Design and Analysis of 5×15Gbps Optical DCDM based communication system

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Abstract—**Multiplexing is an essential part in a communication system. It is widely employed due to increase transmission capacity and to reduce system costs. There are three basic types of multiplexing technique in communication systems; time division multiplexing (TDM), frequency or wavelength division multiplexing (FDM) or (WDM), and code division multiplexing (CDM). However, for multiplexing high number of users with high data rates, high speed multiplexer and de-multiplexer are required. At higher speeds clock recovery is another essential issue which limit the conventional multiplexing techniques. Therefore, many investigations have been done to design and develop reliable and cost-effective clock recovery modules for TDM in both the electrical and optical (thus, OTDM) versions. Realizing these problems the design of five users Duty Cycle Divisio n Multiplexing (DCDM) based Optical communication system has been proposed in this paper. The performancecomparisonof 5 ×5Gbps, 5 ×10Gbps and 5 ×15Gbps has been done.The system performance isevaluatedonthe basisof theBER for all five users, link range, signal to noise ratio & Q-factor. It has been observed that at 15 Gbps data rate the signal is successfully transmitted up to 100 Km distance. Also the minimum received power required for the DCDM users to get BER of 10^{-9} is calculated as -24.12 dBm.**

*Keywords-***Multiplexing; DutyCycle; OpticalCommnication; BER**

I. INTRODUCTION

Communication plays an important role in every aspect of our life, communication means transfer of information from one place to other. The transmission of signals over a distance for purpose of communication start thousands of years agowith the use of smoke signals in Africa, America and parts of Asia. In the 1830s electrical telecommunication systems started to appear where information is in form of electrical signal.The Morse telegraph was introduced in the 1832's, with dots and dashes (analogous to logic 1s and 0s) are transmitted across a wire using electromechanical induction and the transmission rate was 1bit/s. Communication can be defined as the exchange of information between sender and receiver through an accepted code of symbols.Multiplexing began with telegraph systems in the1872, where Western Union had duplex operations on their lines. In 1874, Emile Baudot invented a telegraph multiplexer, which allowed signals from up to six different telegraphs to be transmitted simultaneously over a single wire.This allowed two individual messages to travel the same direction on the line at the same time, which was called duplexing. The invention of the telephone in 1876 and first coaxial cable system 1940 with the capability to transmit 300 voice channels. The first microwave system was put into service in 1948 with a carrier frequency of 4GHz. Coaxial and microwave systems were operating at 100Mbit/s. High speed coaxial systems need repeater spacing of 1km.Increase of the bandwidth and decreases of the cost per transmitted bit for optical communication systems during the 1990's.

Multiplexing is the technique that allows the simultaneous transmission of multiple signals across a single data link or channel. In existing systems, the medium isnormally shared based on time slot (TDM), carrier frequency (FDM) or spectrum coding (CDM) [3]. The goals of all multiplexing techniques are to support as many users at as high speed and at the lowest cost possible [1]. Shannon's Law states that the highest obtainable error-free data speed, is a function of the bandwidth and the signal-to-noise ratio [4]. In communication systems, medium impairment factors, coding schemes and architecture of modulation formats and multiplexing techniques are the favourite targets of investigations towards achieving Shannon's limit. Researchers implement Error Correction Code in order to achieve performance close to Shannon limit. At the same time, enhancement on multicarrier modulation systems would also bring us closer to Shannon limit.

In this paper we introduce a novel multiplexingtechnique, which is based on RZ duty cycles, thus Duty-cycle Division Multiplexing (DCDM), which can be used to achieve the performance as close as possible to Shannon's limit. This technique can be implemented in both wireless and wire line communication systems; for any types of carriers; RF, Microwave and optical. In this paper, DCDM technique is implemented in an optical communication link with a setup as shown in Figure-1. Although the setup uses only a single wavelength channel, the system can be easily duplicated for other wavelengths to represent a DWDM system. However, this is only relevant when the maximum number of DCDM channels per user has been reached, while a larger bandwidth is still required.

However, DCDM system for the three users has been defined yet for data rate of 10 Gbps, in this paper it has been investigated for five user and data rate of 15 Gbps for better improvement.

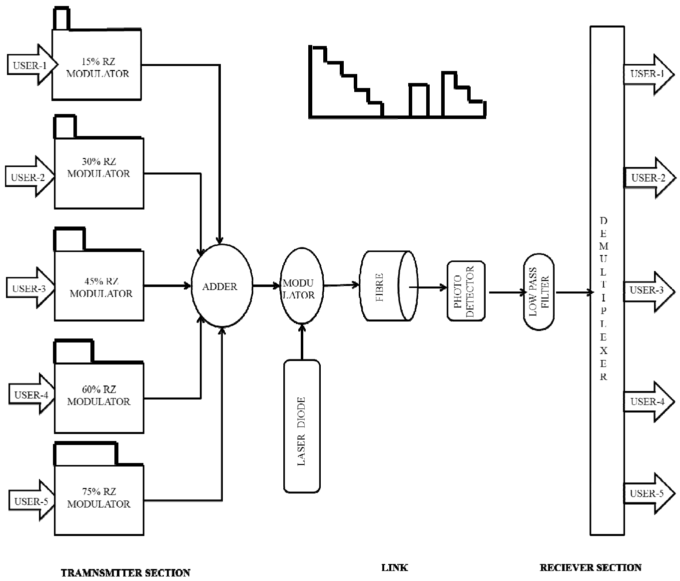


Figure: 1 Block diagram of five user DCDM system

II. WORKING PRINCIPLE

Realizing the problems of conventional multiplexing strategies, duty cycle division multiplexing (DCDM) is proposed as an alternative multiplexing technique. In this technique, different users can share communication media and transmit data simultaneously by using the same frequency band but with a different duty cycle. The proposed technique also has an inherent property which allows for better clock recovery. This technique is based on RZ duty cycle, in which different users are assigned specific RZ duty cycle values. In comparison to conventional RZ (RZ-TDM), DCDM does not required symbol synchronization and has smaller spectral width. The multiplexing process of DCDM can be performed either in the electrical domain or in the optical domain. This technique can be implemented in both wireless and wired communication systems.

Although the simple DCDM technique uses only a single wavelength channel, the system can be easily duplicated for other wavelengths to represent a WDM system. However, this is only relevant when the maximum number of DCDM channels per user has been reached, while a larger bandwidth is still required. It is the novel multiplexing technique based on return-to-zero (RZ) duty cycles which allows signal multiplexing and demultiplexing to be performed economically in the electrical domain or optical domain. Thus DCDM can become a potential alternative to increase the transmission capacity tremendously.

A.Duty cycle-

The duty cycle of a communication system refers to how long it can keep operating before it needs a rest or the proportion of time that a system, device, or component on intermittent duty is operating, rather than remaining idle. The duty cycle includes the time starting, running, stopping, and idling and generally is expressed as a percentage or fraction. A compressor, for example, that operates for 1 minute and then shuts off for 99 minutes is said to have a duty cycle of 1 / 100 or 1 percent what percentage of the time it's designed to be in used in a communication system. When we talk about duty cycle in DCDM technique, the multiplexing and demultiplexing concepts are based on duty-cycle values which allow more than two channels to be multiplexed in a channel. The value of the duty cycle for each user can be assigned in various ways.

The duration for i user T_i is defined as:-

$$T_i = \frac{i * T_S}{(n+1)}$$

Where,

'n' represents number of multiplexing users and T_S is symbol duration.

For example, assigning the duty cycle value for 5 users, using DCDM technique will results:

For the 1st user = $T_s/6$.

For the 2nd user = $2T_s/6$.

For the 3rd user = $3T_s/6$.

For the 4th user = $4T_s/6$.

For the 5th user = $5T_s/6$.

For 'n' number of users, each user will be assigned the duty cycle as above.

B. Duty Cycle Division Multiplexing

The DCDM technique is based on the unipolar RZ line code. In this technique, each user transmits a bit of0 volts within $T_S$second where $T_S$is symbol duration and bit 1 is transmitted with Avolts with a duration less than T*s*seconds. For multiplexing 5 users, the 1st, 2nd, 3rd, 4th& 5thuser uses duration of $T_S/6$, $2*T_S/6$, $3*T_S/6$, $4*T_S/6$ and $5*T_S/6$ respectively to transmit bit 1s.

Based on the number of multiplexing users, there are 2^n possible combinations of bits for n users. In the multiplexed signal, each of these combinations produces a unique symbol. For the five users the total number of combination will be 2^5 = 32.According to number of multiplexed user's amplitude level are increases, if one user sends data than amplitude level at one level if all five users send their data than amplitude level reaches to 5 thlevels. Table-1 shows possible combination of five users and figure-2 shows multiplexed waveform of all five users with possible cases.

Table 1: Possible combination of five user DCDM system

users/cases	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
U-I(15%)	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
U-II(30%)	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
U-III(45%)	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
U-IV(60%)	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
U-V(75%)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

users/cases	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
U-I(15%)	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
U-II(30%)	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
U-III(45%)	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1
U-IV(60%)	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
U-V(75%)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

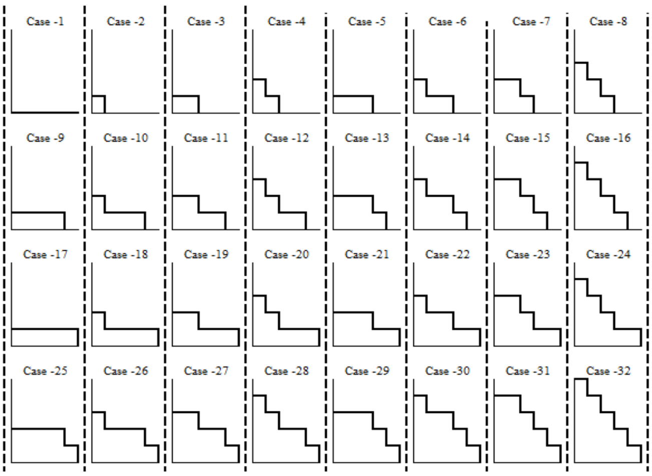


Figure 2:Wave form of possible cases for five user DCDM system

III. SIMULATION SET UP

In transmitter section, the five users send their data at different duty cycles. There are five user define Bit Sequence Generators (BSG), the output of BSGs are modulated by Return to Zero (RZ) pulse generators. The RZ pulse generator modulates duty cycle of input signal as shown in figure-4.1. The RZ-PZ1 modulates 15%, RZ-PZ2 modulates 30%, RZ-PZ3 modulates 45%, RZ-PZ4 modulates 60%, and RZ-PZ5 modulates 75%. The last 25% is used for guard band purpose, to avoid symbol overlapping in communication system. The output of RZ pulse generators are electrically multiplexed using Electrical adder. The Output of electrical adder-4 is the electrical multiplexed signal of all users; the multiplexed data is converted in optical signal by modulating the continuous wave (CW) laser with the multiplexed data and transferred through an optical fiber. The optical signal is received and detected by a PIN detector which converts the optical signal in electrical form. Then low pass filter (LPF) is used to eliminate the noise that produced in optical fiber.

A. Transmitter Section

In transmitter section consist of five BSGs, RZ-PGs, four electrical adders, CW laser and AM modulator as shown in figure-3. The BSG generates data of 5 Gbps, the RZ-PZ modulates the incoming data at different duty cycle, the output of RZ-PGs are electrically added by adder, the electrical signal converted into optical signal with help of CW laser and transmitted into optical fiber. This process is repeated for 10Gbps and 15Gbps.

Table 2: Setup parameterfor five user DCDM system

S.N.	Setup parameter	
1	No. of bit sequence generator	5
2	Pulse Generator	RZ
3	Bit rate, Gbps	25,50,75
4	Operating wavelength, nm/THz	1552.5/193.1
5	Launched power mw	2
6	Distance , km	150
7	Optical amplifier, Gain (db)	20
8	Gaussian LPF, cut off frequency	0.75*bit rate

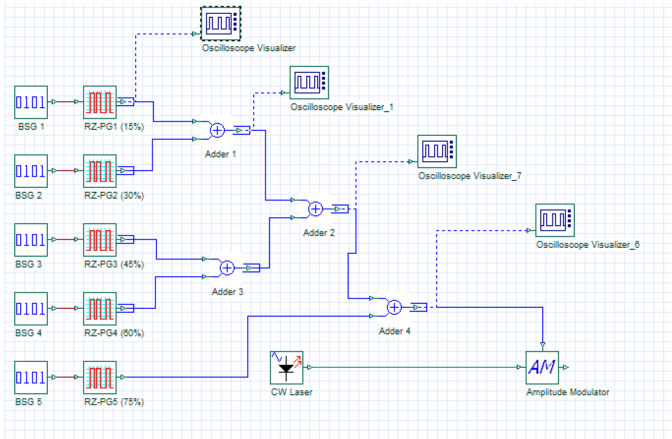
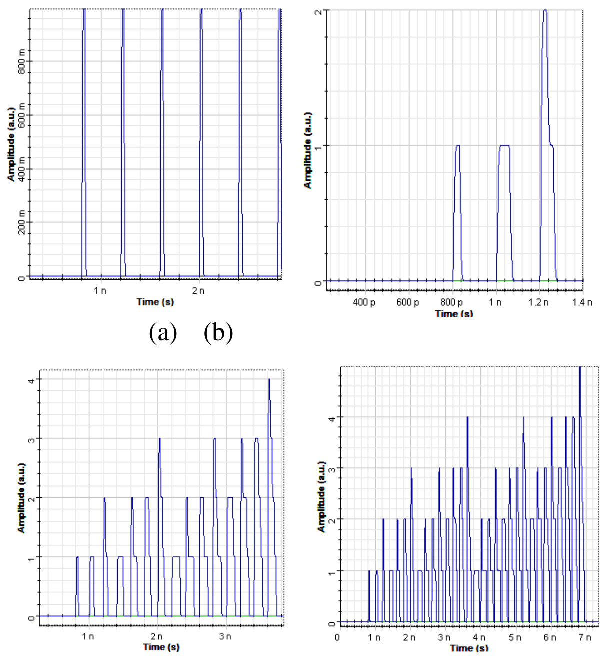


Figure 3:Transmitter Section of five users DCDM System.

The figure: 4 shows the electrically multiplexed data output of user-1, adder-1, adder-3 and adder-4 respectively.



(c) (d)

Figure 4: Electrically Multiplexed data of Users (a) Output of single user. (b) Output of adder-1. (c) Output of adder-3. (d) Output of adder-4.

B. Receiver Section

The receiver section consists of an optical amplifier, PIN detector and Gaussian LPF as shown in figure-5. The optical amplifier increase the gain of received signal, the PIN detector perform optical to electrical conversion and the Gaussian low pass filter (LPF) is used to eliminate the system noises that mainly produced by optical amplifier and photo detector.

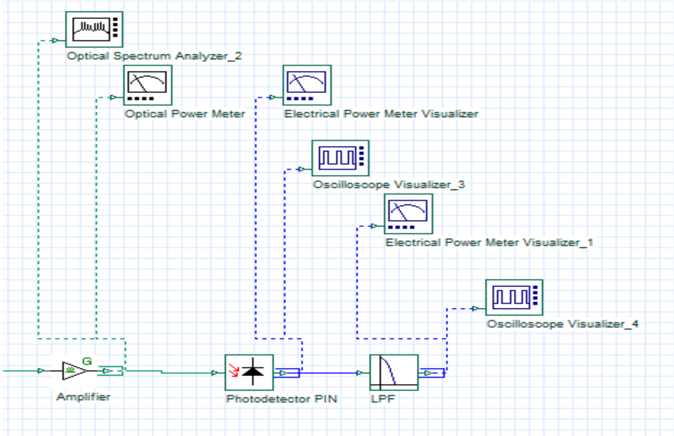


Figure 5: Receiver Section of five users DCDM System.

C. Data Recovery Rules

Decision rules for data recovery are designed for each individual user. There are five threshold values (th_1, th_2, th_3, th_4 and th_5) in y-axis (amplitude) and five sampling points (sp_1, sp_2, sp_3, sp_4 and sp_5) in x-axis (time). From below data recovery rule it is conclude that if value at Sp_i and Sp_{i+1} is at same level than i^{th} user sends zero bit. And if value at Sp_i is one more level than value at Sp_{i+1} than i^{th} user send one bit. Based on these data recovery rules the multiplexed data of five users is recovered. There are different rules for different of users.

Table 3: Data recovery rule for User-1

Rules for User-1			
	Rules	Cases	Data U-1
1.	If $sp_1 < th_1$,$sp_2 < th_1$	1	0
2.	If $th_1 \le sp_1 < th_2$, $sp_2 < th_1$	2	1
3.	If $th_1 \le sp_1 < th_2$, $th_1 \le sp_2 < th_2$	3,5,9,17	0
4.	If $th_2 \le sp_1 < th_3$, $th_1 \le sp_2 < th_2$	4,6,10,18	1
5.	If $th_2 \le sp_1 < th_3$, $th_2 \le sp_2 < th_3$	7,11,13,19,21,25,	0
6.	If $th_3 \le sp_1 < th_4$, $th_2 \le sp_2 < th_3$	8,12,14,20,22,26	1
7.	If $th_3 \le sp_1 < th_4$, $th_3 \le sp_2 < th_4$	15,23,27,29	0
8.	If $th_4 \le sp_1 < th_5$, $th_3 \le sp_2 < th_4$	24,28,30	1
9.	If $th_4 \le sp_1 < th_5$, $th_4 \le sp_2 < th_5$	31	0
10.	If $sp_1 \ge th_5$, $th_4 \le sp_2 < th_5$	32	1

Table 4: Data recovery rule for User-2

Rules For User-2			
	Rules	Cases	Data U-2
1.	If $sp_2 < th_1$,$sp_3 < th_1$	1,2	0
2.	If $th_1 \le sp_2 < th_2$, $sp_3 < th_1$	3,4	1
3.	If $th_1 \le sp_2 < th_2$, $th_1 \le sp_3 < th_2$	5,6,9,10,17,18	0
4.	If $th_2 \le sp_2 < th_3$, $th_1 \le sp_3 < th_2$	7,8,11,12,19,20	1
5.	If $th_2 \le sp_2 < th_3$, $th_2 \le sp_3 < th_3$	13,14,21,22,25,26	0
6.	If $th_3 \le sp_2 < th_4$, $th_2 \le sp_3 < th_3$	15,16,23,24,27,28	1
7.	If $th_3 \le sp_2 < th_4$, $th_3 \le sp_2 < th_4$	29,30	0
8.	If $th_4 \le sp_2 < th_5$, $th_3 \le sp_2 < th_4$	31,32	1

Table 5: Data recovery rule for User-3

Rules For User-3			
	Rules	Cases	DataU-3
1.	If $sp_3 < th_1$,$sp_4 < th_1$	1,2,3,4	0
2.	If $th_1 \le sp_3 < th_2$, $sp_4 < th_1$	5,6,7,8	1
3.	If $th_1 \le sp_3 < th_2$, $th_1 \le sp_3 < th_2$	9,10,11,12,17,18,19,20	0
4.	If $th_2 \le sp_3 < th_3$, $th_1 \le sp_3 < th_2$	13,14,15,16,21,22,23,24	1
5.	If $th_2 \le sp_3 < th_3$, $th_2 \le sp_3 < th_3$	25,26,27,28	0
6.	If $th_3 \le sp_3 < th_4$, $th_2 \le sp_3 < th_3$	29,30,31,32	1

Table 6: Data recovery rule for User-4

Rules For User-4			
	Rules	Cases	DataU-4
1.	If $sp_4 < th_1$,$sp_5 < th_1$	1,2,3,4,5,6,7,8	0
2.	If $th_1 \le sp_4 < th_2$, $sp_5 < th_1$	9,10,11,12,13,14,15,16	1
3.	If $th_1 \le sp_4 < th_2$, $th_1 \le sp_5 < th_2$	17,18,19,20,21,22,23,24	0
4.	If $th_2 \le sp_4 < th_1$, $th_1 \le sp_5 < th_2$	25,26,27,28,29,30,31,32	1

Table 7: Data recovery rule for User-5

Rules For User-5			
	Rules	Cases	Data U-5
1.	If $sp_5 < th_1$	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	0
2.	If $sp_5 \ge th_1$	17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32	1

IV RESULT

We have design five user (5×15 Gbps) DCDM based optical system, in simulation; we tested the Signal to Noise Ratio (SNR), Q-factor and Bit error rate (BER). We evaluated the performance parameters of system for the following consideration:

A. BER versus Length

Figure- 6, Shows the BER versus fiber length considering data rates are 25Gbps, 50Gbps and 75Gbps on the system. . For different data rates, DCDM system performs differently over fiber lengths. As we increases the data rates, performance of system in terms of BER of all five users are decrease. For data rates of 25Gbps and 50Gbps, the maximum length is 110 Km and for 75Gbps it is 100km approximate to maintain minimum BER 10^{-9} .

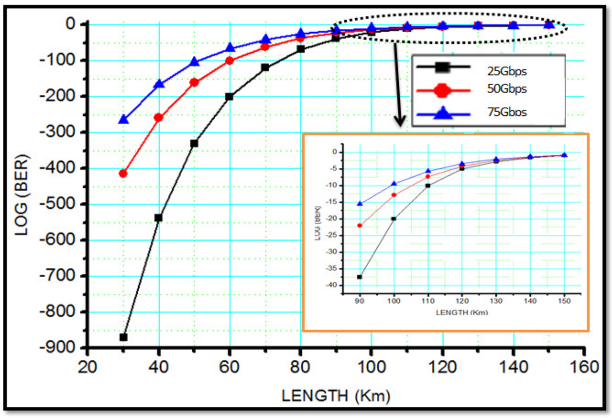


Figure 6: BER v/s Link length

B. SNR & Q-factor Versus Length

Figure-7, shows the SNR and Q-factor versus link range of the data rate 75Gbps system for all the five users. As we increases the fiber length, the performance of system is decrease i.e. the SNR and Q-factor decreases. The minimum SNR is 21.8 db and Q-factor is 7.9 db to obtainBER 10^{-9}in communication system for distance of 100km.

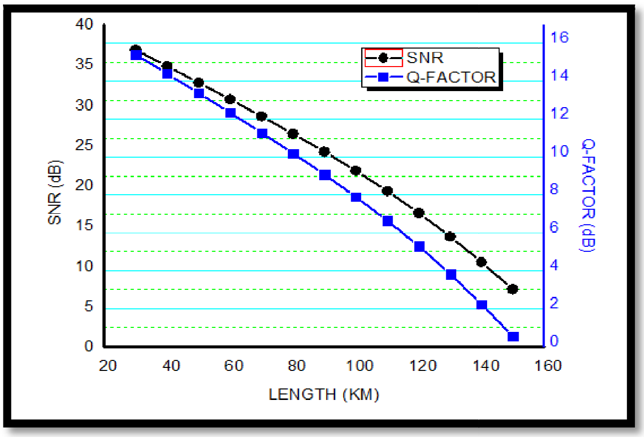


Figure 7:SNR & Q-factor v/s Link range (75 Gbps)

C. BER Versus minimum receive power

Figure-8, alsoshows the system performance.For data rate of 75Gbps, the minimum received power required to get BER of 10^{-9} is -24.12dBm. This is also called sensitivity of DCDM system.

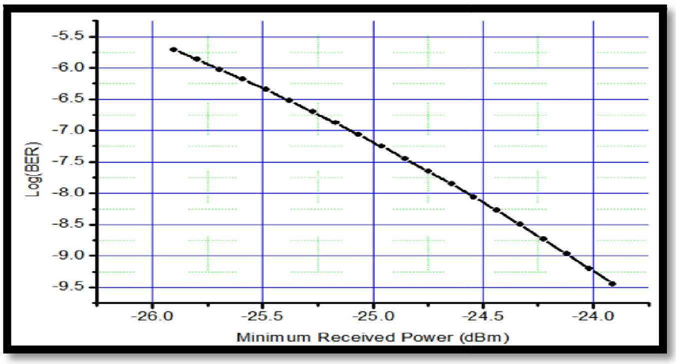


Figure 8: BER v/s minimum received power (75 Gbps)

V CONCLUSION

A 5×15Gbps Duty cycle division multiplexing (DCDM) based communication system is designed successfully. The performance parameters like BER, SNR, and Link Range for the different transmission rates 5 ×5Gbps, 5 ×10Gbps and 5 ×15Gbps has been realized. Performance is reduces for higher data transmission rates as compare to lower data transmission rates. The effect of 5 ×15Gbps system can be shown up to 100km whereas for 5 ×5Gbps and 5 ×10Gbps systems up to 110km.The sensitivity of 5×15Gbps DCDM system has been calculated is -24.12dBm.

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