



## Investigations on Bit error rate performance of DWDM Free space optics system using Semiconductor Optical Amplifier in Rain Environment

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### ABSTRACT

Optical fibers till date are the highest data capacity supported network. The bandwidth supported by fibers is very high but deploying fibers in many cases is not possible. In this scenario the alternate approach that can carry same data rate is FSO (Free space optics) but FSO link can not support a long distance transmission because FSO links are affected by the atmospheric conditions adversely.

To increase the link distance of FSO, optical amplification of signal can be done. In this paper use of SOA (Semiconductor optical amplifier) as preamplifier is presented, performance of free space optical system is investigated with varying number of channels and with varying channel spacing. With 8 channels, 10 dBm input power the link range is 6.5 Km, for 16 channels it is 5.1 Kms.

Investigation on bit rate and receiver sensitivity is also done. Maximum bit rate achieved with WDM system is 10 Gbps and receiver sensitivity with varying bit rate values are analyzed and found that receiver is most sensitive with 2.5 Gbps.

### General terms

SOA (semiconductor optical amplifier), EDFA (erbium doped fiber amplifier), FSO (free space optics).

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## 1. INTRODUCTION

Free-space optical communication (FSO) is an optical communication technology that uses LOS communication system and carrier frequency is (in 20 THz - 375 THz) range [2]. FSO links are low cost, simple and easy to install [1], and license-free also avoids electromagnetic pollution and provide wiretapping safety. The range of FSO is 1-4 Km [3]. The reason behind low range is the atmospheric channel.

FSO channel affect the quality of the signal due to atmospheric turbulence present, as FSO links are highly dependent on weather conditions. FSO links are dependent on atmospheric channel which is highly variable and unpredictable. The fog, smoke and turbulence degrade the FSO links performance [5]. Many techniques have been proposed to improve the performance of FSO link like aperture averaging, diversity [8] or amplification of signal using optical amplifiers [7].

Optical amplification of signal can be achieved by EDFA (Erbium doped fiber amplifier), Raman amplifier or SOA (semiconductor optical amplifier). Most deployed optical amplifier is EDFA because the gain and bandwidth provided by EDFA is very high and due to high bandwidth it can be used for the amplification of multiple wavelengths, therefore can be used with WDM networks easily. The disadvantages associated with SOA like nonlinearity, inter channel cross talk etc make EDFA a better alternate.

Despite of all the disadvantages associated with SOA, it proves to be a better alternate for small area networks due to its various properties

- SOA is compact and easily integrated with other devices.
- Size of SOA as compared to erbium doped fiber amplifiers (EDFAs) and Raman optical amplifiers is small.
- High-speed capability, low switching energy.
- SOA amplifiers have Large BW.
- SOA can operate at 800, 1300, and 1500 nm wavelength regions

Therefore in our work SOA preamplification is implemented. The analysis is done considering low to medium rain conditions because bad weather condition is most limiting factor of FSO link range. Organization of the paper is as

In section 2 characteristics of SOA are explained. Section 3 represents results and discussions. In section 4 conclusion of paper is presented.

## 2. SEMICONDUCTOR OPTICAL AMPLIFIER

Semiconductor optical amplifiers (SOAs) are laser diodes with fiber attached to both ends. SOA uses the principal of stimulated emission. In stimulated emission a signal is applied into the fiber core which excites the ions present in the ground level and move to the excited level for a short period of time then come back to the ground level but during this process photons are emitted which results in amplification.

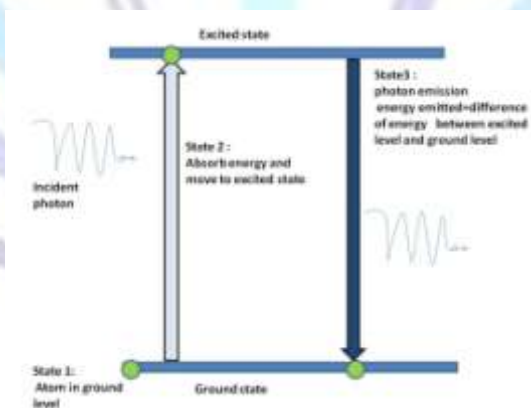


Figure1. Stimulated emission

### 2.1 Comparison Of Soa With Other Optical Amplifiers

Gain provided by SOA is  $>30$  dBm whereas in EDFA gain value is  $>40$  dBm and in raman amplifier it is  $>25$  dBm. SOA is a polarization sensitive device where as in the other two polarization have no impact. Noise figure of SOA is 8 in the other two it is 5. The SOA range of frequency is from 1280 to 1650 which is 1530-1560 in case of EDFA. The cost of SOA is also low compared with the other two amplifiers. The pump power requirement of SOA is also low it is less than 400 ma.



### 3. RESULTS AND DISCUSSIONS

Analysis consider 8 and 16 channel WDM system with the rain conditions from light to medium rain whose values lie in the range of 2.8142 dB/Km to 7.7573 dB/Km according to ITU recommendations [6].

The rain attenuation is calculated by the following formula [6]

$$rain_{att} = kR^\alpha \dots\dots\dots (1)$$

Here k and  $\alpha$  depends on rain characteristics.

In the above formula k=1.58,  $\alpha$  =0.63 for Japan.

k=1.076,  $\alpha$  = 0.67 for France [6].

We have considered the case of Japan and the rain attenuation value of FSO channel is taken as 5 dBm for rain rate value of 6 mm/hr. The commercially available FSO product gives data rate of 2.5 Gbps [9]. In our experimental evaluation same data rate is taken and SOA is employed as preamplifier. The reference BER value is taken as  $10^{-9}$  as this is the performance evaluation factor in many applications.

#### 3.1 Number Of Channels Vs Distance

From the simulation results we have analyzed that as we increase the number of channels the distance of the link decreases. The distance for 8 channels with 100 GHz spacing is 6.5 Kms while for 16 channels with same channel spacing distance reduces to 5.1 Kms. From above results we can say that increasing number of channels decreases distance.

**Table 1. Number of channels vs. channel spacing**

Channel Spacing	Number of channels	
	8	16
100 GHz	6.5 Kms	5.1 Kms
50 GHz	6.5 Kms	5.1 Kms
25 GHz	6.5 Kms	5.1 Kms

From above table we can see that for 8 channels with 100 GHz, 50 GHz and 25 GHz channel spacing the distance range remains 6.5 Kms. Similarly for 16 channels with channel spacing of 100 GHz, 50 GHz and 25 GHz the distance range is same that is 5.1 Kms. That is the distance values does not get affected by the channel spacing. Only the change noticed is in BER values, decrease in channel spacing increases BER. BER results for 8 channel 100 GHz and 50 GHz channel spacing are presented in the table below

**Table 2: Channel spacing and BER at transmitted power of 10 dBm**

Number of Channels	Channel Spacing	
	100 GHz	50 GHz
Channel 1	$2.06108 \times 10^{-11}$	$1.2021 \times 10^{-9}$
Channel 2	$1.41108 \times 10^{-17}$	$8.58597 \times 10^{-14}$
Channel 3	$5.20887 \times 10^{-18}$	$2.14379 \times 10^{-14}$
Channel 4	$1.71252 \times 10^{-19}$	$1.45675 \times 10^{-15}$
Channel 5	$3.44082 \times 10^{-19}$	$1.12803 \times 10^{-15}$
Channel 6	$3.1385 \times 10^{-17}$	$9.35707 \times 10^{-15}$
Channel 7	$3.82717 \times 10^{-14}$	$5.85583 \times 10^{-13}$
Channel 8	$1.91911 \times 10^{-12}$	$2.0469 \times 10^{-11}$



Effect of channel spacing on BER can be analyzed with the help of visualize tool eye diagram. Eye diagram of channel no 1 of 8 WDM system with 100 GHz channel spacing and 50 GHz channel spacing are given below.

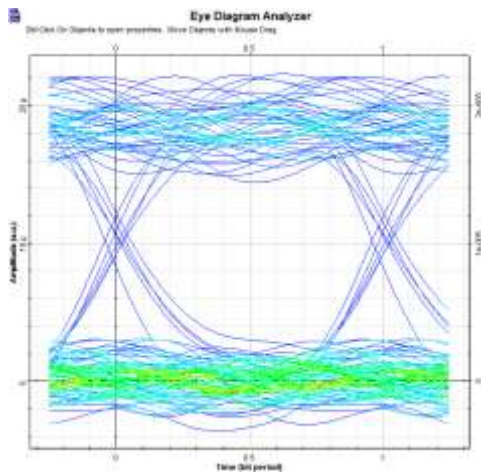


Fig 2: Eye diagram with 100 GHz spacing

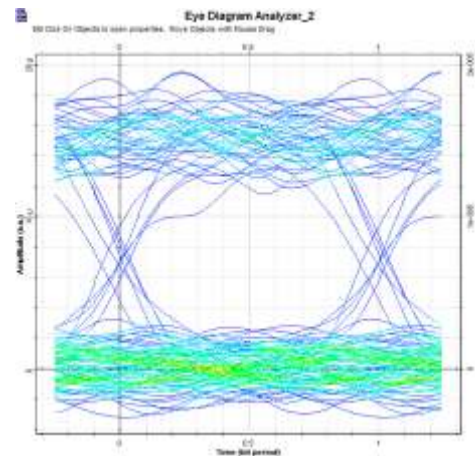


Fig 3: Eye diagram with 50 GHz spacing

From eye diagram we can see that the eye height is more with 100 GHz channel spacing and with 50 GHz channel spacing the eye height is less which shows that with less channel spacing bit error rate is high.

### 3.2 Effect of input Power on BER

For linear operation of SOA one important parameter is input power, because output depends on the input power applied. If the output power is high then the gain saturates and compresses. Therefore to make SOA work in an efficient manner the input power values should not be very high. Here we have investigated the value of SOA input power level.

The gain coefficient of SOA is [5]

$$g(\omega) = \frac{g_o}{1 + (\omega - \omega_o)^2 T_2^2 + \frac{P}{P_s}} \dots\dots\dots(2)$$

- Here  $g_o$  =Peak value of gain.
- $\omega$  =optical frequency of incident signal.
- $\omega_o$  =Atomic transition frequency.
- $P$  =Optical power of signal being amplified.
- $P_s$  =Saturation power.
- $T_2$  =Dipole relaxation time.

From the formula it is clear that gain started to decrease when  $P$  becomes comparable to  $P_s$ . Which shows that the input power to WDM SOA can not exceeds the saturation limit it should be less than that.

The effect of saturation power is calculated here by simulation for a single channel.

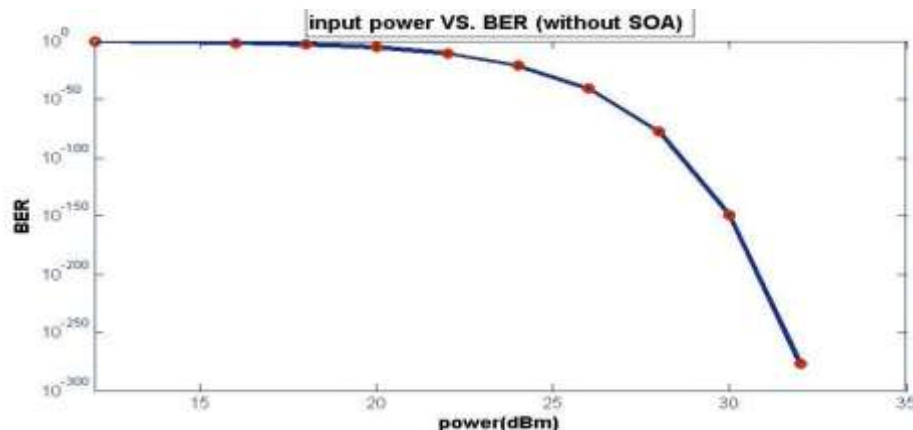
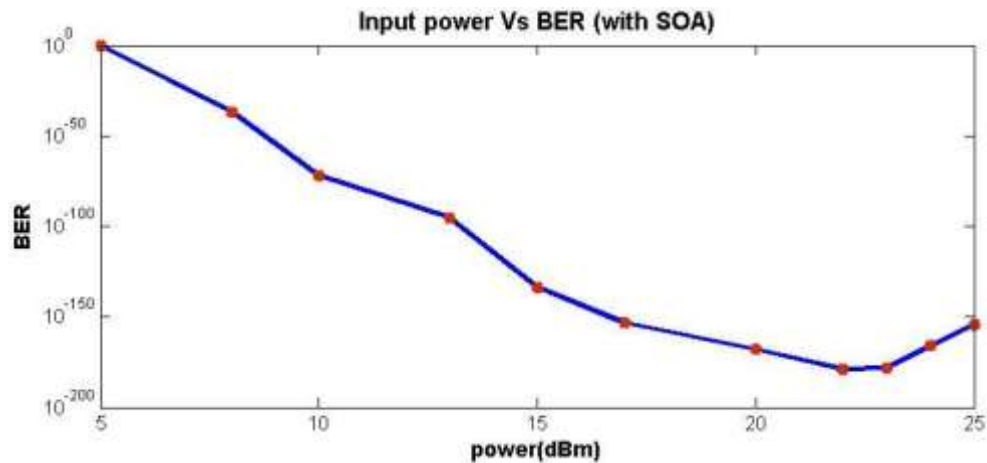


Fig 4: Input power Vs. BER (without SOA preamplification)

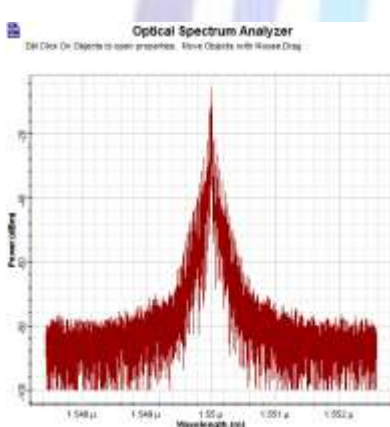




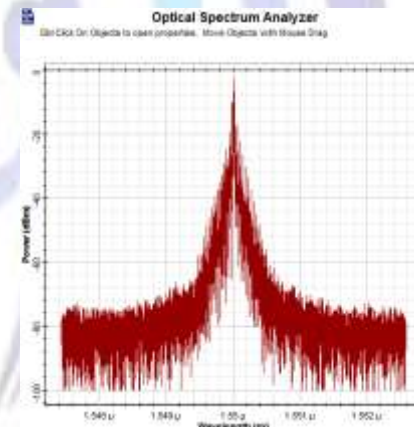
**Fig 5: Input power Vs. BER with SOA preamplification**

From the graph it is clear that as we increase the input power the BER values decreases upto a certain level which by simulation we have found 20 dBm, at 22 dBm the BER value remains same and then BER value started to increase. All the above data is with the use of SOA preamplification. From figure 1 it is clear that more the input power, less is BER value.

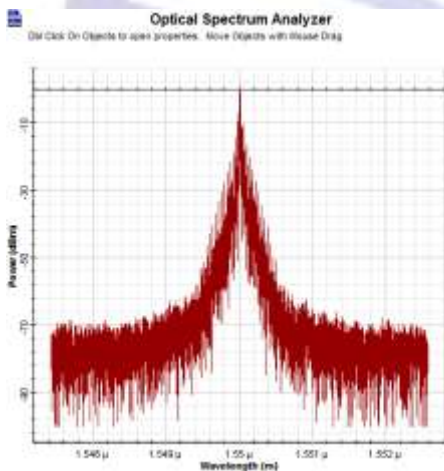
This can also be verified with the optical spectrum at varying input power levels given below



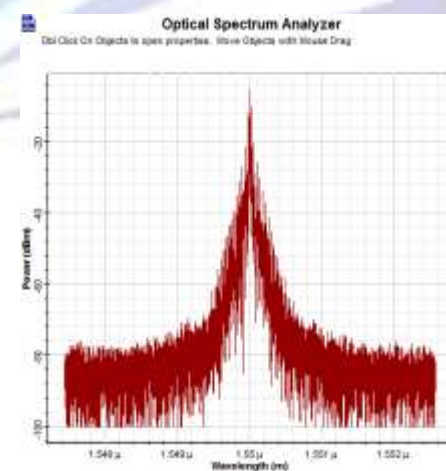
**Fig 6: Spectrum at 8 dBm input power.**



**Fig 7: Spectrum at 12 dBm input power.**



**Fig 8: Spectrum at 18 dBm input power**



**Fig 9: Spectrum at 22 dBm input power.**

It can be seen that optical spectrum broadens as the input power is increased in to SOA. There is increase in the power of neighbouring wavelengths around the central wavelength, which results in crosstalk and thus increases in BER.



The broadening of the spectrum can be attributed due to non linear effects present in SOA.

The nonlinear effects in SOA are cross gain saturation, four wave mixing, saturation induced self phase modulation which induces cross talk. The gain of amplifier is

$$g = \frac{g_o}{1 + \frac{P}{P_s}} \dots\dots\dots (3)$$

Here  $g_o$  =Peak value of gain.

$P$  = input power.

$P_s$  =saturation power.

For WDM case the gain depends on total power of all the channels. That is the gain of a specific channel saturates not only due to its own power but due to power of neighboring channels this phenomena is known as cross gain saturation. Because of this the amplified signal fluctuates, which degrade the SNR of receiver [5].

In four wave mixing signal from one channel is scattered to other channel causes cross talk this is due to the high power associated with the channels in WDM. In this the carrier population N got modulated which create gain and index grating that induces crosstalk [5].

When the pulses passes through the amplifier, the pulses modulate its own phase through gain saturation, this phenomenon is known as saturation induced self phase modulation.

The input power effects on BER with SOA preamplification can be seen with eye diagrams given below

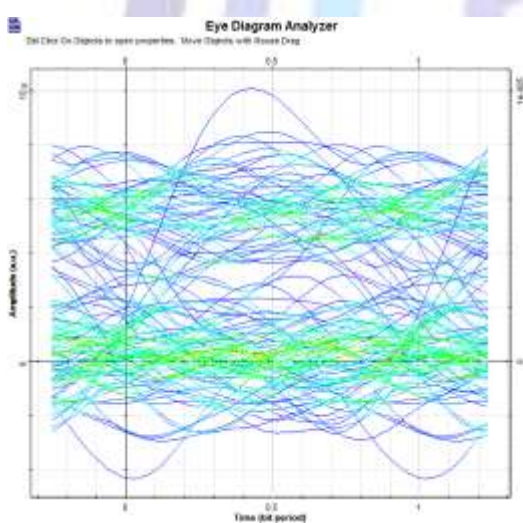


Fig 10: Eye diagram at 8 dBm input power

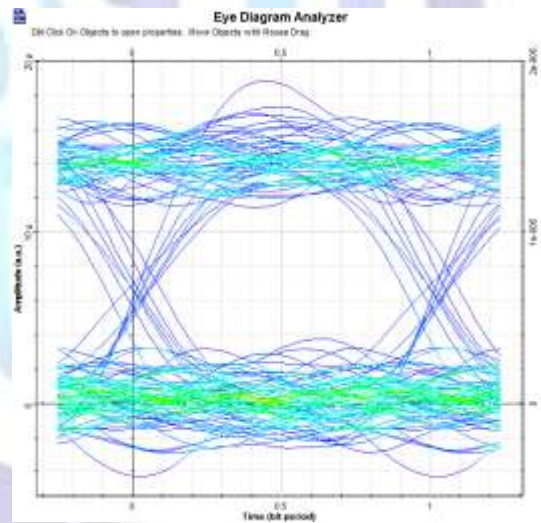


Fig 11: Eye diagram at 12 dBm input power

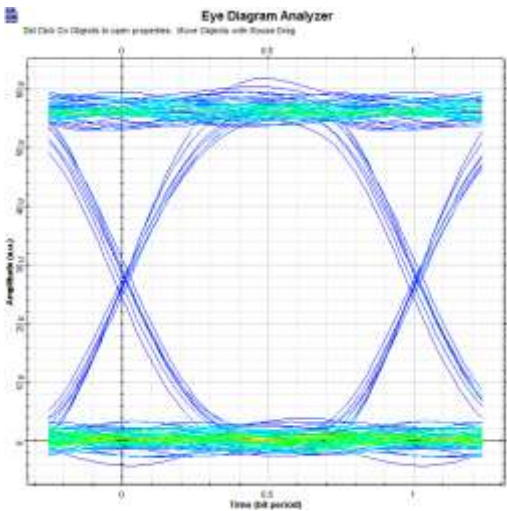


Fig 12: Eye diagram at 18 dBm input power

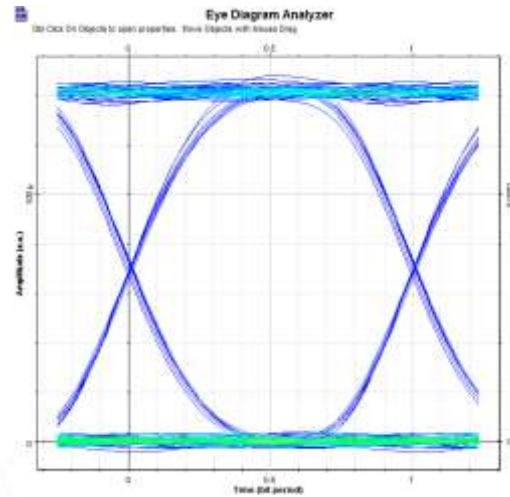


Fig 13: Eye diagram at 22 dBm input power

From the eye diagrams it is clear that more input power upto a certain level decrease the BER, at 8 dBm input power the eye is almost closed, at 12 dBm we can see a improvement in the eye height, at 18 dBm the eye diagram is very clear and eye height is also very high when the input power is further increased to 22 dBm the eye height is maximum and BER achieved is nearly negligible.

Power comparison for 8 and 16 channels WDM system is also done. Three input power values are taken 8 dBm, 10 dBm and 12 dBm. BER values of each channel with these input power levels are shown in the diagram.

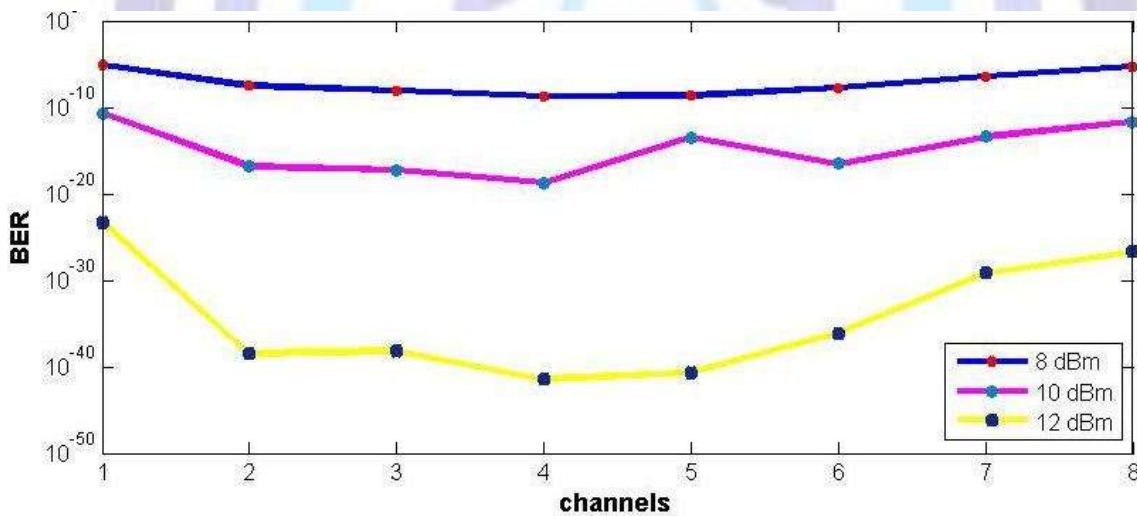


Fig 14: 8 channels BER curve for various input power levels with 100 GHz Spacing, SOA preamplification.

It is clear from the diagram that as we increase the input power the BER decreases. For 8 dBm input power the minimum BER achieved is 1.87e-9 on channel 8 and the maximum BER is 4.85e-6. For 10 dBm input power minimum BER is 1.71e-19 for channel 1 and the maximum BER observed is 2.06e-11 for channel 4. With 12 dBm input power minimum BER is 3.5573e-42 for channel 1 and maximum BER is 5.106e-24 for channel 4. From all the above data it is clear that more the input power less the BER.



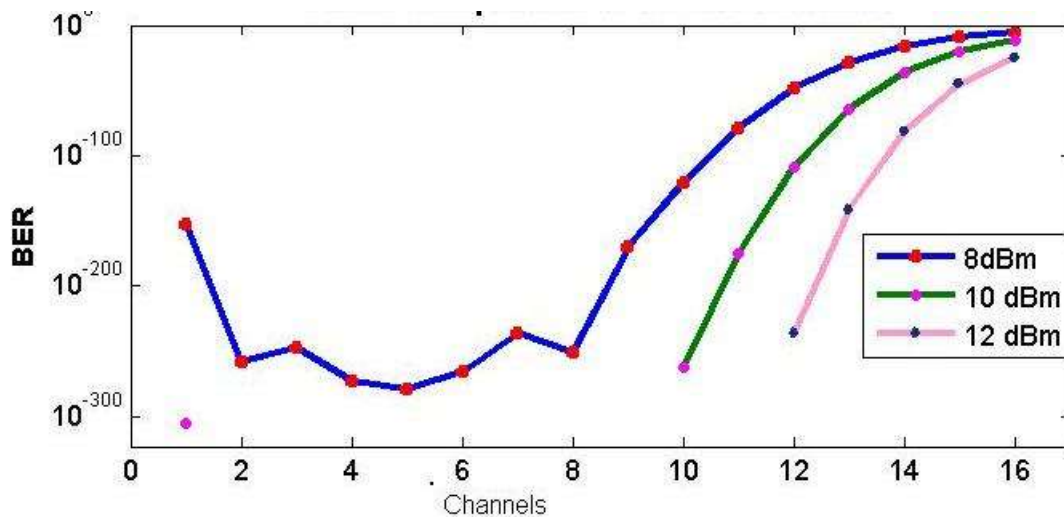


Fig 15: 16 channels BER curve for various input power levels with 100 GHz Spacing, SOA preamplification.

Same results are analysed with 16 channels, as we increase the input power less BER value is observed.

With 8 dBm input power, the minimum BER achieved is 3.310e-259 as we increase the power by 2 dBm the minimum BER achieved is almost near to 0 for 8 channels. When we further increase the power by 2 dBm the same minimum BER value is achieved for 11 channels.

### 3.3 Receiver Sensitivity

The bit rate supported by WDM is 10 Gbps for each channel, with 8 and 16 channels. BER values with various bit rates and varying input power are calculated and plotted in the graph with received power.

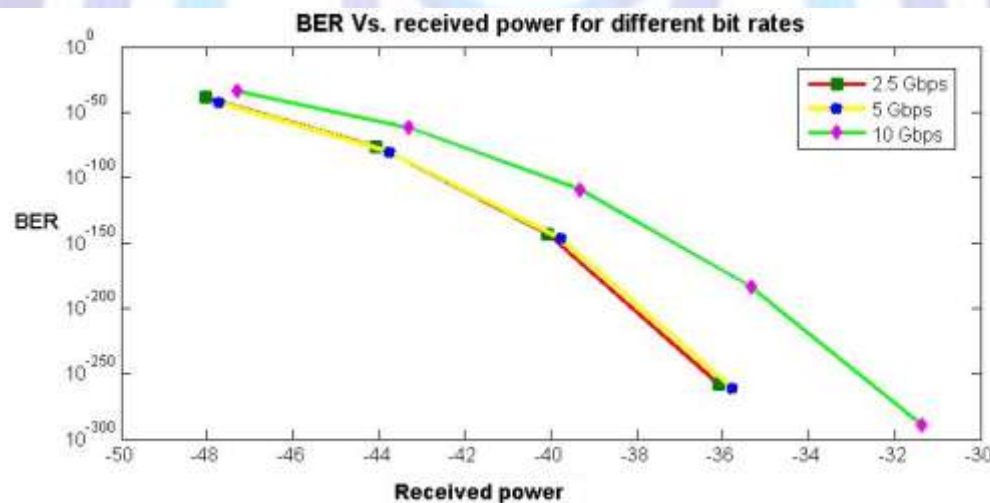


Fig 16: BER Vs. Received power

From the graph it is clear that sensitivity of the receiver with 2.5 Gbps is highest. At 2.5 Gbps reference BER is achieved with less received power that is at 2.5 Gbps less number of photons are required to achieve the reference BER value. At 2.5 Gbps bit rate, and at received power of -48.038 the BER observed is 1.6647e-39. for 5 Gbps bit rate the BER value observed is 1.07887e-43 at received power of -47.715 and for 10 Gbps 1.4142e-34 BER is observed for received power of -47.288.

## 4. CONCLUSION

The results for 8 channel and 16 channel WDM system are presented and discussed. Effect of number of channel on distance is evaluated and results shows that as we increase the number of channels distance decreases. For 8 channels the distance evaluated is 6.5 Kms while for 16 channels it is 5.1 Kms which is better than the results in [10] where the





distance achieved is 2.16 Kms for clear or cloudy days. Next the Effect of channel spacing is studied for 8 channels and found that decreasing channel spacing increases BER with distance unaffected.

Input power behavior of SOA is also studied and it shows that after the saturation level of input power, increase in input power increases the BER.

Bit rate comparison is done, with SOA use in WDM systems 10 Gbps bit rate can be easily supported. The receiver sensitivity of 2.5 Gbps link is highest.

From all the above results it can be said that SOA can increase the distance, bit rate and can be a good alternate to other optical amplifiers with respect of cost and size.

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## Author's Biography



Er. Charu Sharma was born in 1988. She did her engineering in Electronics and Communication from Himachal Pradesh University, Shimla in 2009. She is presently pursuing her Masters in same stream from Eternal University, Baru Sahib (Himachal Pradesh). Her research area of interest includes Free space optical communications, Signal processing, Wireless communication.



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