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Three dimensional optical CDMA framework with direct detection technique

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ABSTRACT

In this paper, a three-dimensional (3-D) wavelength/time/space code is developed for optical code division multiple access (OCDMA) networks with direct detection technique in the receiver side. The 3-D codes are developed by mixing two-dimensional modified quadratic congruence (MQC) code and one-dimensional prime hop code (PHC) code. The encoders and decoders are constructed using fiber Bragg gratings and delay lines to minimize the bit error rate (BER). The performance analysis of the 3-D OCDMA system is based on measurement of signal to noise ratio (SNR), BER, received power and eye diagram for different numbers of simultaneous users. Also, in the analysis, various types of noises and multiple access interference (MAI) effects are considered. The received optical power is also measured at various levels of BER to analyze the effect of attenuation.

Keyword**:** Cross correlation (CC), Three dimensional optical code division multiple access (3-D OCDMA), Spectral amplitude coding optical code division multiple access (SAC-OCDMA), Multiple access interference (MAI), Phase induced intensity noise (PIIN), Three dimensional modified quadratic congruence/prime hop code (3-D MQC/PHC)

1. INTRODUCTION

The optical CDMA technology is one of the major techniques in recent times for optical access networks supporting large number of simultaneous users by using available bandwidth with less time delay, flexible provisioning, higher data rate transmission, lower bit error rate (BER) and security [1]. But the OCDMA systems always suffer due to the influence of various types of noises like thermal noise, shot noise, phase induced intensity noise (PIIN) and most importantly multi-access-interference (MAI) [2]. In OCDMA systems, different types of codes have been proposed like one-dimensional (1-D) codes [3], which spread in time or frequency, and two-dimensional (2-D) codes [4], which spread in both time and wavelength. With the increase in number of active users in the OCDMA network, the MAI increases which degrades system performance. To minimize MAI, the number of chip collisions in the receiver should be less, the length of the code should be increased and the weight of the code chips should be reduced. By increasing the length of the one dimensional unipolar code and two dimensional codes, the complexity of the encoder and decoder increases which reduces the data transmission rate. To nullify the above system limitations, 3-D OCDMA code (MQC/PHC) is designed by mixing 2-D modified quadratic congruence (MQC) code [5] and 1-D prime hop code (PHC) code [6].

In 3-D OCDMA coding, pulses are positioned in various chips of different wavelength across the bit period, making a wavelength hopping pattern which results increased code design flexibility and better coding performance. Hence, all simultaneous users share the exact wavelength, time domain and space, achieving better division of wavelength, synchronous access and easier network control and management.

The 3-D wavelength/time/polarization OCDMA coding requires polarization maintaining fiber and polarization sensitive optical components for network implementation. This polarization control in all stages of optical network increases complexity and cost of the network. To avoid these complexities, normally 3-D wavelength/time/space OCDMA codes are used for improving the performance of optical networks which avoids the complexities arising due to polarization.

In this work, the encoders and decoders for the proposed 3-D wavelength/time/space OCDMA codes have simple design procedures and the codes are flexible. Direct detection technique is used in the receiver side for improving the performance of the OCDMA system.

2. THE PROPOSED 3-D MQC/MP CODE CONSTRUCTION

The three dimensional (3-D) MQC/PHC code is constructed by mixing the properties of wavelength hopping and temporal spreading modified quadratic congruence (MQC) code [5] and spatial coded prime hop code (PHC) code [6]. The 3-D MQC/PHC code with X as number of wavelengths, Y as the temporal code length and Z as the spatial code length, W as weight, λ_a and λ_c are auto-correlation and cross-correlation values, is referred as ($X \times Y \times Z$,W, λ_a , λ_C).

2. 1. THE PROPOSED 3-D MQC/PHC DESIGN PROCEDURE

The following steps describe the construction of 3-D MQC/PHC code for various orders.

A. 2-D MQC code construction

The 2-D modified quadratic congruence (MQC) code is constructed using the following stages.

Stage 1:

In this stage, At first, we have constructed a sequence of integer numbers as $t_{i,j}(k)$ that are elements of a Galois finite field GF (*p*) over an odd prime *p* (*p* > 2) by using the equation 1 [5].

$$t_{i,j}(k) = \begin{cases} \left[c(k+i)^2 + j\right](\text{mod } p), & k = 0,1,\cdots\cdots, p-1 \\ \left[i+b\right](\text{mod } p), & k = p \end{cases} \qquad (1)$$

where $c \in \{1, 2.........., p\text{-}1\}$ and $b, i, j \in \{0, 1, 2.........., p\text{-}1\}$

Every sequence of $t_{i,j}(k)$ generates p+1 elements and p^2 different code sequences for every pair of parameters *c* and *b* by modifying parameters *i* and j.

Stage 2:

To construct a sequence of binary numbers (0, 1) as $x(l)$ based on original sequence $t_{i,j}(k)$, the following mapping method is used.

$$x_{i,j}(l) = \begin{cases} 1 & if \quad l = kp + t_{i,j}(k) \\ 0 & otherwise \end{cases} \qquad (2)$$

where *l*=0, 1, 2, 3......., $p^2 - 1$ and $k = \left\lfloor \frac{l}{p} \right\rfloor$ representing highest number less than or equal to the value of (*l*/*p*).

The following 2-D MQC code sequences are generated by using the parameters p=5, *c*=1 and *b*=2 as shown in Table 1.

Table 1. 2-D MQC sequence for p=5

i	j	$t_{i,j}(k)$	$x(l)$
0	0	0 1 4 4 1 2	1 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0
1	0	1 4 4 1 0 3	0 1 0 0 0 0 0 0 0 1 0 0 0 0 1 0 1 0 0 0 1 0 0 0 0 0 0 0 1 0
4	0	1 0 1 4 4 1	0 1 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 1 0 0 0 0 1 0 0 0
1	3	4 2 2 4 3 3	0 0 0 0 1 0 0 1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 1 0

3	4	304030	00010 10000 00001 10000 00010 10000

Each of the 2-D MQC code sequences contains $p^2 + p$ elements that are subdivided into *p*+1 groups, where each group contains one “1” and (*p*-1) “0”s.

B. 1-D PHC code construction

The 1-D prime hop code (PHC) code is constructed using the following stages [6].

Stage 1:

The construction of prime hop code (PHC) code starts with considering Galois field GF (*p*) of a prime number *p*. A modified prime sequence $y_{\alpha,\beta}(z)$ is designed by taking elements of Galois field with an odd prime number using the following expression

$$y_{\alpha,\beta}(Z) = \begin{cases} (\alpha+\beta Z)\Theta\, p, z=0,1,2,\ldots p-1 \\ \beta, z=p \end{cases} \tag{3}$$

where $\alpha \in \{0,1,2,\cdots\cdots,p-1\}$ and $\beta \in \{0,1,2,\cdots\cdots,p-1\}$.

By using the equation 3, a prime code family of p^2 sequences is generated for different values of parameters α and β . A prime code set of PC for p=5 is established by the Table 2.

Table 2. A prime code set for p=5 for 3-D coding

y(0)	0	0	0	0	0
y(1)	0	1	2	3	4
y(2)	0	2	4	1	3
y(3)	0	3	1	4	2
y(4)	0	4	3	2	1

Considering each number in the above code set in Table 2 consisting of *p* time slots, the value of the number plus ‘1’ is the location of the optical pulse. So the Table 2 can be modified to get the prime hop code (PHC) as shown in Table 3.

Table 3. A PHC set for *p*=5 for 3-D coding

y(0)	1	1	1	1	1
y(1)	1	2	3	4	5
y(2)	1	3	5	2	4
y(3)	1	4	2	5	3
y(4)	1	5	4	3	2

Stage 2:

To generate a prime hop code (PHC) from the prime code sequence, each sequence is mapped into a binary form (0, 1).The prime hop code sequence will be

$$y_{\gamma} = \left\{ d\gamma(0), d\gamma(1), d\gamma(2), \cdots\cdots, d\gamma(p^2 + p - 1) \right\} \tag{4}$$

where $$d_{\gamma}(s) = \{ \begin{matrix} 1, & where \quad s = zp + y_{\alpha,\beta}(z) \\ 0, otherwise \end{matrix} \tag{5}$$

Here $s = 0,1,2,\cdots\cdots, p^2 + p - 1$ and $\gamma = 0,1,\cdots\cdots, p^2 - 1$.

Here, each number represents the position of ‘1’ in a string of 5 bits where other four bits are ‘0’. Prime hop code has a correlation of one as represented in Table 4.

Table 4. A binary representation of prime hop code code set for p=5 for 3-D coding

D(0)	10000	10000	10000	10000	10000
D(1)	10000	01000	00100	00010	00001
D(3)	10000	00100	00001	01000	00010
D(4)	10000	00010	01000	00001	00100
D(5)	10000	00001	00010	00100	01000
D(1)	10000	01000	00100	00010	00001

C. MQC/PHC code construction

The 3-D MQC/PHC code matrix $m_{i,j,\gamma}$ is generated using the following expression.

$$m_{i,j,\gamma} = \begin{bmatrix} d_\gamma(0)x_{i,j}(l) \\ d_\gamma(1)x_{i,j}(l) \\ d_\gamma(2)x_{i,j}(l) \\ \vdots \\ d_\gamma(p^2+p-1)x_{i,j}(l) \end{bmatrix} \tag{6}$$

where l= 0, 1, 2, 3......., p^2-1 and $\gamma \in \{0, 1, 2.........., p^2-1\}$.

3. DESIGN OF TRANSMITTER AND RECEIVER FOR IMPLEMENTATION OF THE PROPOSED 3-D CODES

The developed 3-D OCDMA MQC/PHC codes are validated using an OCDMA trans-receiver circuit and simulated using opti-System v14.0 software. The block diagram for the implementation of the proposed 3-D codes for multiple users is shown in Figure 1. Here, we have a set of eight light sources composing a group, each of them differing by a unique wavelength. Eight continuous wave lasers (wavelengths 1-8) are multiplexed using wavelength division multiplexer and then split using 1:3 power splitters to produce three carriers.

The first carrier is modulated by RZ pulse. The second and third carriers are first optically phase shifted by 0 and 180 degrees and then modulated by 180 and 0 degrees by electrically phase shifted RZ data pulses respectively for implementing the third dimension of spatial encoding. After modulation, each signal is given to 1:5 wavelength division demultiplexers which distribute the modulated optical signals to 15 respective encoders (encoder 1-15). In an encoder, one optical Bessel filter and one time delay are used to produce encoded bit stream for generating wavelength hopping and time spreading 2-D codes. Each of the five encoded streams after demultiplexing, are then combined using 5:1 power combiner. Then all the encoded 3-D data are combined using 15:1 power combiner, amplified and sent over a single mode optical fiber.

The received optical bit stream is given to 1: 15 demultiplexer, followed by 15 numbers of decoders. In a decoder, one optical Bessel filter and one inverse time delay are used to decode the bit sequences. All the decoded signals are multiplexed using 15: 1 multiplexer and output is taken to optical time domain analyzer, optical power meter and photo detector. Optical power meter is used for optical power measurement. Photo detector detects the intensity of optical signal and transfers that information into electrical form followed by low pass Bessel filter (LPBF). The LPBF filters light in 1.5 micrometer wavelength where the fiber undergoes minimum loss. The 3-R Regenerator is used to re-amplify, re-shape and re-time the electrical signal.

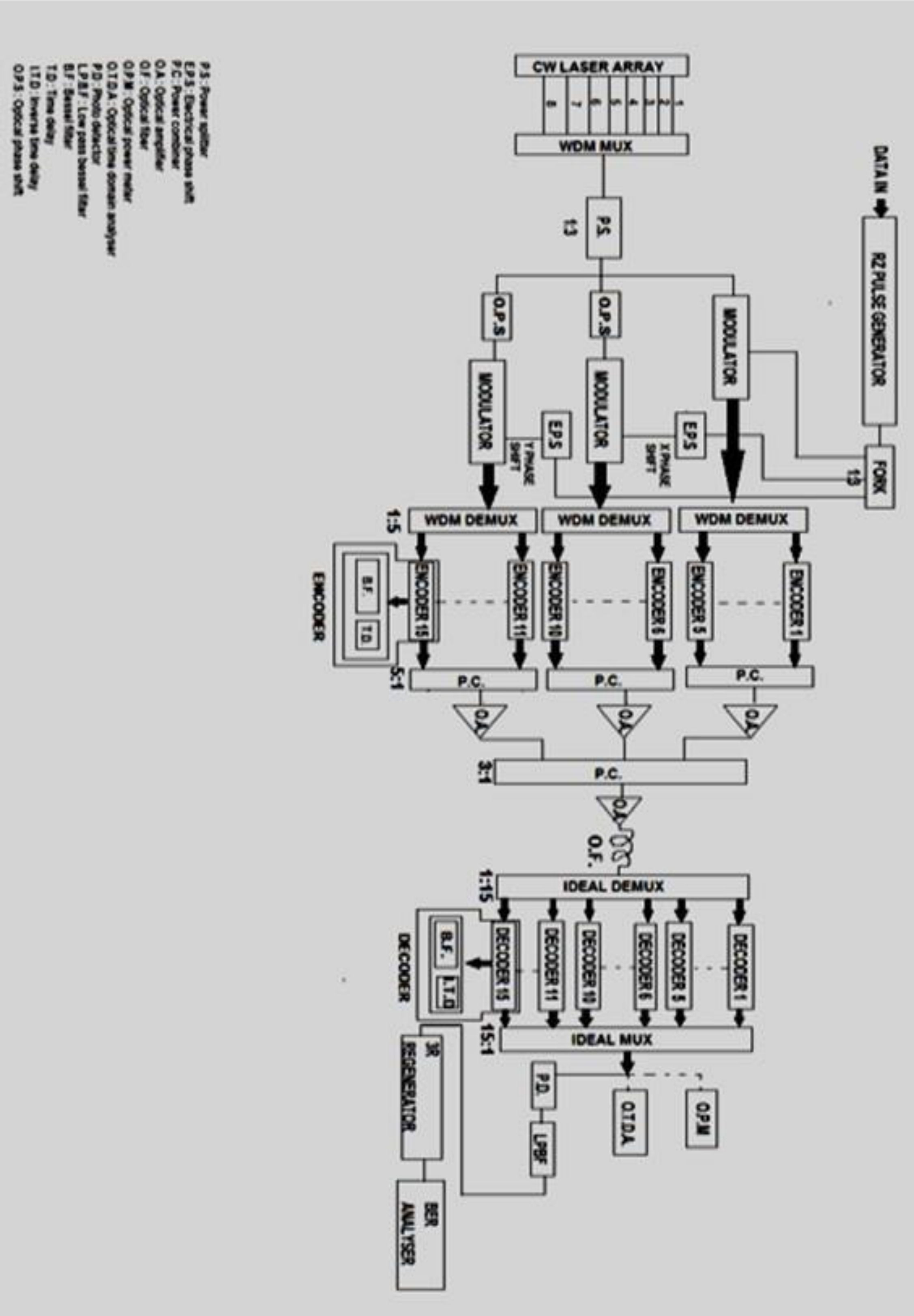


Fig. 1. Block diagram of transmitter and receiver used for the proposed 3-D MQC/PHC code

The simulation setup for OCDMA system 3-D MQC/PHC code is implemented using opti-system version 14. The continuous wave laser is used for generating light pulses. The wavelengths range from 193.1 nm to 193.8 nm, with 0.1 nm wavelength spacing. Eight continuous wave lasers (wavelength 1-8) are used to create a dense WDM multi-frequency light source i.e. carrier signal using wavelength division multiplexer. The generated carrier is used to modulate the pseudo-random bit sequence data of user. The data rate used in the system is 2.5 gbps and the input power is 10 dBm. The RZ pulse generator is used to convert logical data into electrical signal. A mach-zehnder modulator which is an external modulator uses on-off keying technique to modulate the multiplexed eight wavelengths according to RZ electrical data.

The modulated signals are distributed to the respective encoders using wavelength division demultiplexer, which assigns a unique 3-D code to each encoder. The encoded data from all the users are multiplexed by power combiner and then passed through 0.5-25 kilometer single mode optical fiber followed by a loss compensating optical amplifier with gain of 10 dB and noise figure of 4 dB. The output signal from fiber is then passed through Ideal demultiplexer to split the signal and is routed to user's decoder. The decoded signals are combined using ideal multiplexer and finally arrive at optical receiver. Eye diagram analyzer is used to take the plot of eye pattern at the receiver end. Bit error values for different number of users are taken from BER analyzer. The Table 5 depicts the system parameters that are used in simulation.

Table 5. System parameters used in the simulation of 3-D OCDMA coding

Sl. No.	**Parameters**	**Quantity**
1	Line encoding	RZ
2	Effective power at the source	0 to -10 dBm
3	Number of users	20 to 120
4	Operating Wavelength	1550 nm
5	Fiber length	10 to 50 km
6	Data rate	622 Mbps to 1 Gbps
7	Received power	0 to -35 dBm
8	Fiber attenuation	0.2 dB/km
9	Dispersion	16.75 ps/nm/km
10	PMD coefficient	0.5 ps/sqrt(km)

4. SYSTEM PERFORMANCE ANALYSIS OF 3-D OCDMA CODE

For the analysis of our system, Gaussian approximation is used for the calculation of BER. Since 3-D MQC/PHC code has zero to one cross-correlation property, there is no overlapping in the spectra of different users, which reduces the multiple access interference improving the overall system performance. In this work, for 3-D OCDMA codes, thermal noise (σ_t), phase induced intensity noise (σ_{PIIN}) and shot noise (σ_{sh}) in the photo detectors are considered. The performance of an optical receiver depends on the signal to noise ratio (SNR). The SNR of an electrical signal is defined as the ratio of average signal power to noise power (SNR=$\frac{I^2}{\sigma^2}$), where σ^2 is defined as the variance of different noise sources. I is the average photo current and I^2 is the aggregate signal power.
For MQC/MP code, the composite noise variance is [7]

$$\sigma^2 = \sigma_{shot}^2 + \sigma_t^2 + \sigma_{PIIN}^2 = 2eI_{shot}B + \frac{4K_B T_n B}{R_L} + I_{PIIN}^2 B t_c \tag{7}$$

where 'e' is the electronic charge, B is the noise equivalent of electrical bandwidth of the receiver, K_B is Boltzmann's constant, T_n is the absolute receiver temperature, R_L is the receiver load resistance, I_{shot} is the shot noise current and I_{PIIN} is the PIIN noise current.

The 3-D codes have M as number of wavelengths, N as temporal code length and S as spatial code length. The k-th user of 3-D code $C_{i,j,q}^k$ is a matrix of M row vectors and $b_{S,N}^k$ is related to Spatial/temporal spreading.

$$b_{S,N}^k = \begin{pmatrix} c^k{}_{11} & \cdots & c_{1N} \\ \vdots & \ddots & \vdots \\ c_{S1} & \cdots & c_{S,N} \end{pmatrix} \tag{8}$$

where $c_{\lambda,S,N}^k \in \{1,0\}$

Here emitted wavelengths are $\lambda \in \{1,2,\cdots\cdots,M\}$ [8]

$$c_{i,j,q}^k = \begin{bmatrix} b_{1,S,N}^k \\ b_{2,S,N}^k \\ \vdots \\ b_{M,S,N}^k \end{bmatrix} \tag{9}$$

Since shot noise, phase induced intensity noise (PIIN) and thermal noise obey negative binomial distribution, the following assumptions are used to analyze the system without much difficulty and for mathematical straightforwardness [8].

The assumptions are

- Each light source is ideally unpolarized and its spectrum is flat over the bandwidth $\left[v_0 - \Delta v/2, v_0 + \Delta v/2\right]$ where v_0 the central optical frequency is and Δv is the optical source bandwidth expressed in Hz.
- Each power spectral component has an identical spectral width.
- Each user has equal power at the transmitter.
- Each bit stream from each user is synchronized

Using the assumptions, the system performance is analyzed using Gaussian approximation. The Power Spectral density (PSD) of the received optical signal is described as

$$G(v) = \frac{P_r}{\Delta v k_s} \sum_{k=1}^{k} b_k \sum_{i=1}^{M} \sum_{j=1}^{N} \sum_{q=1}^{S} c_{i,j,q}(w) rect(v,i) \qquad (10)$$

P_r is the effective power of a broadband source at the receiver, $c_{i,j,q}(w)$ is the element of *w*-th user's codeword, *k* is the number of active users, *M* is the spectral code sequence code length, *N* is the temporal code sequence code length, k_s is the spatial code sequence code weight and b_k is the data bit of the *k*-th user.

The *rect(v,i)* function is given by

$$rect(v,i) = \left[v - v_0 - \frac{\Delta v}{2M}(-M+2i)\right] - u\left[v - v_0 - \frac{\Delta v}{2M}(-M+2i-2)\right] \qquad (11)$$

where *u(v)* represents unit step function

The aggregate power spectral density at the input of photo detector is given by

$$P = \int_0^\infty G(v)dv =$$

$$\int_0^\infty \left[\frac{P_r}{\Delta v k_s} \sum_{k=1}^{k} b_k \sum_{i=1}^{M} \sum_{j=1}^{N} \sum_{q=1}^{S} c^k_{i,j,q}(w) c^l_{i,j,q}(w) rect(v,i)\right] dv \qquad (12)$$

$$= \frac{P_r}{MN-1} \sum_{k=1}^{k} b_k$$

Here, b_k is the data bit of the *k*-th user that represents the value either "1" or "0".

$$\left[\sum_{k=1}^{k} b_k\right] = [b_1 + b_2 + b_3 + \cdots\cdots + b_k] = W \qquad (13)$$

The photo detector current *I* is represented as

$$I = \Re P = \frac{\Re P_r W}{MN - 1} \tag{14}$$

where $\Re$ is the Responsivity ($= {}^{\eta e}\!/\!{}_{hf}$) of photo diode.

The aggregate signal power is represented as

$$P_s = I^2 = \left[\frac{\Re P_r W}{MN - 1}\right]^2 \tag{15}$$

The Thermal noise power is expressed as

$$P_{ther} = I^2_{thermal} = \frac{4K_B T_n B}{R_L} \tag{16}$$

The aggregated shot noise power obtained at photo detectors in the receiver part is expressed as [9]

$$P_{shot} = I^2_{shot} = 2eBI = \frac{2eB\Re P_r W}{MN - 1} \tag{17}$$

The total PIIN noise power obtained at photo detectors in the receiver part is expressed as

$$P_{PIIN} = I^2_{PIIN} = BI^2\tau\sum c_k = B\left[\frac{\Re P_r W}{MN - 1}\right]^2 \tau \frac{kW}{MN - 1} = \frac{BkW^3\tau\Re^2 P_r^2}{(MN - 1)^2} \tag{18}$$

where $\sum c_k = \frac{kW}{MN - 1}$

Since, the probability of sending either “1” or “0” is 0.5, the P_{PIIN} is simplified as

$$P_{PIIN} = I^2_{PIIN} = \frac{BkW^3\tau\Re^2 P_r^2}{2(MN - 1)^2} \tag{19}$$

When a broadband pulse is source input to a group of fiber Bragg gratings, the incoherent light fields are mixed and applied to the photo detector, and the phase noise of the fields appear in the photo detector output. The coherence time of the thermal source is expressed as

$$\tau = \frac{\int_0^\infty G^2(v)dv}{\left[\int_0^\infty G(v)dv\right]^2} \tag{20}$$

where, *G(v)* is the single sideband power spectral density (PSD) of the source

Taking into consideration aggregate signal power and various noise powers, the signal to noise ratio (SNR) is expressed as

$$SNR = \frac{P_s}{P_{ther} + P_{shot} + P_{PIIN}}$$
$$= \frac{\left[\frac{\Re P_r W}{MN - 1}\right]^2}{\frac{4K_B T_n B}{R_L} + \frac{2eB\Re P_r W}{MN - 1} + \frac{BkW^3 \tau \Re^2 P_r^2}{2(MN - 1)^2}} \tag{21}$$

Now using the Gaussian approximation, the bit-error-rate (BER) is expressed as

$$BER = P_e = \frac{1}{2} erfc\left(\sqrt{\frac{SNR}{8}}\right) \tag{22}$$

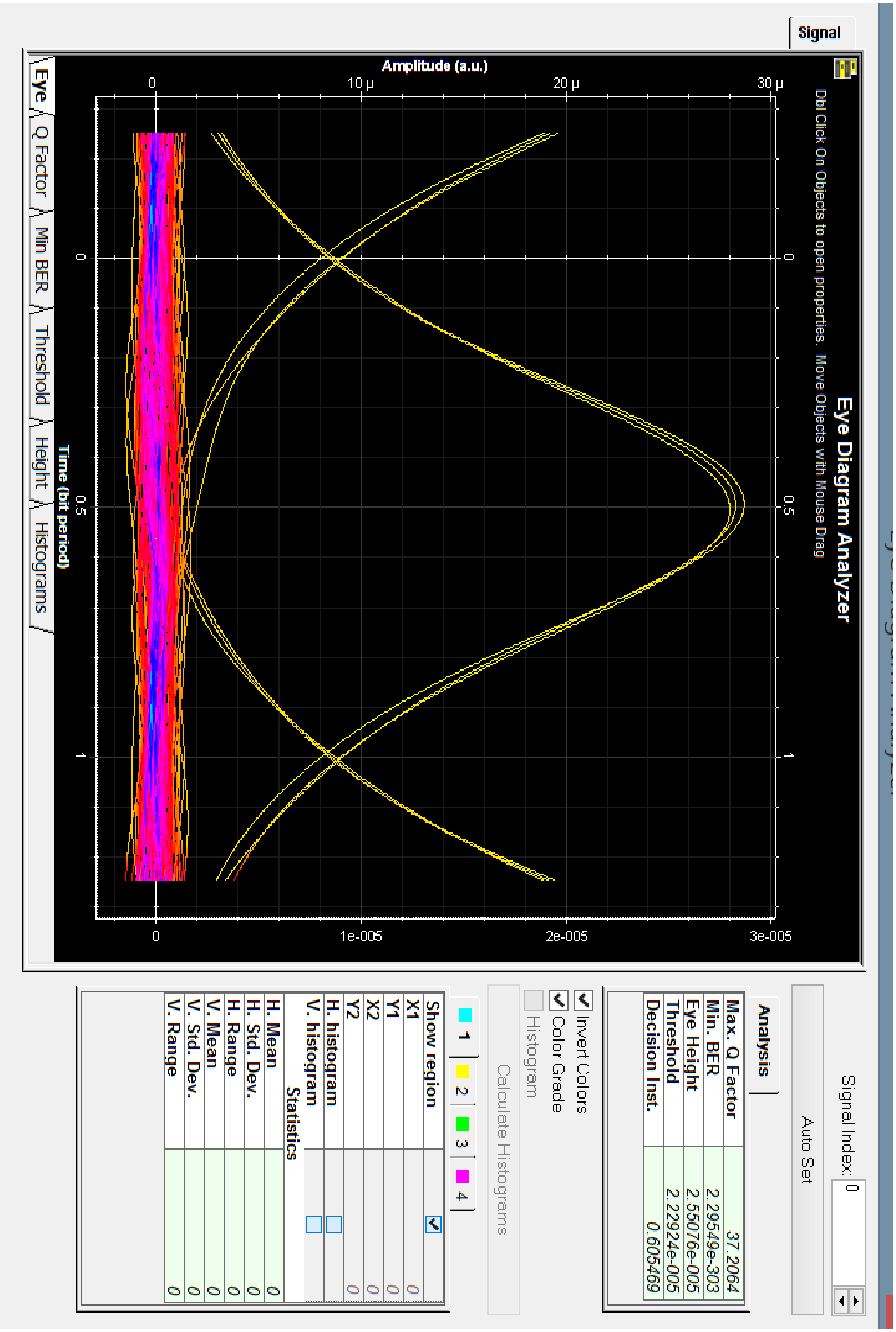
where, *SNR* represents the signal to noise ratio and "*erfc*" is the error complimentary function.

5. THE PERFORMANCE COMPARISON OF 3-D MQC/PHC CODE

The eye diagrams of the received signals for direct detection technique is shown in Figure 2. It is obseved that the system produces higher signal quality with direct detection technique with less bit error rate. The more the eye closes, difficulty arises in identifying one's and zeroes in the signal. The height of the eye opening at a certain time represents the noise immunity of the signal.

The BER variation against number of simultaneous users for different types of 3-D and 2-D codes is demonstrated in Figure 3. It is observed that BER performance is much better for 3-D MQC/PHC code in comparison to 2-D perfect difference code (PDC) [10] and 2-D modified quadratic congruence (MQC) code for a given number of simultaneous users.

The BER variation against effective transmitted power (dBm) for various types of 3-D codes and 2-D codes is shown in Figure 4. It is observed that the proposed 3-D MQC/PHC code requires lowest optical transmission power compared to other codes like 2-D MQC and 2-D PDC codes because of effective suppression of PIIN noise which improves the overall system performance.



Signal Index: 0

☑ Invert Colors
☑ Color Grade
☐ Histogram

Analysis	
Max. Q Factor	37.2064
Min. BER	2.29549e-303
Eye Height	2.55076e-005
Threshold	2.22924e-005
Decision Inst.	0.605469

Show region	☑
X1	0
Y1	0
X2	0
Y2	0
H. histogram	☐
V. histogram	☐
Statistics	
H. Mean	0
H. Std. Dev.	0
H. Range	0
V. Mean	0
V. Std. Dev.	0
V. Range	0

Fig. 2. Eye diagram at 2.5 Gbps for direct detection technique in receiver

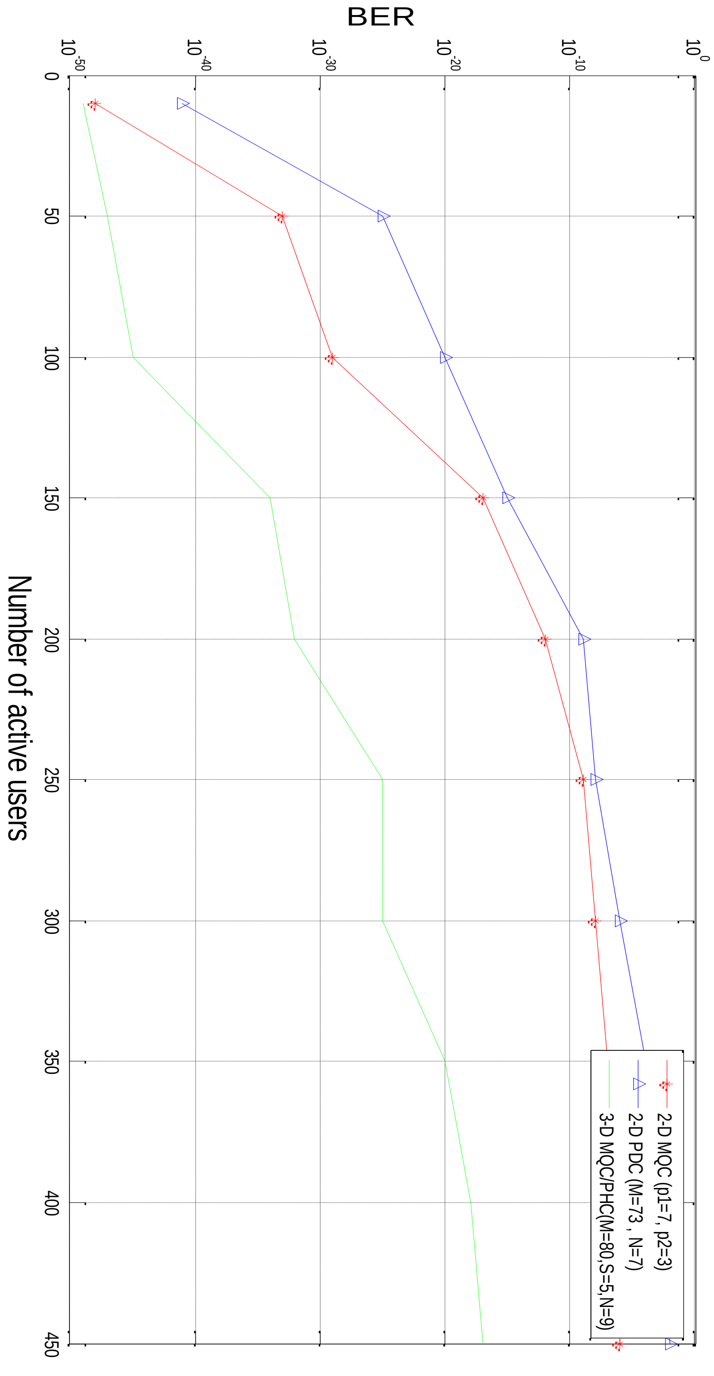


Fig. 3. BER vs. Number of active users comparison for 3-D MQC/PHC code at 2.5 gbps

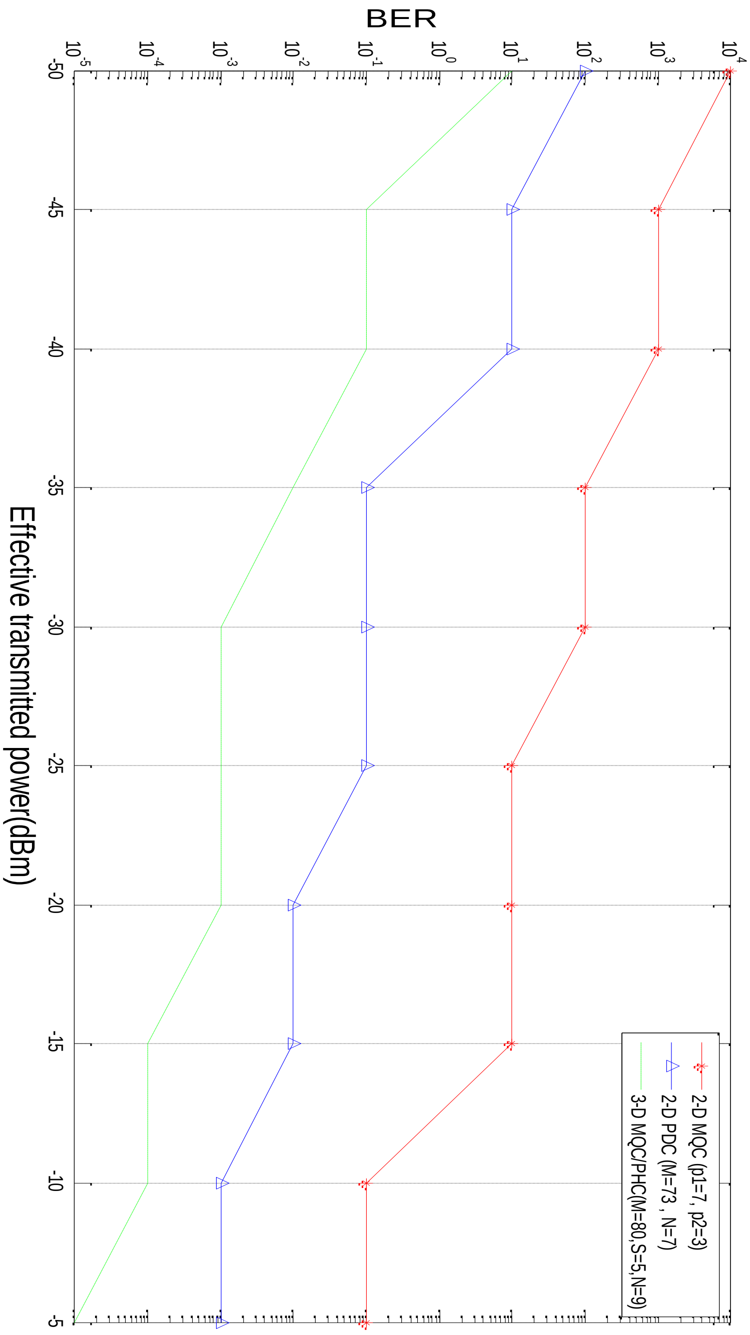


Fig. 4. BER vs. Effective transmitted power (dBm) for 3-D MQC/PHC code at 2.5 gbps

6. CONCLUSION

In this paper, we have proposed a new 3-D MQC/PHC optical CDMA code for enhancing system performance by suppressing various types of noises like thermal noise, shot noise and PIIN noise. The system architecture of the proposed 3-D code, achieves higher cardinality, better BER performance and lower effective transmitted power compared to other two dimensional OCDMA codes. The performance degradation due to PIIN noise can be minimized by lowering cross-correlation and BER [11]. We have also analyzed the OCDMA system performance for 3-D MQC/PHC code for direct detection technique. The analysis result obtained by the direct detection technique with 3-D MQC/PHC code found to be supporting more number of simultaneous users and it can improve the system performance by minimizing the MAI significantly.

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References

[1] Zouine Y, Dayoub I, Haxha S and Rouvaen J. M., Analysis of constraints on high speed optical code division multiplexing access (OCDMA) link parameters due to fiber optic chromatic dispersion, *Journal of Optical Communication*, 281 (2008) 1030-1036

[2] Santoro M A and Fan T R., Spread spectrum fiber optic local area network using optical processing, *Journal of. Light wave Technology*, 4 (1986) 547-554

[3] Satyasen Panda, Effect of SHIFTZCC codes for optical CDMA system, *World scientific news*, 67 (2017) 365-389

[4] Satyasen Panda, Two dimensional optical CDMA network with incoherent detection technique, *Imperial journal of interdisciplinary research*, 3 (2017) 818-827

[5] Zou Wei, H.M.H Shalaby, H Ghafouri-shiraz, Modified quadratic congruence code for fiber Bragg Grating based spectral amplitude coding optical cdma system, *Journal of light wave technology*, 19 (2001) 1274-1281

[6] Yang G.C and Kwong W.C., Prime code with applications to CDMA optical and wireless networks, *Boston: Artech House*, 2002.

[7] Hasson F. N., Aljunid S. A., Samad M. D. A and Abdullah M. K., Spectral amplitude coding OCDMA using AND subtraction technique, *Application of Optics*, 47 (2008) 1263-1268

[8] M.K. Abdullah, N.F. Hasoon, S.A. Aljunaid, S. Shaari., Performance of OCDMA systems with new spectral direct detection (SDD) technique using enhaced double weight (EDW) code, *J. Opt. Communication*, 281 (2008) 4658-4662

[9] N. Ahmed, S. A. Aljunaid, A. Fadil, R.B. Ahmad, M.A. Rashid., Performance enhancement of OCDMA system using NAND detection with modified double weight (MDW) code for optical access network, *Journal of Optik*, 124 (2013) 1402-1407

[10] J. H. Wen, J. S. Jhou, C. P. Li, optical spectral amplitude coding cdma systems using perfect difference code and interference estimation, *IEEE proceedings Optoelectronics*, 153 (2006) 152-160

[11] Aljunaid S.A, Ismail M, and Ramil A.R., A new family of optical code sequence for spectral-amplitude-coding optical CDMA systems, *IEEE Photonic Technology Letters*, 16 (2004) 2383-2385

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