rectangular) consists of the number of ones which are situated in odd square. It has a maximum W1 in first row and decrease when we go down towards bottom, it reduces to zero for the last user (user number $K_{B1}$). The second group (gray rectangular) involves number of the ones which are situated in even square starting from user number two with (W1=1) and increase when we go down towards bottom. For the last user (user number $K_{B1}$) it takes maximum value of W1.In the table. II we put the first right column is column number one and the first row is the row number one. Equation (10) used to obtained any user of basic matrix. We use the mapping technique for TABEL II to get TABEL III.

In this equation (11) which it used to get Table.III we have two partial equations .the first equation is for the odd group and the second one for the even group. The symbol lower bounded $\lfloor x \rfloor$ denotes the integer portion of the real value of X, $n_1$ and $n_2$ represents the number of ones in each group.

$$n_1 + n_2 = \mathrm{W1}$$

In the first partial equation, the first part is used for the plotting the odd one while the second two parts is used to shift the starting point of the odd group. The second partial equation is used to plot the even square group (gray rectangular) which is controlled by the number of row (i).

$$ZCC_{i,j} = \begin{cases} 1 \quad if & \begin{cases} j = (n_1 - 1) + \left\lfloor \frac{(2n_1+1)}{2} \right\rfloor + \sum_{m=0}^{i \bmod K_{B1} - 2} (2W1 - 2m) & for \quad n_1 = \{1,2,..,W1-(i-1)\} \\ j = 2(i-1) + \sum_{m=1}^{\lfloor n_2 - 1 \rfloor} (2W1 - 2m) & for \quad n_2 = \{1,2,\ldots,(i-1)\} \end{cases} \\ 0 \quad Otherwise & \end{cases}$$

(10)

$$ZCC_{i,j} = \begin{cases} 1 \quad if & \begin{cases} j = (n_1 - 1) + \left\lfloor \frac{(2n_1+1)}{2} \right\rfloor + \sum_{m=0}^{i \bmod K_{B1} - 2} (2W1 - 2m) + \left\lfloor \frac{(i-1)}{K_{B1}} \right\rfloor \mathrm{N}_{B1} & for \quad n_1 = \{1,2,..,w1-((i-1) \bmod K_{B1})\} \\ j = 2\{(i-1) \bmod K_{B1}\} + \sum_{m=1}^{\lfloor n_2 - 1 \rfloor} (2W1 - 2m) + \left\lfloor \frac{(i-1)}{K_{B1}} \right\rfloor N_{B1} & for \quad n_2 = \{1,2,\ldots,(i-1) \bmod K_{B1}\} \end{cases} \\ 0 \quad Otherwise & \end{cases}$$

(11)

The first part and the third are used to put the even ones in their square and the second is used to shift the one to the next square in the same row (i).

For the user number i

$$1 \le i \le k$$

(12)

Where $k$ is the total number of users, and column *j* for the position of each chip:

$$1 \le j \le L$$

(13)

Where *L* is the maximum length given below

$$L = \{ \sum_{m=1}^{i \bmod K_{B1}} 2(W1 - (m-1)) - (\frac{1}{i \bmod K_{B1}}) \} + \left\lfloor \frac{i}{K_{B1}} \right\rfloor N_{B1}$$

(14)

To find user number three (i=3) for the basic matrix which has been shown in Table above with weight equal 2 (W1=2) using equation (10) above. The simulation result is shown in Figure II below

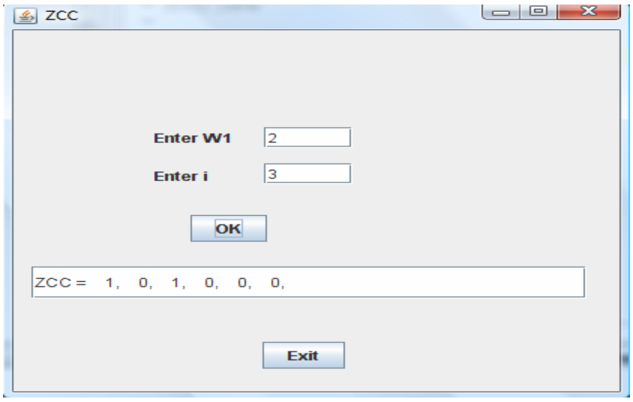


Figure II: shows the simulation result of user number 3 in the basic matrix with weight equal 2

To find user number five (i=5) for the mapping technique which has been shown in table III above with weight equal 2 (W1=2) using equation (11) above. The simulation result is shown in Figure III below

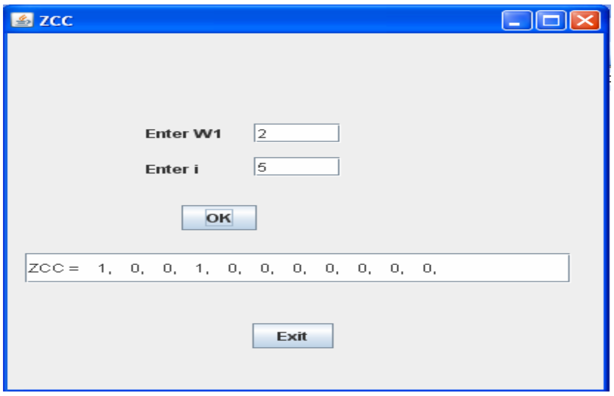


Figure III shows the simulation result of user number 5 with weight equal 2

To calculate the maximum length of user number 5 in table III with weight equal 2 (w1=2) above using equation (14) above . The simulation result is shown in Figure IV below

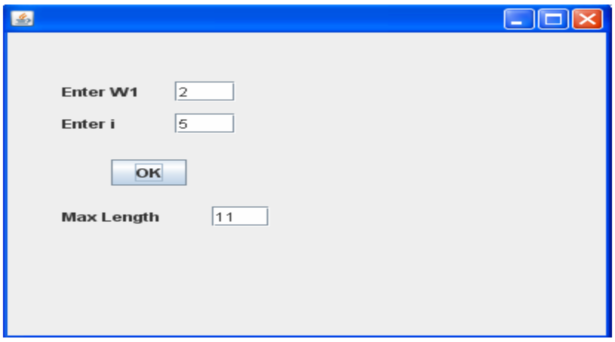


Figure IV: shows the simulation result of maximum length of user number 5 of the mapping technique.

## 7. Conclusion

With the large number of users the performance of OCDMA system is degraded because the MAI will increase. This new code is not influenced by number of user because the cross correlation value is zero.

The general equation for ZCC ode has been constructed for the basic matrix instead using the traditional way. Also a general equation for this code has been formulated for the mapping of basic matrix. Apart from that, we also derived the exact length of specific code for any weight.

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