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OCDMA System Using Two Code Keying Encryption Introducing a SOA Based CMUX And CDEMUX Over a WDM System

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***Abstract*—This paper introduces an Optical Code Division multiplexing (OCDMA) system using two code keying encryptions. In this paper proposed OCDMA system is designed using Semiconductor optical amplifiers (SOAs) which has nonlinear character and can implementor different logic functions. SOA based 2 × 1 Codeword Multiplexer (CMUX) is designed to multiplex the user data and a 1 × 2 Codeword DE Multiplexer (CDEMUX) to demodulate the user data. Then a multiple user access is provided using WDM system to design the whole OCDMA system. Transmission distance of 70 km is achieved with acceptable bit error rate and Q factor. Open eye diagram is also verified at the receiving end.**

Keywords*—*Two code keying, encryption, Optical Code Division Multiple Access , Codeword Multiplexer,Code Word De-Multiplexer.

I. INTRODUCTION

OCDMA Technology is one of the promising advances to execute optical system, which can possibly misuse the un-mined data transmission of optical fiber and exploit the prevalence of CDMA innovation which will perform important part in the future optical networks [1], [2]. For large capacity and high-speed communication in multiple access technique provided by OCDMA system has become very promising in Optical networks [3], [4]. Presently communication demand is extremely high because of research and production of various new communication methods. All-optical communication, offering security amid transmission, and being proficient in transfer speed use are the cases of the properties that are produced because innovative work of OCDMA network [5]. OCDMA has turned out to be vital piece of the computerized communication framework for long haul, fast LAN and MAI networks [6]. For OCDMA systems, the performance matrices like bit error rate and quality factor depends upon the number of users accessing the bandwidth at a time and number of users also depends upon the types of codes used. As a result, many code, algorithms, methods and techniques have been proposed [7], [8]. In this research a two-code keying encryption technique is used to design the proposed OCDMA technique. In this paper OCDMA system is designed using Semiconductor Optical Amplifiers (SOAs). SOA is very attractive nonlinear elements for the realization of different logic functions, since they can exhibit a strong change of the refractive index together with high gain. Due to tremendous growth in the volume of information exchange and strong demands in security and privacy, the issues and degree of physical-layer confidentiality potentially supported by OCDMA have become an interesting research topic [9], [10]. From the concept of multi code keying encryption the two-code keying encryption is used in this research to enhance the confidentiality and security of the user.

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This paper introduces the concept of physical-layer confidentiality enhancement in OCDMA systems and network by means of two code-keying with the one-time-pad encryption. The software implementation of the proposed two code-keying encryption techniques, which relies on all-optical exclusive-or (XOR) gate and codeword multiplexer (CMUX) are also investigated. The new all optical design is scalable and integrable and also able to handle both data bits and encryption keys in the optical and non-return to-zero (NRZ) format. In the NRZ format, the signal to the CMUX can provide large enough (time) window to switch optical codewords, without the need of any pulse duplicator (if RZ format is used). To get the data at the receiver side a Code Word De-Multiplexer (CDEMUX) is also introduced. Using CMUX the user data is modulated and transmitted through fiber and then demodulated using CDEMUX to get the actual user data and multiple CMUXs are passed over a WDM system to enhance the multiple user access.

II. OPTICAL CDMA DESIGN

Chapter II described the overall concept of proposed OCDMA system. From Fig. 1, it can be seen that N number of CMUXs (codeword multiplexer) are multiplexed with the help of WDM system and transmit through an optical fiber. Optical CMUX consists of SOA (semiconductor optical Amplifier) based optical combinational logic circuit which multiplex the user data with two optical codes and a unique key. On the other hand, at the receiver side optical CDEMUX (codeword demultiplexer) is introduced to get the original data which is also a SOA based logic circuit. The advantage of using the SOAs in the all-optical logical modules is the integrality as both modules can be integrated in waveguide as one unit. Also, there are some other advantages such as SOA has no electronic

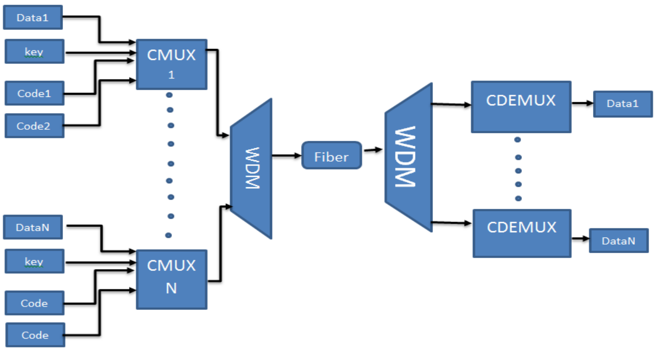

Fig. 1. OCDMA system using CMUX and DEMUX

speed bottleneck caused by high-speed data encryption and transmission and it has no encryption-speed bottleneck because symbol rate is m times slower than data rate. SOA is also useful for rapid codeword swapping and optical packet switching [11].

A. 2× 1 Codeword Multiplexer (CMUX)

The 2 × 1 CMUX is designed with the all optical logic gates made with SOAs which is polarization independent. This CMUX is actually 2 × 1 Code Word Multiplexer where two code words are multiplexed and passed through a single line. The encrypted key E_i found from the XOR gate is used as input of the CMUX as shown in Fig.2. The principle of CMUX is when encryption key $E_i = 0$, C_j will pass. On the other hand, when encryption key $E_i = 1$ and the lower SOA will pass the optical codeword C_{j+1}.

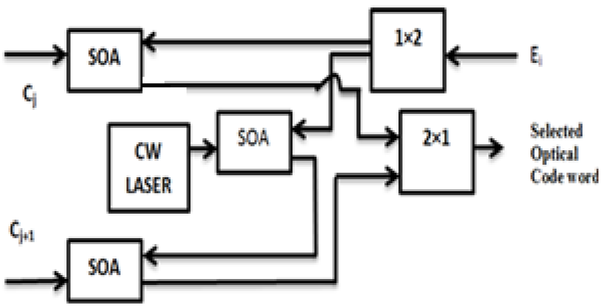

Fig. 2. 2 × 1 Optical Codeword Multiplexer (CMUX)

The middle SOA can invert the optical signal. Where CW laser beam is injected in forward to the SOA and E_i is injected in backward to the SOA. Both outputs are combined with the help of 2×1 optical combiner. As a result, the final logic of the all-optical 2×1 CMUX is $C_j \overline{E_i} + C_{j+1} E_i$.

B. Two input XOR gate design

The two XOR gate is designed with SOA as it can only deal with optical signals. It can work with the data bits of up to 10 Gb/s. In this all optical XOR gate there are two inputs. One is key stream K_i and another is data stream D_i. In principle, at the top SOA the K_i (which is optical NRZ pulse) is injected in backward and simultaneously D_i is also injected in forward which is also NRZ format. As a result, the output from the top SOA will be $D_i \overline{K_i}$. So, the D_i pulse can pass through SOA when the K_i pulse is absent.

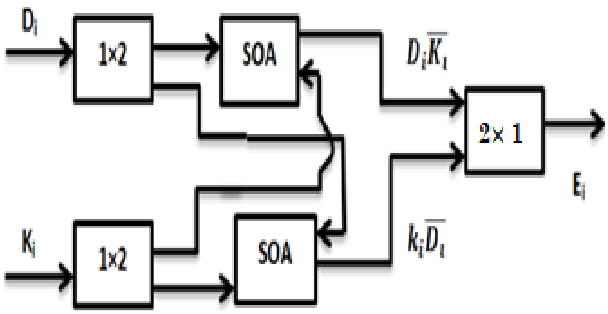

Fig. 3. Two input optical XOR design

K_i (which is optical NRZ pulse) is injected in forward and simultaneously D_i is also injected in backward which are also NRZ format. As a result, the output from the bottom SOA will be $\overline{D_i} K_i$. Ki pulse can pass through SOA when the Di pulse is absent. Similarly, two outputs are combined together with help of optical 2×1 passive combiner to get the final output $D_i \overline{K_i} + \overline{D_i} K_i$ which is all optical XOR operation and also the XOR output is denoted as encryption key E to the CMUX.

C. Codeword De-Multiplexer (CDEMUX) design

Table I. shows truth table of the CMUX logic circuit. From the truth table, CDEMUX logic circuit can be designed. It is observed that by making NOR gate of CMUX output and codeword C_1 we can get E which was XOR output. Then making XOR of E and KEY finally we can get the user data (Shown in Fig.4).

TABLE I. TRUTH TABLE OF CDEMUX

E	C_0	C_1	o/p= $C_0 \bar{E} + EC_1$
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	1

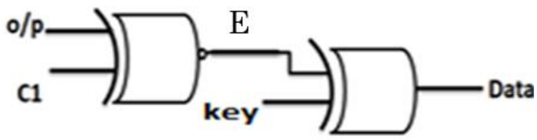

Fig. 4. Logic for CDEMUX design

After designing the CMUX and CDEMUX different data can transmit thorough a fiber over the OCDMA system to observe the performance of the whole designed system.

III. SIMULATION

In this section the simulation of all XOR gate, CMUX, CDEMUX, OCDMA with WDM system are presented using Optisystem and the results are discussed.

D. XOR gate design

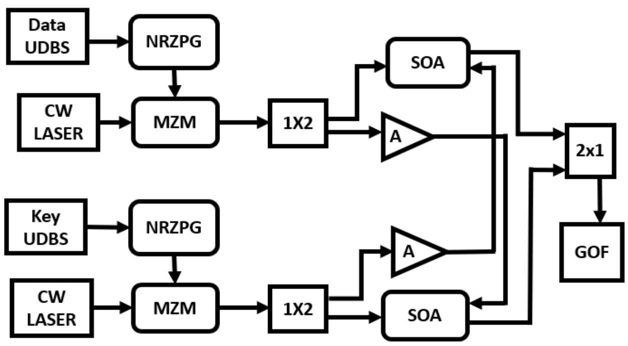

Fig. 5. Designed optical XOR gate design in optisystem

Here, A = Optical Amplifier
UDBS = User Defined Bit Sequence
NRZPZ=NRZ Pulse Generator
MZM= Mach-Zehnder Modulator
2×1 Power Combiner
1×2 Power Splitter
SOA = Semiconductor Optical Amplifier
GOF= Gaussian Optical Filter

Fig. 5. shows the simulation set-up of the all-optical XOR gate. Here two User Defined Bit Sequence (UDBS) are used to represent the user data stream and key stream. The Mach-Zehnder Modulator used to modulate the bit sequence and convert the it into optical signal. Here two input power combiners are used to combine two optical signals. On the other hand, power splitter is used to split the signal. SOAs are optical amplifiers are also used to maintain the logic function. Also, optical amplifier is used to amplify the signal. At last GOF is used to eliminate the unwanted signal and get the original signal.

For two input XOR logic gate, if two bits are presented together and two bits are absent together the XOR output will be 0. On the other hand, any one bit is absent and another bit is present together the output will be 1. In the optical format, a stream of NRZ data bits D = 01011011 and a stream of NRZ encryption keys K= 11010110 are applied to the XOR gate. XOR output is a steam of NRZ cipher bits $E0 = D0 \oplus K0 =$ 10001101 as shown in Fig.6.

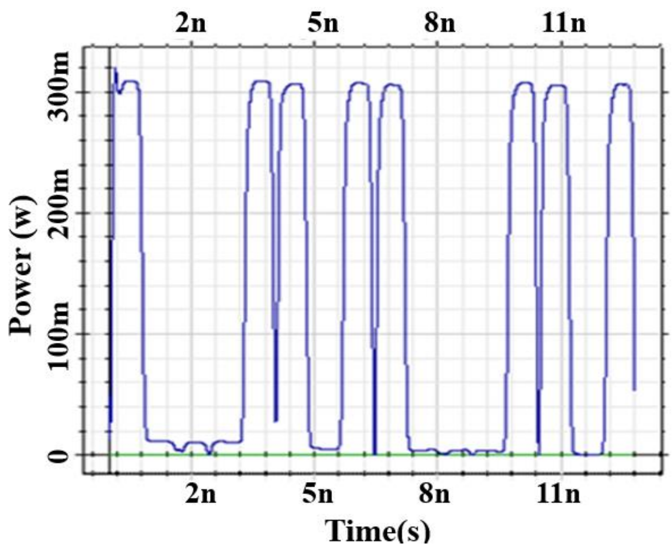

Fig. 6. Designed optical XOR gate output

E. CMUX design

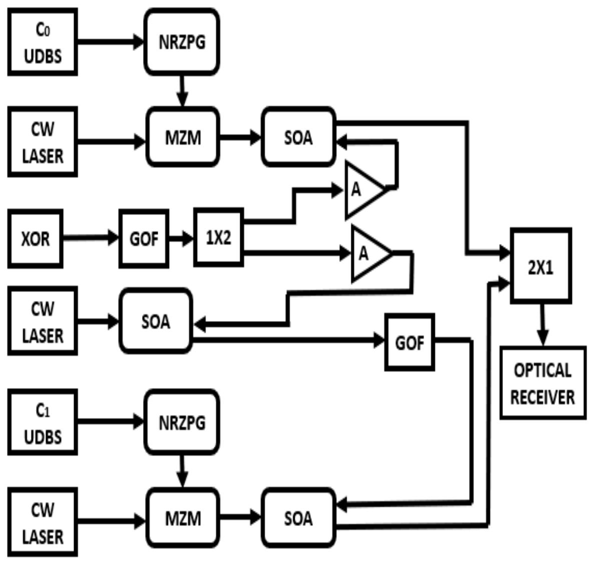

Fig. 7. CMUX design in Optisystem

The simulation set-up of the all-optical 2 × 1 CMUX has been presented in Fig.7. From the design structure section, it can be observed that the CMUX output will be $C_1E+C_0\bar{E}$. For E=0, C_0

will be selected as output as well as for E=1, C_1 will be selected as output. For, C_0=01101101, C_1= 10010010 and XOR output, E=10001101 the CMUX output should be 00011111. Fig.8 shows the output which is same as the CMUX logic.

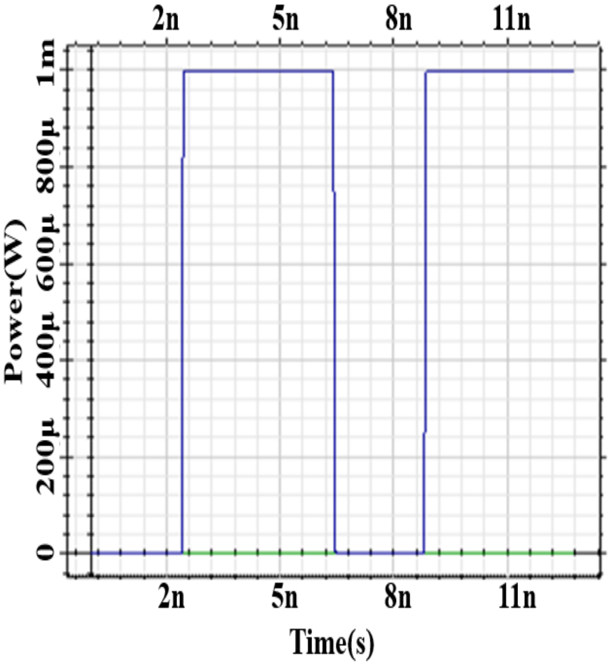

Fig. 8. Optical CMUX output

F. CDEMUX design

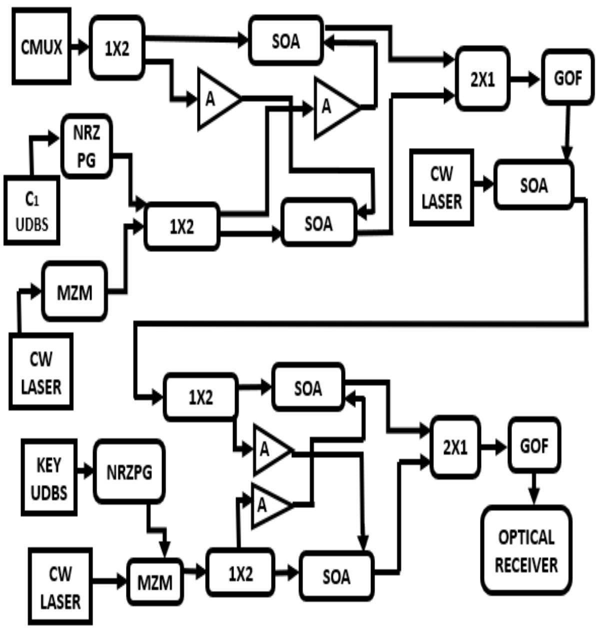

Fig. 9. Optical CDEMUX design in Optisystem

Fig. 9 is the simulation set-up of the CDEMUX. At the 1×2 power splitter (on the left), this module accepts the output of the CMUX. The output of the CMUX and code C_1 is making NOR gate in this design. CMUX output = 00011111 and C_1=10010010 are the two inputs of the NOR gate and the output is 10001101 which is actually equal to encryption key E. After that this E=10001101 and Key K=11010110 is making XOR and get the CDEMUX output=01011011 which is actually the user data received in the receiving end (shown in Fig.10)

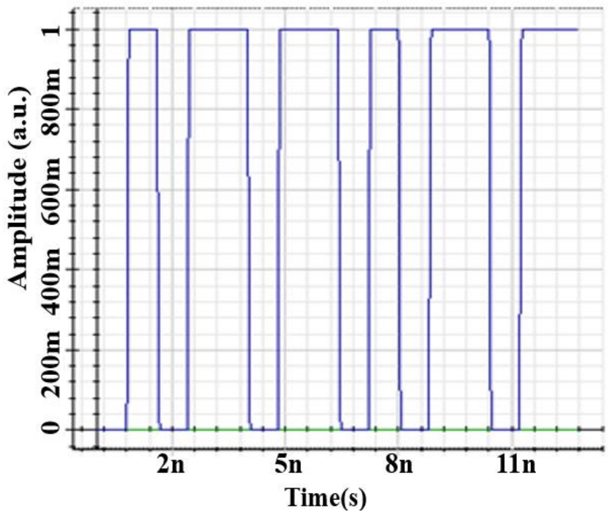

Fig. 10. Optical CDEMUX output

A. OCDMA SYSTEM

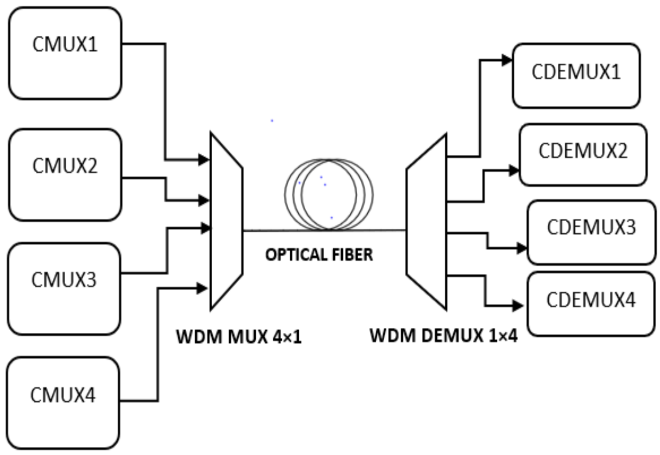

Fig. 11. OCDMA System for four User

Fig. 11 shows the OCDMA system simulated in Optisystem. CMUX 1 ,CMUX 2,CMUX 3, CMUX 4 represents the User 1, User 2, User 3 and User 4 respecticelvly. These four CMUXs data passed through a WDM 4 × 1 MUX and transmitted through a fiber and then at the receiver side multiplexed data stream passed through a WDM 1×4 DEMUX. CDEMUX demodulates the received data to corresponding user. Table II is showing the used key and code words for corresponding user data where each user Data is carrying two different codewords and one unique key.

TABLE II. TRUTH USED DATA, KEY, AND CODEWORD

User data	Key (K)	Codeword(C_0)	Codeword(C_1)
D_0(01011011)	11010110	01101101	10010010
D_1(00101100)	11100100	01011101	10100010
D_2(01011000)	01010101	11110000	00001111
D_3(10110000)	11001100	01000111	10111000

IV. RESULT AND DISCUTION

In this Section the Bit Error rate and Quality factor(Q) are investigated and the result is analyzed for the proposed OCDMA System.

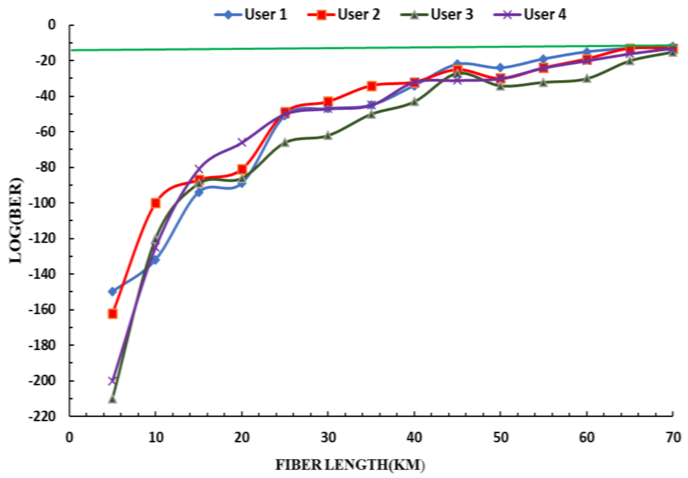

Fig. 12. Log BER Vs Fiber length

Fig.12 shows the log BER(Bit Error Rate) performance of the User 1, User 2, User 3 & User 4 of the designed OCDMA system. At fiber length 70km the log(BER) of of the User 1, User 2, User 3 & User 4 are respectively -12, -15 ,-13, -13 (shown in Fig. 15). The average log(BER) of the four users at 70 km is -13.25. In optical communication, the acceptable BER (without the application of any error correcting schemes) can be considered less than 10^{-12} and the corresponding value of quality factor is, Q ≥6 [12]. The proposed OCDMA system performs maintaining the above mentioned criterion up to 70 km. After 70 Km the log(BER) increased beyound the acceptable range (grater than -12) for some of the user.

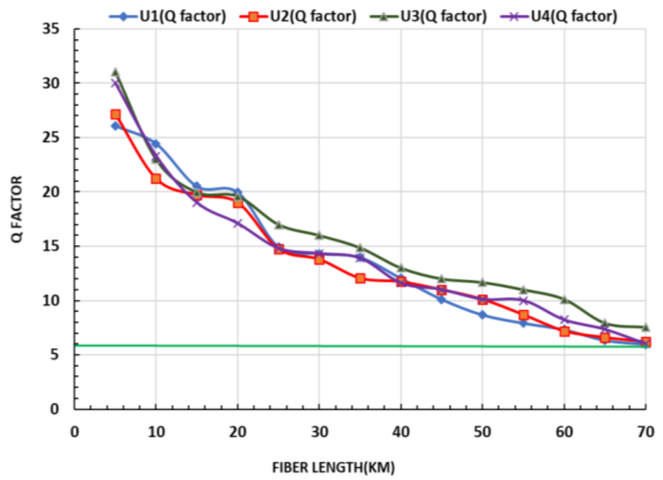

Fig. 13. Q Fctor Vs Fiber length

At fiber length 70 km the Q factor of the User 1, User 2, User 3 & User 4 are respectively 6, 6.2, 7.53 ,6. (shown in Fig. 13). So, the average Q factor of the four users at 70 km is 7.26. After 70 Km the Q factor falls to below 6 which is not acceptable . So, from the two graphs it can be observed that the proposed OCDMA systemperforms well up to 70 km of Fiber length.

TABLE III. COMPARISON WITH SIMILAR RESEARCH OUTPUT

Reported design	Fiber length(km)	Bit Rate	Log(BER) (Average)
Long-haul fiber SAC-OCDMA detection [13]	100	622 Mbps	-16
OCDMA system with DW and MDW code [14]	10	200 Mbps	-22
SAC-OCDMA for FTTH system [15]	10	200Mbps	-45
OCDMA System using W/T Codes [8]	50	1.25Gbps	-22
System design for a SAC OCDMA-FSO Network [16]	15	2.5Gbps	-50
OCDMA/WDM System with DPSK Modulation [3]	20	2.5Gbps	-9
Proposed OCDMA system	70	1.25Gbps	-13.25

Table III represents the previously published research works on OCDMA. In our proposed OCDMA system we achieved average BER of $10^{-13.25}$ at bit rate of 1.25Gbps for 70 km of fiber length. From the table it is clear that in terms of transmission distance our proposed system performs better than most of the existing designed network. Moreover if we consider both transmission distance and data transmission speed, proposed systemprovides a better solution than other similar research.

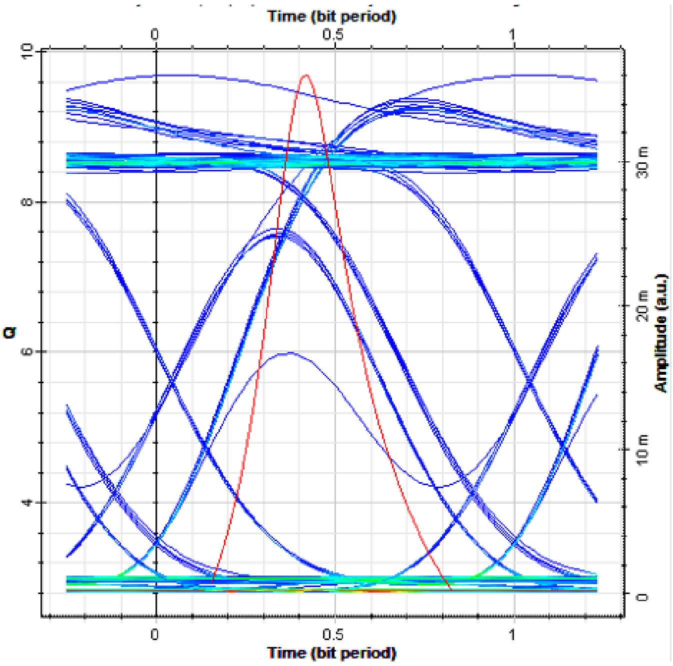

Fig. 14. Eye diagram of User 1 (70 Km fiber length)

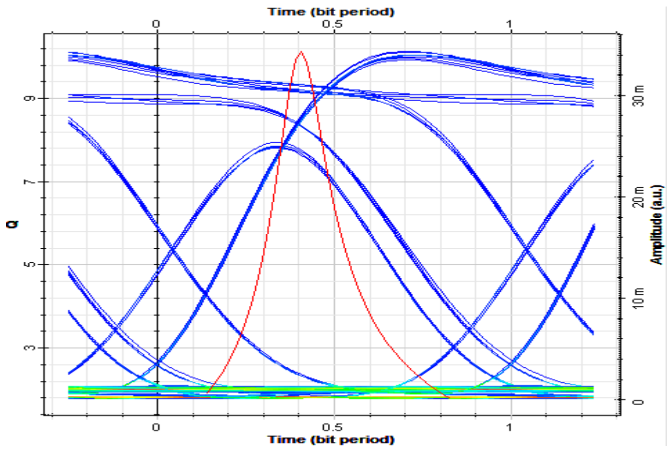

Fig. 15. Eye diagram of User 2 (70 Km fiber length)

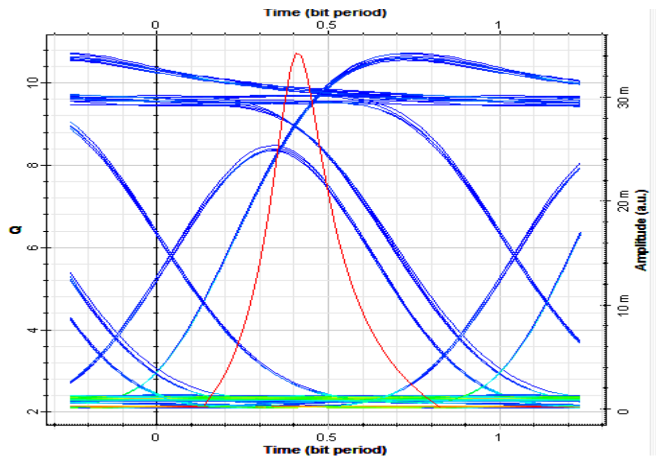

Fig. 16. Eye diagram of User 3 (70 Km fiber length)

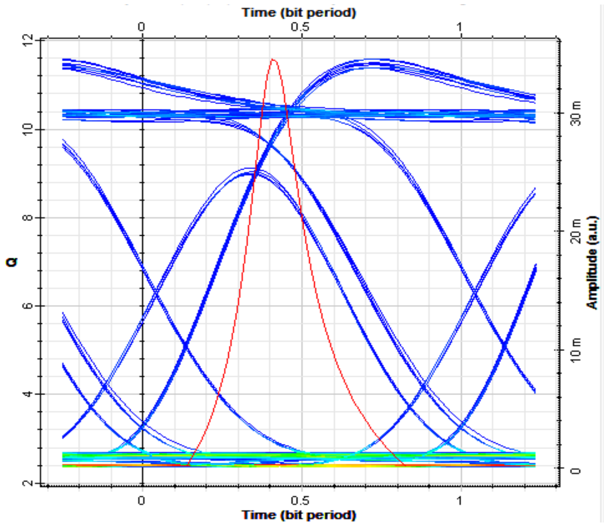

Fig. 17. Eye diagram of User 4 (70 Km fiber length)

Fig. 14, Fig. 15, Fig. 16, Fig. 17, shows the eye diagram of User 1, User 2, User 3, and User 4 at 70km of transmission distance respectively.

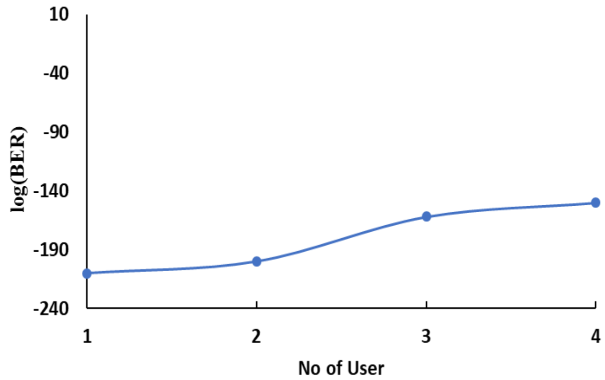

Fig. 18. BER vs no of users

Fig. 18. shows that as the number of user increases BER also increases. So , BER performancec decreases due to inter channel interferance in WDM system.

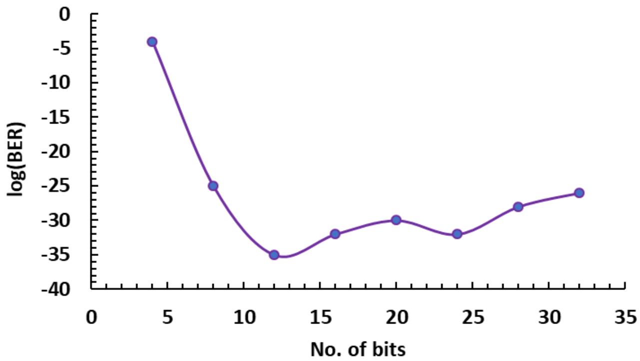

Fig. 19. BER vs no of Data bits

Fig.19 shows the log(BER) performance with respect to no of data bits. It can be found that BER at 4 bits of user is very low (logBER is -5 at 4 bits of user) and from 8 bits to 32 bits the BER performance is good (ie less than -12). So this system will perform better for more than 8 bits.

V. CONCLUSION

To enhance physical-layer confidentiality the proposed OCDMA system is desinged. In this paper a SOA based Optical CDMA system is introduced using two code keying encryptions. From graphs and results it is observed that the designed system has the moderate transfer rate of 1.25 Gb/s for each user that achieved after 70 km of fiber transmission. (Without application of any error correcting schemes and amplifier).

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