Design and Performance Analysis of a newly designed 32-User Spectral Phase Encoding system operating at 2.5Gb/s for Fiber-Optic CDMA Networks

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***Abstract* - Multiple access techniques are required to meet the demand for high-speed and large-capacity communications in optical networks, which allow multiple users to share the fiber bandwidth. Optical code-division multiple-access (O-CDMA) is receiving increased attention due to its potential applications for broadband access networks. We analyze a new technique for encoding and decoding of coherent ultra short light pulses. In particular, we discuss the temporal pseudo noise bursts generated by spectral phase coding of ultra short optical pulses.**

This paper describes a performance analysis of Spectral Phase Encoding optical code-division multiple-access scheme based on wavelength/time (W/T) codes and random phase codes. We have studied the optical simulator Encoding/Decoding at different fiber lengths & gain in terms of Quality factor (Q) and Bit Error Rate (BER) performance. We derive the bit error rate (BER) and QoS as a function of data rate, number of users, receiver threshold. We find that performance improves dramatically with optical power normalizer.Ultrashort light pulse CDMA could provide tens to hundreds of users with asynchronously multiplexed, random access to a common optical channel. The system supports 32 users while maintaining bit-error rate (BER) < 10^{-9} and required QoS for the correctly decoded signal at 2.5 Gbits/s bit rate.

Keywords : BER, ISD, MAI, NRZ, OCDMA, OOC, PSO, QoS, RZ.

I. Introduction

Due to economic advantages, maturing technology, and high information capacity, single-mode fiber- optic transmission media will be embedded in future telecommunications networks. A desirable feature for these future optical networks would be the ability to process information directly in the optical domain for purposes of multiplexing, demultiplexing, filtering, amplification, and correlation. Optical signal processing would be advantageous because potentially it can be much faster than electrical signal photon-electron-photon conversions. Several new classes of optical networks are now emerging [1]. For example, code-division multiple access (CDMA) networks using optical signal processing techniques were recently introduced [2]-[9].

CDMA is a type of spread spectrum communications [10] in which multiplexing is achieved by assigning different, minimally interfering code sequences to different user pairs. In fiber optic CDMA, users communicate by imprinting their message bits upon their own unique code, which they transmit asynchronously (with respect to the other transmitters) over a common channel. A matched filter at the receiver end ensures that data are detected only when they are imprinted on the proper code sequence (see Fig. 1). This approach to multiplexing allows transmission without delay and handles multi-access interference (contention) as an integral part of the multiplexing scheme.

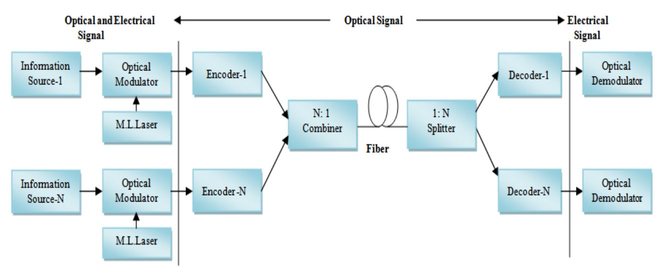

Fig. 1. Block diagram of Optical CDMA Network

In coherent OCDMA, encoding and decoding are performed either in time domain or in spectral domain based on the phase and amplitude of optical field . In coherent time spreading (TS) OCDMA, where the encoding/decoding is performed in time domain. In such a system, the encoding is to spread a short optical pulse in time with a phase shift pattern representing specific codes. The decoding is to perform the convolution to the incoming OOC using a decoder, which has an inverse phase shift pattern as the encoder and generates high level auto-correlation and low level cross correlations.

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II. NUMERICAL SIMULATION

The encoders use delay line arrays providing delays in terms of integer multiples of chip times. The placement of delay line arrays and the amount of each delay and phase shifts are dictated by the specific of the signatures. PSO matrix codes are constructed using a spanning ruler or optimum Golomb ruler is a (0,1) pulse sequence where the distances between any of the pulses is a non repeating integer,hence the distances between nearest neighbors, next nearest

g (1,7)=

1	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1

M1

	C1	C2	C3	C4	C5	C6	C7	C8
r1	1	1	0	0	0	0	0	0
r2	1	0	0	0	0	0	1	0
r3	0	0	1	0	1	0	0	0
r4	0	0	0	0	0	1	0	0

M2

	C1	C2	C3	C4	C5	C6	C7	C8
r1	0	0	0	0	0	0	1	0
r2	1	1	0	0	0	0	0	0
r3	1	0	0	0	0	0	1	0
r4	0	0	1	0	1	0	0	0

M3

	C1	C2	C3	C4	C5	C6	C7	C8
r1	0	0	0	1	0	1	0	0
r2	0	0	0	0	0	0	1	0
r3	1	1	0	0	0	0	0	0
r4	1	0	0	0	0	0	1	0

M4

	C1	C2	C3	C4	C5	C6	C7	C8
r1	0	1	0	0	0	0	0	1
r2	0	0	0	1	0	1	0	0
r3	0	0	0	0	0	0	1	0
r4	1	1	0	0	0	0	0	0

Mi from g(1,7)

	Column 1 (C1)				Column 2 (C2)				Column 3 (C3)				Column 4 (C4)				Column 5 (C5)				Column 6 (C6)				Column 7 (C7)				Column 8 (C8)			
	r1	r2	r3	r4	r1	r2	r3	r4	r1	r2	r3	r4	r1	r2	r3	r4	r1	r2	r3	r4	r1	r2	r3	r4	r1	r2	r3	r4	r1	r2	r3	r4
M1=	1	1	0	0	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	0
M2=	0	1	1	0	0	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
M3=	0	0	1	1	0	0	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
M4=	0	0	0	1	1	0	0	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

Fig. 2. Constructing the four pseudo orthogonal (PSO) matricesM1. . .M4 from the single optimum Golomb ruler g(1,7).

neighbors, etc., can be depicted as a difference triangle with unique integer entries. The ruler-to-matrix transformation increases the cardinality (code set size) from one (1) to four(4) and the ISD (=Cardinality/CD)from 1/26 to 4/32=1/8. The ISD translates to bit/s/Hz when the codes are associated with a data rate and the code dimension is translated into the bandwidth expansion associated with the codes as follows:

$$\mathrm{ISD} = \frac{(\text{throughput})}{(\text{bandwidth required})}$$

$$= \frac{(\text{cardinality} \times \text{data rate})}{\left(\frac{1}{\mathrm{Tb}}\right)(\text{bandwidth expansion})}$$

$$= \frac{(n \times r \times R)}{(R)(CD)}$$

$$= \frac{n \times r}{(CD)}$$

The enhanced cardinality and ISD, while preserving the OOC property, are general results of the ruler-to-matrix transformation. We can convert the PSO matrices to wavelength/time (W/T) codes by associating the rows of the PSO matrices with wavelength (or frequency) and the columns with time-slots, as shown in Table I. The matricesM1….M32 are numbered 1…32 in the table, with the corresponding assignment of wavelengths and time-slots. For example, code M1 is (λ1 ; λ1 ; λ3; λ1) and M9 is (λ1,λ4;0;λ7,λ8;0); here the semicolons separate the timeslots in the code. (The codes M1 and M9 are shown in bold numerals.)We focus on codes like M1 because it shows extensive wavelength reuse, and on codes likeM9 because it shows extensive time-slot reuse. It is the extensive wavelength and time-slot reuse that gives these matrix codes their high cardinality and high potential ISD.

Four mode-locked lasers are used to create a dense WDM multi-frequency light source. Pseudo-orthogonal (PSO) matrix codes [3] are popular for OCDMA applications primarily because they retain the correlation advantages of PSO linear sequences while reducing the need for bandwidth expansion. PSO matrix codes also generate a larger code set. An interesting variation is described in [1] where some of the wavelength/time (W/T) matrix codes can permit extensive wavelength reuse and some can allow extensive time-slot reuse. In this example, extensive time-slot reuse sequence is used. There are four time slots used without any guard-band giving the chip, period of 100 ps. Code1,code 5,code3 and code9 codes are used for time spreading. Code set to apply binary phase shift mapped as M1:{1;0;1;0;1;1;1;1} M2:{1;0;1;1;1;1;1;1}…………………. M32:{0;0;1;1;1;1;1;0} (1 represents as a π phase shift, 0 represents as no phase shift)

TABLE I
THE 32 PSO MATRIX CODES INTERPRETED AS W/T MATRIX CODES

Wavelengths (W)	Time slots (S)			
	1	2	3	4
λ1	1,9, 17,25	1,14, 29	19,24, 26	1,7,10, 11,20,32
λ2	2,10, 18,26	2,15, 17,30	20,25, 27	2,8,11, 12,21
λ3	3,11, 19,27	3,16, 18,31	1,21, 26,28	3,12, 13,22
λ4	4,9,12, 20,28	4,19, 32	2,22, 27,29	4,13, 14,23
λ5	5,10,13, 21,25,29	5,20	3,23, 28,30	5,14, 15,24
λ6	6,11,14, 22,26,30	6,21	4,17,24, 29,31	6,15, 16
λ7	7,12,15, 23,27,31	7,17, 22	5,9,18, 30,32	7,16
λ8	8,13,16, 24,28,32	8,18, 23,25	6,9,10, 19,31	8

TABLE II
SPE O-CDMA SYSTEM PARAMETERS USED FOR SIMULATION

Parameter	Value
Code length	8
Channel spacing	0.4 nm
Wavelength	4 at 1550,1550.4,1550.8,1551.2 nm
Chip time	4
Chip rate	1.25E-10
Bit rate	2.5 Gbits /s
Modulation Format	NRZ and RZ
Fiber length	60 to 180 km
Measurements	Eye diagram, Bit error rate and Quality factor

III. PROPOSED SCHEME SPE O-CDMA

1) Lasers (mode locked laser)2) Encoders 3) Multiplexers 4) Optical fiber of 60 to 180 km length 5) De multiplexers 6) Decoders 7) Receiver 8)BER analyzer 9) Eye Diagram analyzer 10) Signal analyzer The simulation setup for Spectral Phase Encoding Optical CDMA is shown in figure 3. The MLL is used to generate four wavelengths, range from1550 nm to 1551.2 nm, with 0.4nm wavelength spacing, this carrier signal is used to modulate the pseudo random bit sequence (PRBS) data of the user. An intensity modulator which is External Modulator uses on-off keying modulation to modulate the multiplexed 4 wavelengths according to the NRZ and RZ electrical data. For analysis, Eye Diagram analyzer, Beat Error tester and Signal analyzer is used.

IV. SIMULATION OF SPE O-CDMA SYSTEM ONE USER

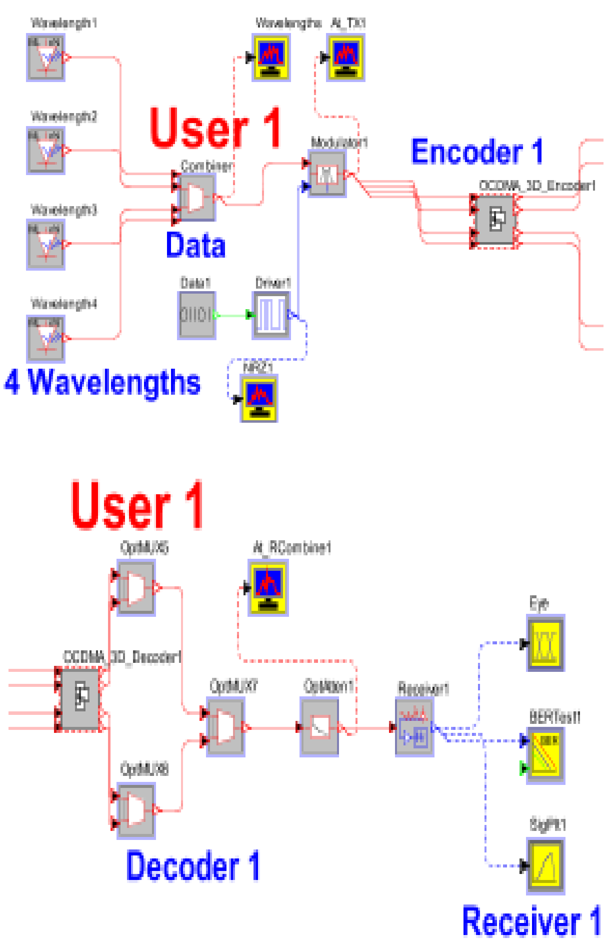

Fig. 3. Simulation setup for SPE O-CDMA Transmitter and Receiver of User1

Figure 4 shows dense wavelength spectrum for four wavelengths respective encoders, which have been assigned a unique W/T code respective to each encoder.

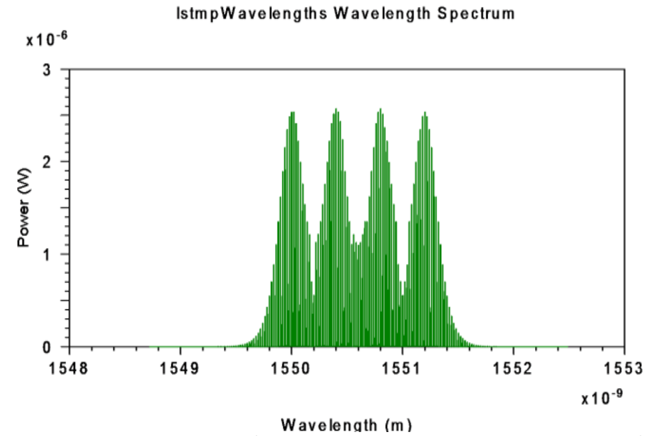

Fig. 4. Wavelength Spectrum for Spectral Phase Encoding Optical CDMA for 32 Users

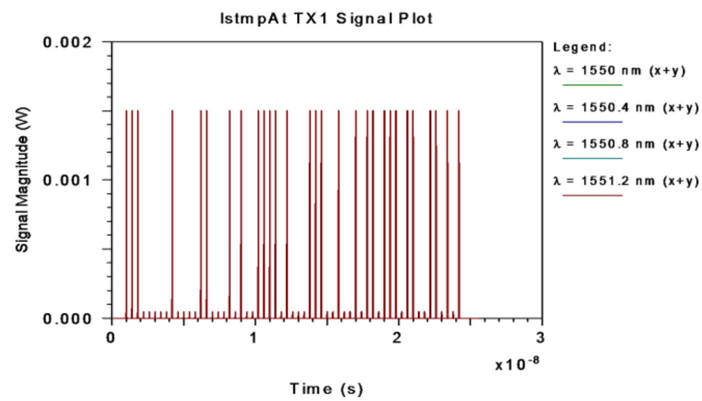

Fig. 5. Modulated data before encoder of User 1

Figure 5 shows modulated data before encoding.

The encoded data from all users are multiplexed by Optical MUX and then passed through a 60 km and 180 km span of standard single mode optical fiber followed by a loss compensating optical amplifier which is Opt Amp. The output signal from a fiber span is then passed through OptSplit1 to split the signal and routed to the user's decoder. The decoder uses optical filters and inverse delay line arrays providing delays in terms of integer multiples of chip times and phase shift pattern. The decoded signal finally arrives at optical receiver (Receiver), BER Test and Eye Diagram. Eye diagram analyzer has been used to take the plot of Eye pattern at the receiver end. Bit error rate values for different number of transmitting users have been taken from BER Tester.

The system has been redesigned for different number of users. In spite of the use of orthogonal codes, the main effect limiting the effective signal-to-noise ratio of the overall system is the interference resulting from the other users transmitting at the same time, which is called Multiple Access Interference (MAI). MAI is the major source of noise in OCDMA systems. System performance is tested at 2.5 Gbits/s bit rate, NRZ and RZ data modulation format, BER and quality factor at different data modulation format noted. Eye diagram observed at different fiber length.

V. Performance Analysis

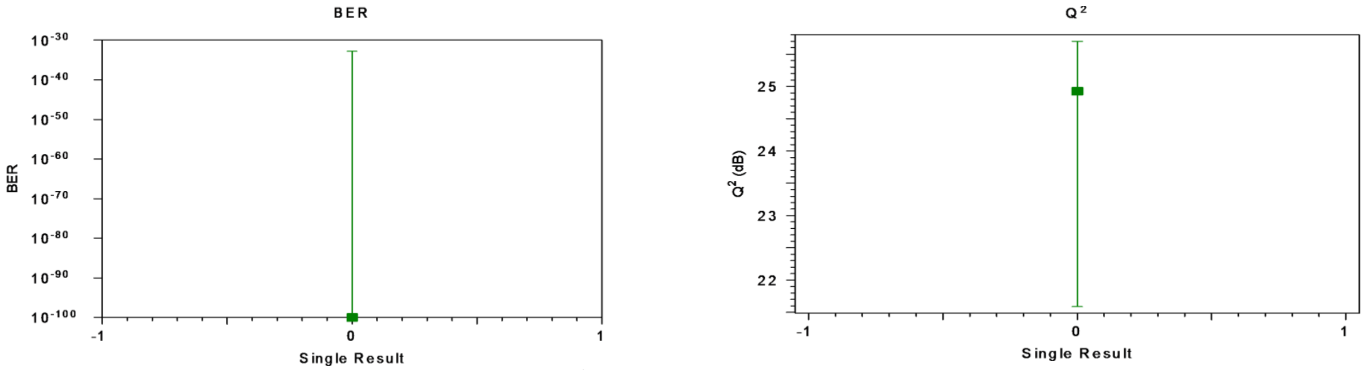

Fig. 6. BER and Quality factor at User1 using Optical Power Normalizer

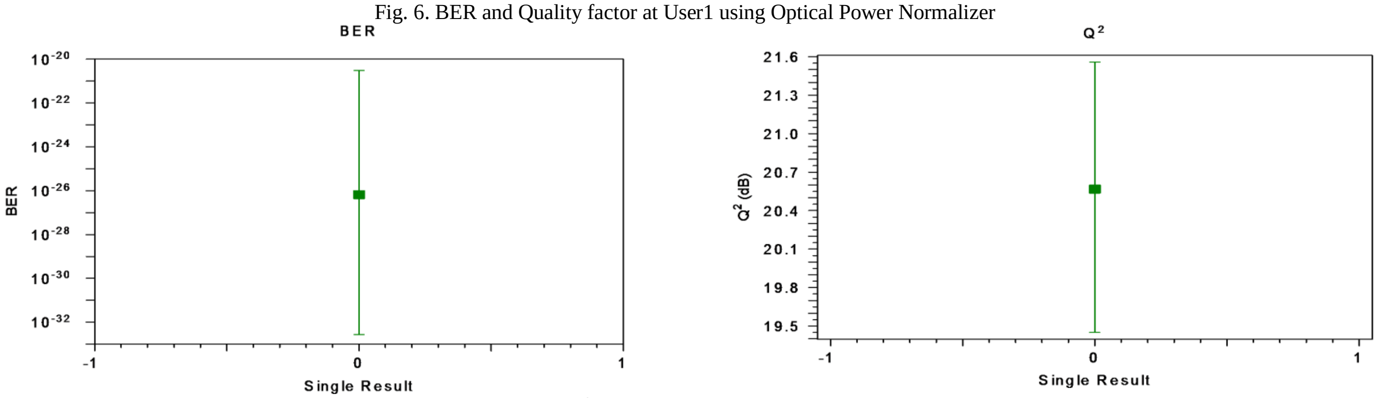

Fig. 7. BER and Quality factor at User16 using Optical Power Normalizer

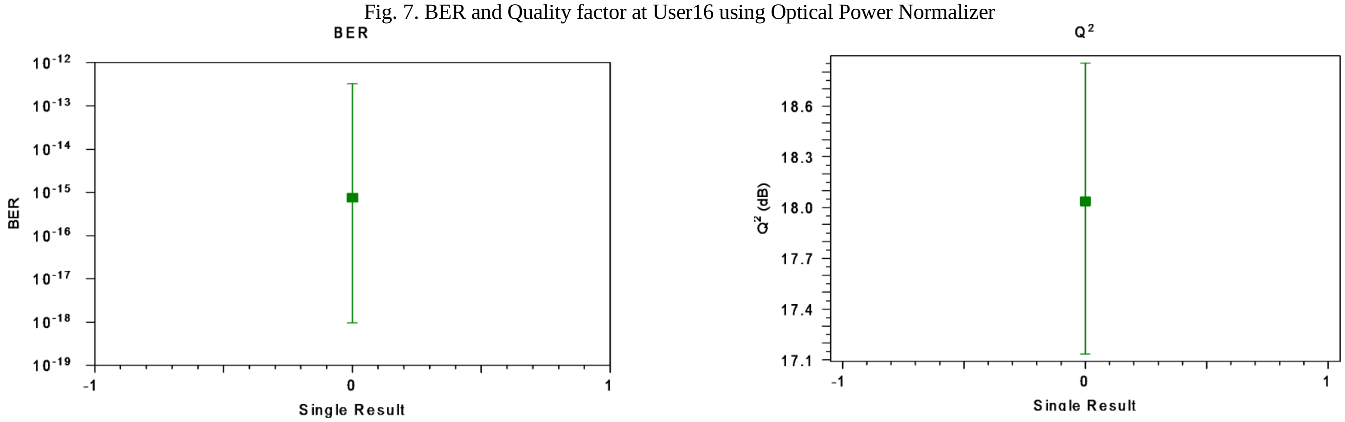

Fig. 8. BER and Quality factor at User32 using Optical Power Normalizer

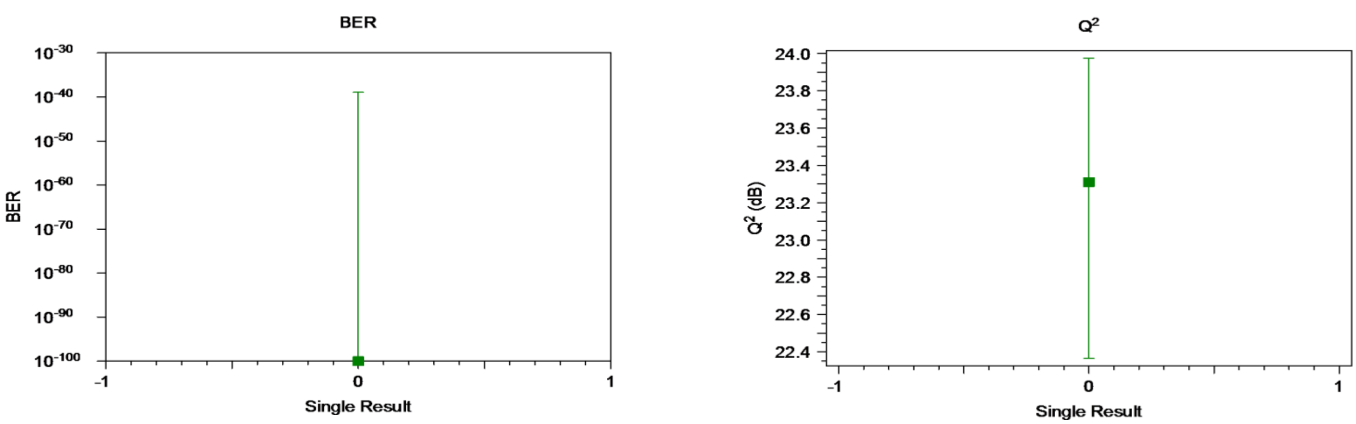

Fig. 9. BER and Quality factor at User1 using Optical Attenuator

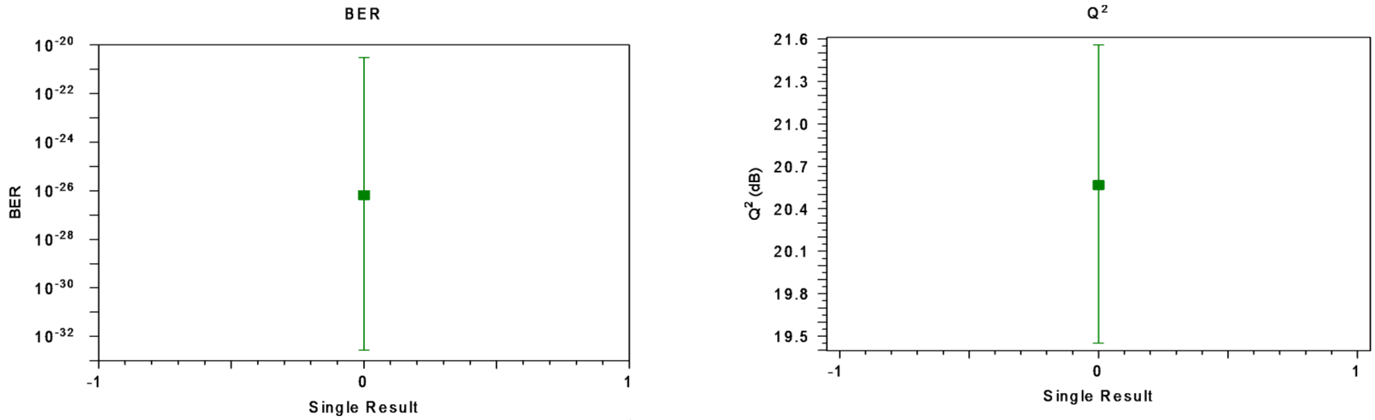

Fig. 10. BER and Quality factor at User16 using Optical Attenuator

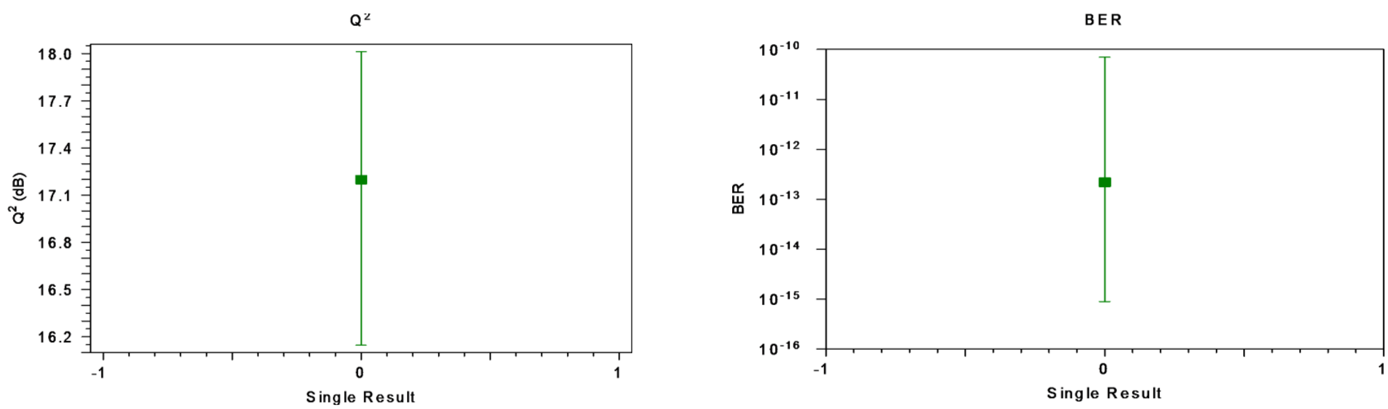

Fig. 11. BER and Quality factor at User32 using Optical Attenuator

Figure 6,7, 8, 9,10 and 11 shows BER and Quality factor of SPE O-OCDMA system using optical attenuator and optical power normalizer at User1,User8,User16 and User32 respectively. As active number of users increases system performance degrades. System performance is analyzed at 2.5 Gb/s bit rate, -20 dB received power and 60km to 180 km fiber span. System performance is extremely good by using optical power normalizer. Spectral phase encoding O-CDMA system using optical attenuator and optical power normalizer system supports 32 users at 2.5Gb/s and offer s low Bit Error Rate and good quality of service.

Figure 12 and 13 shows System performance degrades as fiber length increases .The SPE O-CDMA system offers High Quality factor and extremely less BER at -20 dBm received power and over 60km to 180 km fiber length.

Eye opening is good using optical power normalizer as compare to optical attenuator. Eye diagram analysis is carried out at 60 km fiber span and at 180 km fiber span.SPE OCDMA system using optical power normalizer performance is good as compare to optical attenuator over 60km and180 km fiber span.

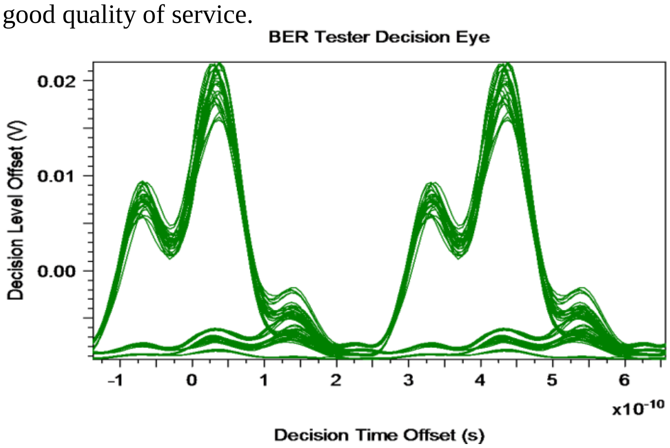

Fig. 12. Eye Diagram analysis at User32 using Optical Power Normalizer over 60 km fiber span

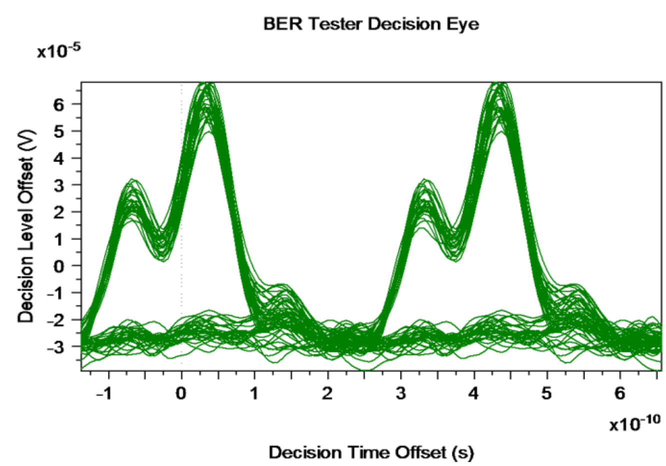

Fig.13. Eye Diagram analysis at User32 using Optical Power Normaliszr over180 km fiber span

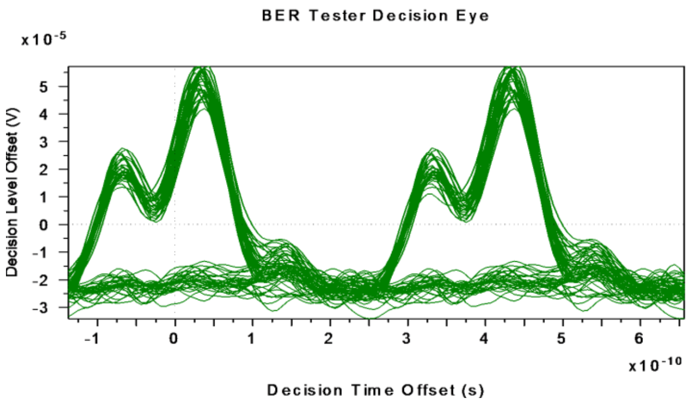

Fig. 14. Eye Diagram analysis at User32 using Optical Attenuator over 60 km fiber span

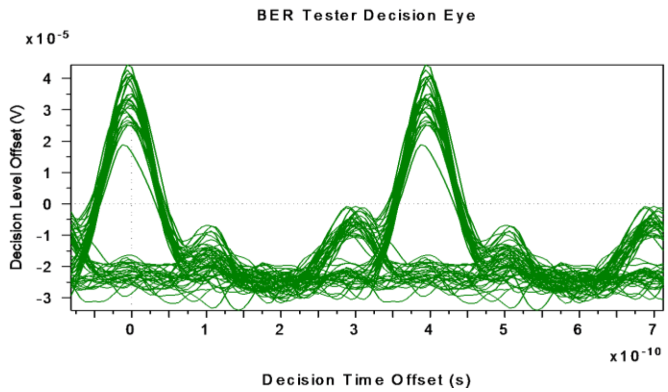

Fig. 15. Eye Diagram analysis at User32 using Optical Attenuator over 180 km fiber span

Figure 12,13,14 and 15 shows System performance degrades as fiber length increases .The SPE O-CDMA system offers high Quality factor and extremely less BER at -20 dBm received power and over 60 km to 180 km fiber length using optical power normalizer.

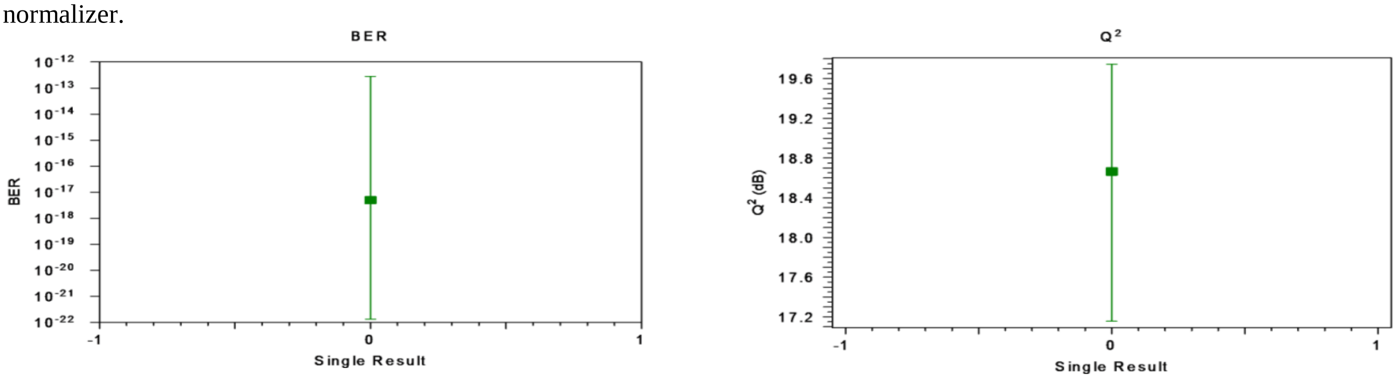

Fig. 16. BER and Quality factor at User1 using Optical Attenuator for RZ data modulation format

Figure 16, 17 and 18 shows SPE O-CDMA system performance of RZ data modulation format, Results indicates enhancement in BER and quality factor for NRZ data modulation format as compared to RZ data modulation.

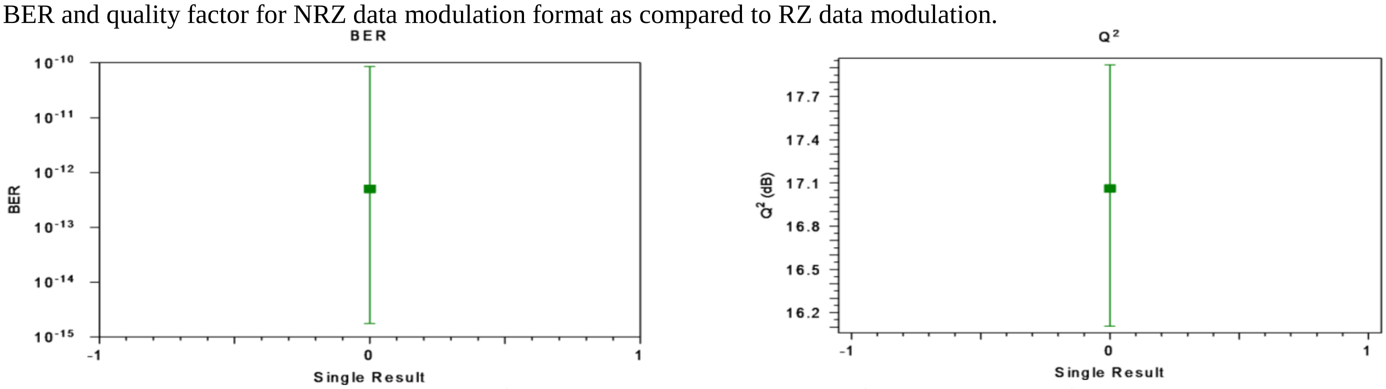

Fig. 17. BER and Quality factor at User16 using Optical Attenuator for RZ data modulation format

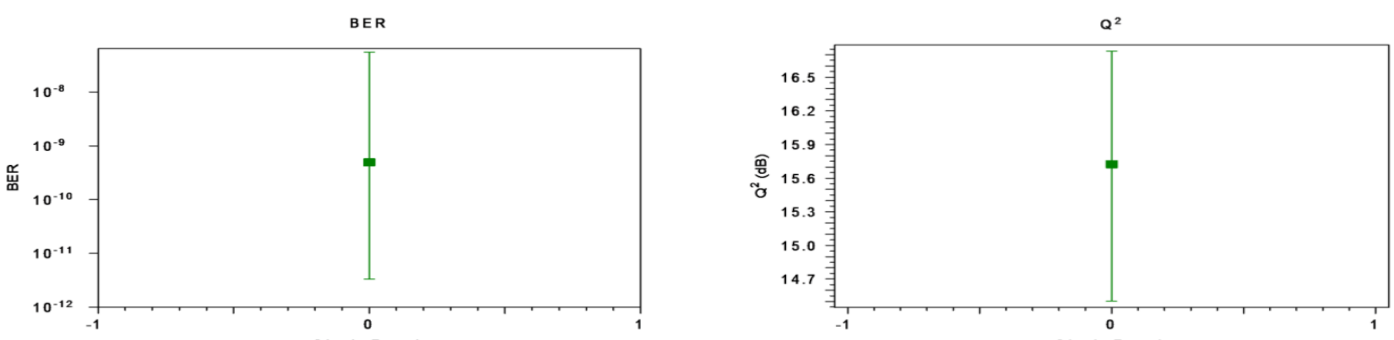

Fig. 18. BER and Quality factor at User 32 using Optical Attenuator for RZ data modulation format

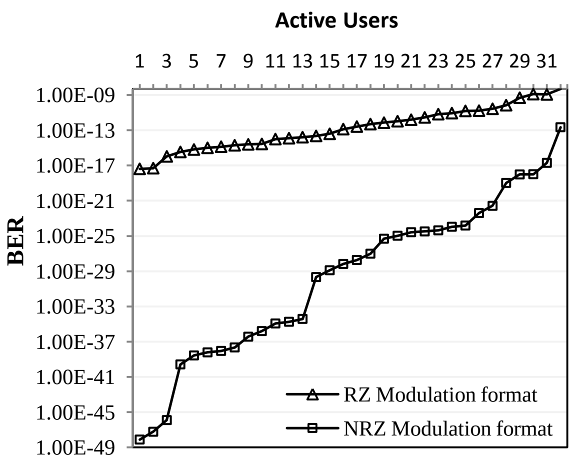

Fig. 19. System performance for RZ and NRZ data modulation format for 32Users

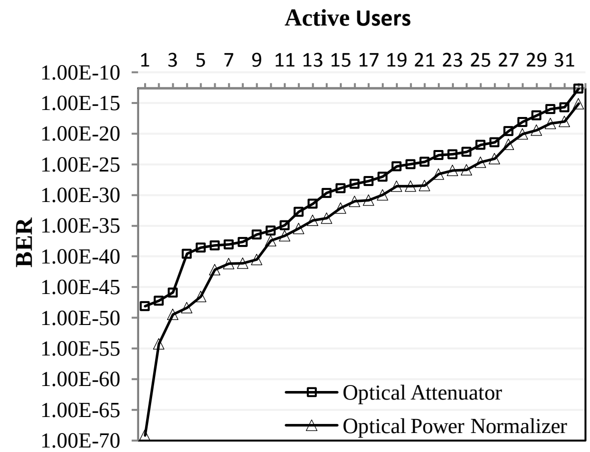

Fig. 20. System performance using Optical Power Normalizer and Optical Attenuator in terms of Quality factor for 32 Users

Figure 19 and 20 represents graphical representation of Beat Error rate and Quality factor of SPE O-CDMA system .System performance is analyzed for NRZ and RZ data modulation format and using optical attenuator and optical power normalizer for 32 numbers of active users. Results indicates enhancement in BER and quality factor for NRZ data modulation format as compared to RZ data modulation format, low BER and high Quality of service using optical power normalizer.Beat Error Rate of SPE OCDMA system using Optical Power Normalizer at User1 and User32 is 1.00E-70 and 1.00E-16 respectively, while SPE OCDMA system using Optical Attenuator at User1 and User32 is 1.00E-49 and 1.00E-13 respectively, for NRZ and RZ data modulation format BER for NRZ is at User1 and User32 is 1.00E-49 and 1.00E-13 respectively, for RZ format at User1 and User32 is 1.00E-17 and 1.00E-09 respectively.

V. CONCLUSION

The multiple access interference effect was also seen at the optical receiver end in optical CDMA which degraded the efficiency of system by increasing bit error rate. Use of spectral phase encoding O-CDMA system reduced the MAI as seen in the bit error rate performance and quality factor. The spectral phase encoding O-CDMA system performance is good for 32 users at 2.5Gbits/s bit rate using optical power normalizer. The performance of SPE O-CDMA system is analyzed by using NRZ and RZ data modulation format, while NRZ data modulation format offers extremely good performance than RZ data modulation format. The SPE O-CDMA system has been successfully demonstrated at system capacity of 80 Gbits/s over 180 km of fiber length. This newly designed SPE O-CDMA offers high Quality factor and less Beat Error Rate $<10^{-9}$ .Moreover these results are more realistic as practical impairments have been considered with -15 dB and -20 dBm received power for optical attenuator, optical power normalize respectively and for permissible BER of 10^{-9}.

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