# Simulated Transmission of Four Users with 5 WDM × 4 TDM × 4 CODE at 20 Gbps 3D OCDMA System Based on Model A Using GF (5)

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*Abstract*

The transmission of four active users has been illustrated with 5 WDM × 4 TDM × 4 CODE channel at 20 Gbps data rate 3 Dimensional Optical Code Division Multiple Access system based on newly designed Model A having signature sequences in temporal domain, spectral domain and spatial domain with optical orthogonal codes, cubic congruent operator from algebra theory respectively, using Galois field GF (5) with varying receiver attenuation on optsim simulation software. The results, numerically shown in terms of bit error rate and graphically represented in terms of eye diagram and signal strength, indicate that the novel 3D coding technique is designed to support four users with good BER with variable attenuation at the front end of the receiver.

***Keywords***

*OCDMA; OOC; Cubic Congruent Operator; Galois Field (5); 3 Dimensional, Model*

## Introduction

Challenges faced by OCDMA networks include Coding Algorithms and Schemes, Network Architecture, Advanced Encoding and Decoding hardware, Simulation and Applications [1]. Out of these most important that evaluates the performance of OCDMA system is coding scheme. Many code sequences are available in literature like 1D, 2D [5] and 3D. To increase the spectral efficiency, cardinality, hardware implications and mitigate the complex construction mechanism with good BER, there is a need to explore the 3rd dimension for spreading. In this paper, 3D codeset based on Mathematical Model A is chosen that spreads in temporal domain, hops in spectral domain and encodes in spatial domain with GF (5) using optical orthogonal codes and cubic congruent operator.

The paper is organized as follows. In Section II, Mathematical Modeling of 3D OCDMA system along with Model A is discussed. Section III implements 3D Codeset and calculates the system parameters required for simulation. Section IV shows the implementation details on the simulation software along with the results for four users with 5 WDM × 4 TDM × 4 CODE channel at 20 Gbps 3D OCDMA system based on Model A using GF (5) with varying attenuation at the front end of the receiver. Finally, conclusion is drawn in section V.

## Mathematical Model

In Model A Fig 1, OOC code is used to spread in time domain, coding scheme of cubic congruent operator based on Table 1 used for spreading in spectral domain and the same scheme is used for spreading in spatial domain. Cubic Algebraic Congruent operator is defined by following equation

$$sm(n,a,b) = \left(m\left(a+n\right)^3 + b\right)\left(\bmod p\right),$$

a= b=0 Equation 1[6]

Where $n$ and $m$ are the indexes and elements of the Galois field and their values are expressed in Table 1 along with their multiplicative inverses for GF (5) shown.

TABLE 1 MULTIPLICATIVE INVERSES FOR GF (5) AND SEQUENCES OVER GF (5) USING CUBIC ALGEBRAIC CONGRUENT OPERATOR.

| m,n | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 3 | 2 | 4 |
| 2 | 0 | 2 | 1 | 4 | 3 |
| 3 | 0 | 3 | 4 | 1 | 2 |
| 4 | 0 | 4 | 2 | 3 | 1 |

| × | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 2 | 3 | 4 |
| 2 | 0 | 2 | 4 | 1 | 3 |
| 3 | 0 | 3 | 1 | 4 | 2 |
| 4 | 0 | 4 | 3 | 2 | 1 |

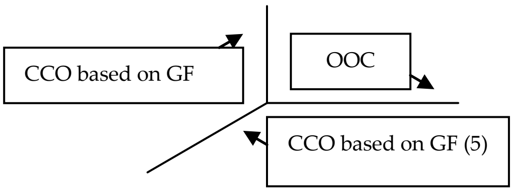


FIG. 1 MODEL A [3]

## D Codeset and Ocdma System Parameters

In accordance with Model A shown in Fig 1, the signature sequence is spreaded as follows. For temporal spreading: Optical orthogonal code is taken from literature C= 1011000100000 which is a (13,4,1) code with c={0,2,3,7} where n=13,w=4 and $\lambda a$ = $\lambda c$ =1. Here, n denotes length of the codeword, w, weight of the codes and $\lambda a$ &$\lambda c$ denotes auto correlation and cross correlation constant. For spectral hopping: codes from cubic congruent operator as calculated in Table 1, from algebra theory are taken based on GF (5) using Model A. For spatial encoding: codes from cubic congruent operator from algebra theory are taken based on GF (5) using Model A. These codes are shown in Table 2.

Simulation parameters: the data rate or bit rate is taken as 5 Gbps and time slot is the length of the temporal codes. In this simulation (13, 4, 1) OOC is taken for spreading in time domain. Thus the bit period is calculated as:

Bit Period=1/Bit Rate=1/5e9=.2e-9 and Chip period=Bit Period/Time Slot =.2e-9/13= .0153e-9.

Now the time delay lines for temporal code (1011000100000) are calculated as

Time Delay lines for Encoder
$t_0$=0×.0153e-9=0; $t_2$=2×.0153e-9=.0306e-9;
$t_3$=3×.0153e-9=.0459e-9; $t_7$=7×.0153e-9=.1071e-9

Inverse delay lines for Decoder
$t_{13}$=13×.0153e-9=.1989e-9;$t_{11}$=11×.0153e-9=.1683e-9;
$t_{10}$=10×.0153e-9=.1530e-9; $t_6$=6×.0153e-9=.0918e-9

## Simulation and Results

Table 3 shows the practical parameters that were taken while the proposed 3D codeset was simulated based on Model A using cubic congruent operator with GF (5). Proposed System [4] has 5 Operating wavelengths in C band i.e. $\lambda_1$= 1550.0e-9m, $\lambda_2$=1550.8e-9m, $\lambda_3$=1551.6e-9m, $\lambda_4$=1552.4e-9m and $\lambda_5$= 1553.2e-9m with repetition rate=5e9 and peak power=1.0e-3 w of MLL (Laser). And Delta=.8e-9 (i.e. spacing between the wavelength) is based on Dense Wavelength Division Multiplexing. Fig 2 shows the snapshots of 3D OCDMA in OPTSIM Simulation Software.

TABLE 2 SPATIAL AND SPECTRAL SEQUENCES BASED ON CUBIC CONGRUENT OPERATOR.

| BLOCK 0 | | | |
|---|---|---|---|
| SET 0 | SET1 | SET2 | SET3 |
| $\lambda_0 S_0 \lambda_0 S_0 \lambda_0 S_0 \lambda_0 S_0$ | $\lambda_0 S_0 \lambda_1 S_1 \lambda_3 S_3 \lambda_2 S_2$ | $\lambda_0 S_0 \lambda_2 S_2 \lambda_1 S_1 \lambda_4 S_4$ | $\lambda_0 S_0 \lambda_3 S_3 \lambda_4 S_4 \lambda_1 S_1$ |
| $\lambda_0 S_1 \lambda_0 S_1 \lambda_0 S_1 \lambda_0 S_1$ | $\lambda_0 S_1 \lambda_1 S_2 \lambda_3 S_4 \lambda_2 S_3$ | $\lambda_0 S_1 \lambda_2 S_3 \lambda_1 S_2 \lambda_4 S_0$ | $\lambda_0 S_1 \lambda_3 S_4 \lambda_4 S_0 \lambda_1 S_2$ |
| $\lambda_0 S_2 \lambda_0 S_2 \lambda_0 S_2 \lambda_0 S_2$ | $\lambda_0 S_2 \lambda_1 S_3 \lambda_3 S_0 \lambda_2 S_4$ | $\lambda_0 S_2 \lambda_2 S_4 \lambda_1 S_3 \lambda_4 S_1$ | $\lambda_0 S_2 \lambda_3 S_0 \lambda_4 S_1 \lambda_1 S_3$ |
| $\lambda_0 S_3 \lambda_0 S_3 \lambda_0 S_3 \lambda_0 S_3$ | $\lambda_0 S_3 \lambda_1 S_4 \lambda_3 S_1 \lambda_2 S_0$ | $\lambda_0 S_3 \lambda_2 S_0 \lambda_1 S_4 \lambda_4 S_2$ | $\lambda_0 S_3 \lambda_3 S_1 \lambda_4 S_2 \lambda_1 S_4$ |
| $\lambda_0 S_4 \lambda_0 S_4 \lambda_0 S_4 \lambda_0 S_4$ | $\lambda_0 S_4 \lambda_1 S_0 \lambda_3 S_2 \lambda_2 S_1$ | $\lambda_0 S_4 \lambda_2 S_1 \lambda_1 S_0 \lambda_4 S_3$ | $\lambda_0 S_4 \lambda_3 S_2 \lambda_4 S_3 \lambda_1 S_0$ |
| BLOCK 1 | | | |
| SET 0 | SET1 | SET2 | SET3 |
| $\lambda_1 S_0 \lambda_1 S_0 \lambda_1 S_0 \lambda_1 S_0$ | $\lambda_1 S_0 \lambda_2 S_1 \lambda_4 S_3 \lambda_3 S_2$ | $\lambda_1 S_0 \lambda_3 S_2 \lambda_2 S_1 \lambda_0 S_4$ | $\lambda_1 S_0 \lambda_4 S_3 \lambda_0 S_4 \lambda_2 S_1$ |
| $\lambda_1 S_1 \lambda_1 S_1 \lambda_1 S_1 \lambda_1 S_0$ | $\lambda_1 S_1 \lambda_2 S_2 \lambda_4 S_4 \lambda_3 S_3$ | $\lambda_1 S_1 \lambda_3 S_3 \lambda_2 S_2 \lambda_0 S_0$ | $\lambda_1 S_1 \lambda_4 S_4 \lambda_0 S_0 \lambda_2 S_2$ |
| $\lambda_1 S_2 \lambda_1 S_2 \lambda_1 S_2 \lambda_1 S_0$ | $\lambda_1 S_2 \lambda_2 S_3 \lambda_4 S_0 \lambda_3 S_4$ | $\lambda_1 S_2 \lambda_3 S_4 \lambda_2 S_3 \lambda_0 S_1$ | $\lambda_1 S_2 \lambda_4 S_0 \lambda_0 S_1 \lambda_2 S_3$ |
| $\lambda_1 S_3 \lambda_1 S_3 \lambda_1 S_3 \lambda_1 S_0$ | $\lambda_1 S_3 \lambda_2 S_4 \lambda_4 S_1 \lambda_3 S_0$ | $\lambda_1 S_3 \lambda_3 S_0 \lambda_2 S_4 \lambda_0 S_2$ | $\lambda_1 S_3 \lambda_4 S_1 \lambda_0 S_2 \lambda_2 S_4$ |
| $\lambda_1 S_4 \lambda_1 S_4 \lambda_1 S_4 \lambda_1 S_0$ | $\lambda_1 S_4 \lambda_2 S_0 \lambda_4 S_2 \lambda_3 S_1$ | $\lambda_1 S_4 \lambda_3 S_1 \lambda_2 S_0 \lambda_0 S_3$ | $\lambda_1 S_4 \lambda_4 S_2 \lambda_0 S_3 \lambda_2 S_0$ |
| BLOCK 2 | | | |
| SET 0 | SET1 | SET2 | SET3 |
| $\lambda_2 S_0 \lambda_2 S_0 \lambda_2 S_0 \lambda_2 S_0$ | $\lambda_2 S_0 \lambda_3 S_1 \lambda_0 S_3 \lambda_4 S_2$ | $\lambda_2 S_0 \lambda_4 S_2 \lambda_3 S_1 \lambda_1 S_4$ | $\lambda_2 S_0 \lambda_0 S_3 \lambda_1 S_4 \lambda_3 S_1$ |
| $\lambda_2 S_1 \lambda_2 S_1 \lambda_2 S_1 \lambda_2 S_1$ | $\lambda_2 S_1 \lambda_3 S_2 \lambda_0 S_4 \lambda_4 S_3$ | $\lambda_2 S_1 \lambda_4 S_3 \lambda_3 S_2 \lambda_1 S_0$ | $\lambda_2 S_1 \lambda_0 S_4 \lambda_1 S_0 \lambda_3 S_2$ |
| $\lambda_2 S_2 \lambda_2 S_2 \lambda_2 S_2 \lambda_2 S_2$ | $\lambda_2 S_2 \lambda_3 S_3 \lambda_0 S_0 \lambda_4 S_4$ | $\lambda_2 S_2 \lambda_4 S_4 \lambda_3 S_3 \lambda_1 S_1$ | $\lambda_2 S_2 \lambda_0 S_0 \lambda_1 S_1 \lambda_3 S_3$ |
| $\lambda_2 S_3 \lambda_2 S_3 \lambda_2 S_3 \lambda_2 S_3$ | $\lambda_2 S_3 \lambda_3 S_4 \lambda_0 S_1 \lambda_4 S_0$ | $\lambda_2 S_3 \lambda_4 S_0 \lambda_3 S_4 \lambda_1 S_2$ | $\lambda_2 S_3 \lambda_0 S_1 \lambda_1 S_2 \lambda_3 S_4$ |
| $\lambda_2 S_4 \lambda_2 S_4 \lambda_2 S_4 \lambda_2 S_4$ | $\lambda_2 S_4 \lambda_3 S_0 \lambda_0 S_2 \lambda_4 S_1$ | $\lambda_2 S_4 \lambda_4 S_1 \lambda_3 S_0 \lambda_1 S_3$ | $\lambda_2 S_4 \lambda_0 S_2 \lambda_1 S_3 \lambda_3 S_0$ |
| BLOCK 3 | | | |
| SET 0 | SET1 | SET2 | SET3 |
| $\lambda_3 S_0 \lambda_3 S_0 \lambda_3 S_0 \lambda_3 S_0$ | $\lambda_3 S_0 \lambda_4 S_1 \lambda_1 S_3 \lambda_0 S_2$ | $\lambda_3 S_0 \lambda_0 S_2 \lambda_4 S_1 \lambda_2 S_4$ | $\lambda_3 S_0 \lambda_1 S_3 \lambda_2 S_4 \lambda_4 S_1$ |
| $\lambda_3 S_1 \lambda_3 S_1 \lambda_3 S_1 \lambda_3 S_1$ | $\lambda_3 S_1 \lambda_4 S_2 \lambda_1 S_4 \lambda_0 S_1$ | $\lambda_3 S_1 \lambda_0 S_3 \lambda_4 S_2 \lambda_2 S_0$ | $\lambda_3 S_1 \lambda_1 S_4 \lambda_2 S_0 \lambda_4 S_2$ |
| $\lambda_3 S_2 \lambda_3 S_2 \lambda_3 S_2 \lambda_3 S_2$ | $\lambda_3 S_2 \lambda_4 S_3 \lambda_1 S_0 \lambda_0 S_2$ | $\lambda_3 S_2 \lambda_0 S_4 \lambda_4 S_3 \lambda_2 S_1$ | $\lambda_3 S_2 \lambda_1 S_0 \lambda_2 S_1 \lambda_4 S_3$ |
| $\lambda_3 S_3 \lambda_3 S_3 \lambda_3 S_3 \lambda_3 S_3$ | $\lambda_3 S_3 \lambda_4 S_4 \lambda_1 S_1 \lambda_0 S_3$ | $\lambda_3 S_3 \lambda_0 S_0 \lambda_4 S_4 \lambda_2 S_2$ | $\lambda_3 S_3 \lambda_1 S_1 \lambda_2 S_2 \lambda_4 S_4$ |
| $\lambda_3 S_4 \lambda_3 S_4 \lambda_3 S_4 \lambda_3 S_4$ | $\lambda_3 S_4 \lambda_4 S_0 \lambda_1 S_2 \lambda_0 S_4$ | $\lambda_3 S_4 \lambda_0 S_1 \lambda_4 S_0 \lambda_2 S_3$ | $\lambda_3 S_4 \lambda_1 S_2 \lambda_2 S_3 \lambda_4 S_0$ |
| BLOCK 4 | | | |
| SET 0 | SET1 | SET2 | SET3 |
| $\lambda_4 S_0 \lambda_4 S_0 \lambda_4 S_0 \lambda_4 S_0$ | $\lambda_4 S_0 \lambda_0 S_1 \lambda_2 S_3 \lambda_1 S_2$ | $\lambda_4 S_0 \lambda_1 S_2 \lambda_0 S_1 \lambda_3 S_4$ | $\lambda_4 S_0 \lambda_2 S_3 \lambda_3 S_4 \lambda_0 S_1$ |
| $\lambda_4 S_1 \lambda_4 S_1 \lambda_4 S_1 \lambda_4 S_1$ | $\lambda_4 S_1 \lambda_0 S_2 \lambda_2 S_4 \lambda_1 S_3$ | $\lambda_4 S_1 \lambda_1 S_3 \lambda_0 S_2 \lambda_3 S_0$ | $\lambda_4 S_1 \lambda_2 S_4 \lambda_3 S_0 \lambda_0 S_2$ |
| $\lambda_4 S_2 \lambda_4 S_2 \lambda_4 S_2 \lambda_4 S_2$ | $\lambda_4 S_2 \lambda_0 S_3 \lambda_2 S_0 \lambda_1 S_4$ | $\lambda_4 S_2 \lambda_1 S_4 \lambda_0 S_3 \lambda_3 S_1$ | $\lambda_4 S_2 \lambda_2 S_0 \lambda_3 S_1 \lambda_0 S_3$ |
| $\lambda_4 S_3 \lambda_4 S_3 \lambda_4 S_3 \lambda_4 S_3$ | $\lambda_4 S_3 \lambda_0 S_4 \lambda_2 S_1 \lambda_1 S_0$ | $\lambda_4 S_3 \lambda_1 S_0 \lambda_0 S_4 \lambda_3 S_2$ | $\lambda_4 S_3 \lambda_2 S_1 \lambda_3 S_2 \lambda_0 S_4$ |
| $\lambda_4 S_4 \lambda_4 S_4 \lambda_4 S_4 \lambda_4 S_4$ | $\lambda_4 S_4 \lambda_0 S_0 \lambda_2 S_2 \lambda_1 S_1$ | $\lambda_4 S_4 \lambda_1 S_1 \lambda_0 S_0 \lambda_3 S_3$ | $\lambda_4 S_4 \lambda_2 S_2 \lambda_3 S_3 \lambda_0 S_0$ |

TABLE 3 SIMULATED PARAMETERS

| S.No. | Parameter | value |
|---|---|---|
| 1) | Bit rate | 5e9 |
| 2) | Bit period | .2e-9 |
| 3) | Chip period | 2e-9 e-9/13 = .0153 e-9 |
| 4) | Time slot | 13 |
| 5) | Laser wavelength | $\lambda_1$= 1550.0e-9m<br>$\lambda_2$= 1550.8e-9m<br>$\lambda_3$= 1551.6e-9m<br>$\lambda_4$= 1552.4e-9m<br>$\lambda_5$= 1553.2e-9m |
| 6) | Rep rate of source | 5e9 |
| 7) | Peak power of laser | 1.0e-3w |
| 8) | Delta[2] | .8e-9(DWDM) |
| 9) | No. of lasers | 5 |
| 10) | Combiner/ Mux | 5×1 |
| 11) | Combiner loss | 3dB |
| 12) | Pattern type | PRBS |
| 13) | Pattern length | 7 bits |
| 14) | Fiber Attenuator | Variable in dB |

This schematic evaluates the 3D OCDMA link with encoding/ decoding based on Model A with 4 users each transmitting at 5 Gbps data rate coding according to Galois field GF (5) with cubic congruent operator and optical orthogonal codes.

### Cardinality

Cardinality is defined as the number of users supported by the OCDMA system. As shown in the Table 2, 100 users are defined based on the cubic congruent operator for Model A.

$$C = p^2 \times w \qquad \text{Equation 2}$$

Here in Equation 2 c is the cardinality, p is the prime number as given by Galois field GF (p) for cubic algebraic congruent operator and w is the weight of the temporal domain codes. In this simulation work, p is 5 and w is 4 so the cardinality in this case is 100 as given in Table2. Fig 3 shows the cardinality c v/s p with varying weight.

### BER v/s Varying Attenuation.

Fig 4 shows BER v/s Variable Attenuation at the front end of the receiver. Codes based on Model A are analyzed and it is shown that 4 users each with 5Gbps data rate are successfully transmitted with varying attenuation. The values are shown in Table 4. The codes employed for 4 users are shown in red color in Table 2.

TABLE 4 BER WITH VARYING ATTENUATION IN DB FOR 4 USERS

| Attenuation in dB. | -.2 | -.25 | -.5 | -.1 | -1 | -2 | -2.5 | -5 | -10 |
|---|---|---|---|---|---|---|---|---|---|
| BER | 8.0727e-042 | 9.6644e-042 | 1.9746e-040 | 5.6726e-042 | 1.6217e-040 | 3.4995e-036 | 5.1862e-034 | 1.8837e-021 | 2.8620e-005 |

### Graphs for Signal Spectrum, Eye Diagram and Autocorrelation Function

Fig 3 shows the diagram for Signal Spectrum, Eye Diagram and Autocorrelation Function at the input and Fig 4 shows the diagrams for the Signal Spectrum, Eye Diagram and Autocorrelation Function for attenuation with -.2db and -10db respectively. And it is clear from the eye diagram that the performance of the proposed codes is good between attenuation of -5 to -10 db.

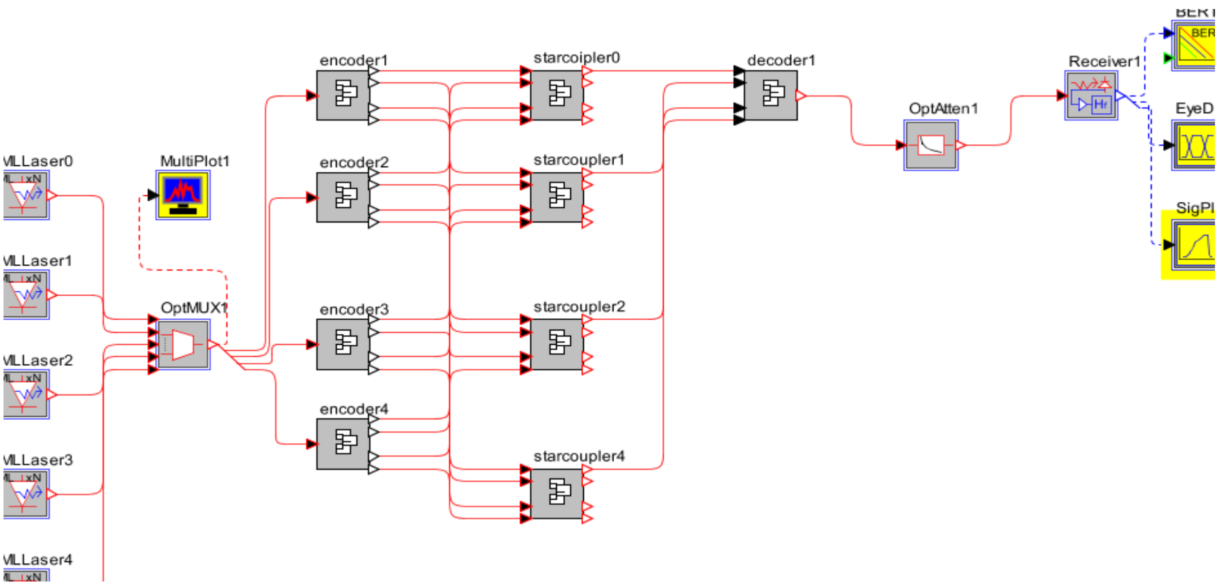


FIG. 2 TECHNOLOGY DEMONSTRATOR OF 3D OCDMA SYSTEM

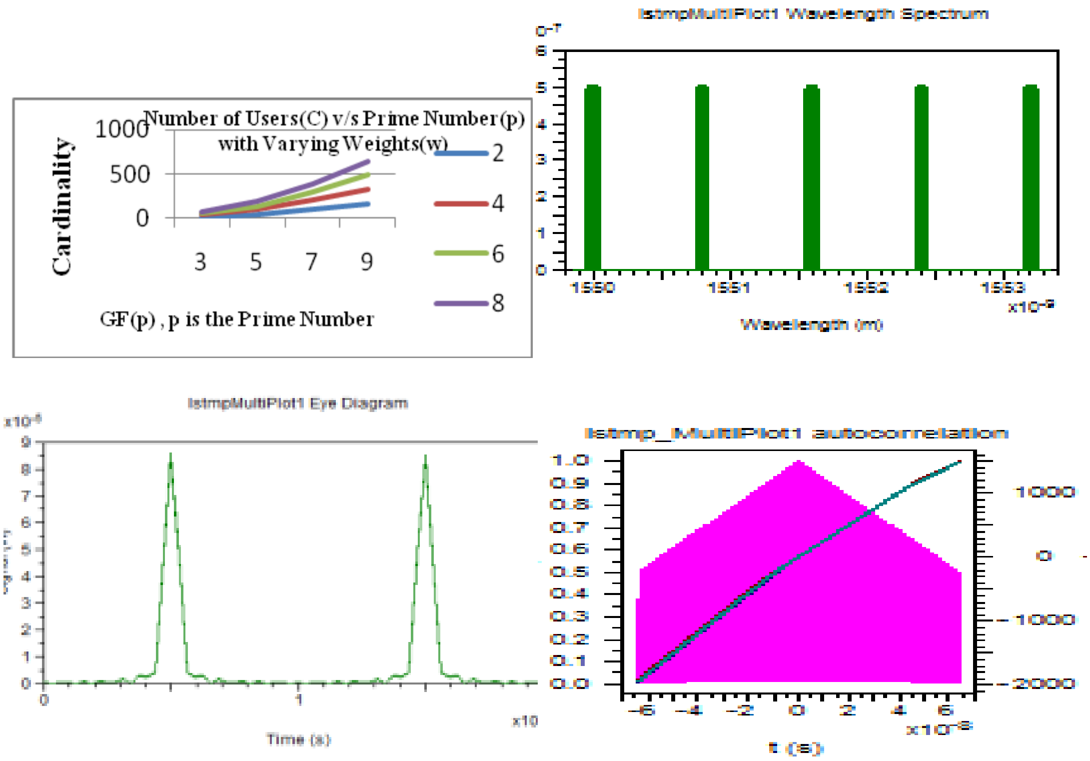


FIG. 3 NUMBER OF USERS(C) V/S PRIME NUMBER (P) WITH VARYING WEIGHTS (W) AND SIGNAL SPECTRUM, EYE DIAGRAM AND AUTOCORRELATION FUNCTION AT INPUT

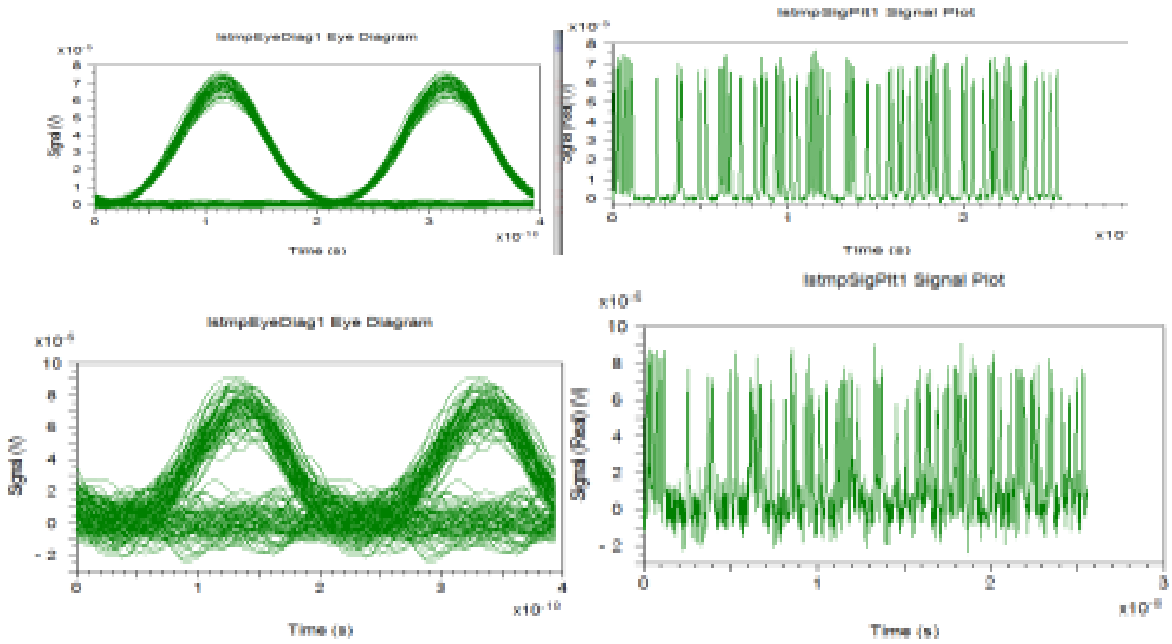


FIG. 4 SIGNAL SPECTRUM, EYE DIAGRAM WITH-2DB AND -10DB ATTENUATION.

## Conclusion

The demonstration of an incoherent OCDMA system has been analyzed and presented. The performance analysis shows significant scalability improvement and system performance for 20 Gbps using 5-wavelength x 4-time-slot x 4-code WDM-TDM-CODE of 3D OCDMA system. En/Decoder is designed based on Model A for -5 dB attenuation with BER= 1.8837e-021. The simulation results show OCDMA transmission system, validating the feasibility of the extended reach.

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