Investigations on Receiver sensitivity of 10 Gbps SOA based optical communication system

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ABSTRACT

In this paper, investigations are done for performance improvement of optimized SOA preamplifier [13] for 32, 64 channels and various channel spacing. The effects of number of channels and channel spacing are analyzed in terms of receiver sensitivity of the optimized preamplifier based optical receiver.

General Terms: Pre-amplifier

Keywords: BER, SOA; Q-factor, OSNR.

1. INTRODUCTION

The advancements in the field of optical communication have revolutionized the flow of information. One of the major concerns have been achieving low bit error rates (BER) at low received power, thus improving the receiver sensitivity. This also helps in increasing the transmission distances. Earlier regenerative repeaters were the only source of increasing the transmission distances. Olsson [1] has presented a detailed analysis of preamplifiers. He has found that at high data rates, longer transmission distance and higher receiver sensitivity can be achieved with optical preamplifier based receivers as compared to coherent and Avalanche Photo diodes (APD) receivers [1]. Erbium doped fiber amplifiers have been widely demonstrated as preamplifiers. At 10 Gbps system, a high receiver sensitivity of -37.2 dBm and -38.8 dBm was achieved using single EDFA [6] and two cascaded EDFAs [7] respectively. APDs have been widely used in low cost and highly sensitive receivers in metropolitan area networks and a receiver sensitivity of -29.5 dBm was achieved using an APD based receiver at 10 Gbps [8],[9]. But low gain bandwidth product limits their use at very higher bit rates. Semiconductor optical amplifiers (SOAs) can also be used as optical preamplifiers. The prime advantages of SOAs are their light weight and compact size. They can also be integrated on chip also. But the higher inherent noise figure, fiber alignments with both ends of SOA and strict requirements on AR coatings are some of the problems associated with SOAs. T. Yamatoya et al. demonstrated an optical amplifier based on optical modulation of Amplified spontaneous emissions (ASE), in saturation region by the optical signal, the output of such an amplifier is amplified but inverted, they showed its operation on 10 Gbps bit rate and also fabricated it [10], [11], [12].The fiber to fiber gain was found to be 11.4 dB and 0.36 dB ripple in output ASE. The preamplifier based system achieved a BER of $10^{-9}$for a received power of -22.7 dBm [15]. Such an amplifier has relaxed requirements on AR coatings and optical alignments. Cross talk in different channels is a consequence of gain fluctuations of an SOA. The nonlinear factors like gain saturation, four wave mixing (FWM) are responsible for cross talk [2, 3, 4, 5, 14]. These effects have a huge impact on multichannel operation. S. Xu et al. [16] showed that increasing carrier life time while reducing the differential gain reduces the crosstalk in SOAs and obtained a BER of 10^{-9} at a received power of -15 dBm while using SOA as a preamplifier. Gain fluctuations, thus cross talk is a function of carrier density, length of active region, confinement factor, power of signals carrier lifetime, bias current [13]. Surinder singh [13], optimized SOA parameters to minimize the gain fluctuations. He evaluated the performance of the preamplifier system on single and multichannel with 20 channels and 100 GHz spacing. It was found that 0.25ns is the optimum value of carrier lifetime to be used. Consequently, such an optimized SOA preamplifier based optical receiver can be used to improve the performance highly sensitive modern multichannel light wave system, so intuitively it becomes necessary to analyze the performance of such preamplifier based optical receiver on different channels and channel spacing. In this paper we have extended the work in [13] further and investigated the performance of the communication system on 32, 64 channels with 100 GHz, 50 GHz and 35 GHz channel spacing and analyzed the effect on receiver sensitivity and BER at the output.

2. SOA STRUCTURE PARAMETERS:

The parameters taken for the SOA are approximately same as in [13], which are as follows: length is 900 µm, the width of active layer is 2 µm, its thickness is 0.2 µm and confinement factor is 0.3.The transparency carrier density in the SOA is taken to be 1.08×10^{18} cm^{-3}. The spontaneous carrier lifetime is taken 0.25 ns and injection current is 400 mA. The input and output coupling losses are taken 3 dB. In order to operate the preamplifier with least crosstalk and ASE, the gain fluctuations have been minimized in [13].

3. SYSTEM DESCRIPTION:

The proposed SOA based multichannel communication system is shown in figure 1. Insat a single channel transmitter is shown. The SOA pre amplifier parameters were same as stated in section 2. The optical communication system has been operated for 32 and 64 channels with 100 GHz, 50 GHz and 35 GHz spacing. A 10 Gbps logical data source and NRZ driver are used to generate random data in each channel. The total length of the fiber link was 350 Km made of five spans. Each span was made of one Standard single mode fiber (SSMF) of length 60 Km and one Dispersion compensating fiber (DCF) of 10 Km and an inline SOA having the same parameters as given in section 2. The fiber loss parameter was set 0.2dB/Km for SSMF and 0.55

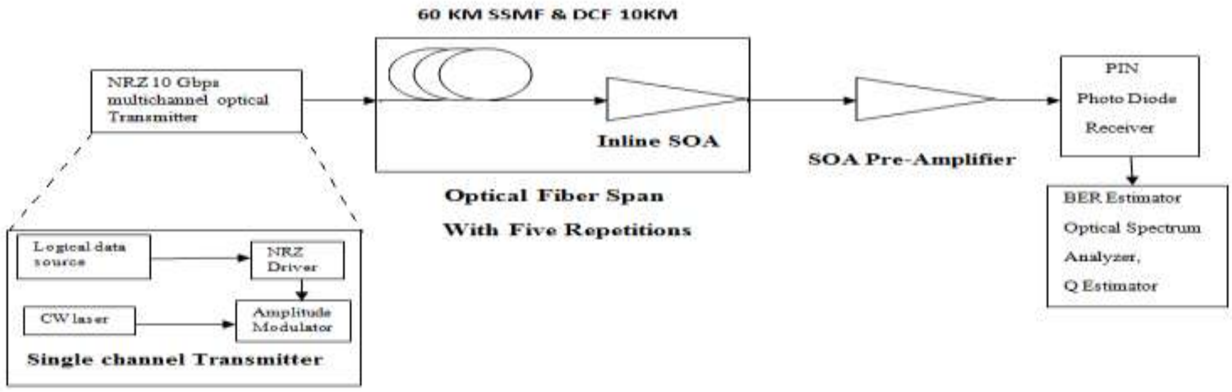

Figure 1: System set up for multichannels SOA based communication system

dB/Km for DCF at 1550 nm while dispersion at this frequency was selected 16 ps/nm/km for SSMF and -80ps/nm/km for DCF. The fiber non linear effects were considered and Raman cross talk was turned off. The receiver consists of a raised cosine optical band pass filter, PIN photodiode and an electrical low pass filter. The optical filter has a raised cosine function exponent 1, roll-off factor 0.5, 3 dB two sided bandwidth is 0.17 nm. The quantum efficiency, responsivity (at reference frequency), dark current of the PIN diode is set as 0.7, 0.8751 A/W, 0.1 nA respectively. Quantum noise was considered.

4. RESULTS and DISCUSSION:

4.1 32 channels, 100 GHz channel spacing:

To simulate the above the above system, a compound component transmitter of 32, 64 channels was used as transmitter in system set up. The plot of BER vs. received power per channel and the corresponding details are shown in table 1 and figure 2. Power to be transmitted was varied from -20dBm, in increments of 2.5 dBm. The BER and Q-factor were observed at two channels 193.6 THz (highest OSNR, channel no 1) and 195.6(lowest OSNR, channel no. 26). The lowest BER of 0.99×10^{-40} was achieved on the 195.6 THz channel for a received power of -30.8 dBm (launched power of -15 dBm). The lowest value of BER collectively for both channels was recorded for a received power of -19.248 and -19.237 dBm (launched power) on the two channels respectively and the values were 0.3435×10^{-31} and 0.99×10^{-40} respectively. The corresponding values of Q factors were 11.75 and 13.31 while the jitter was 0.02387 and 0.01448 respectively. This performance is better as compared to the works in [16] and [15]. As compared to [16], this system produces BER 10^{31} times smaller with a received power nearly 4.2 dBm lesser. When compared to [15], the BER is again 10^{31} times smaller but requires nearly 3.5 dBm more power. The BER reduced up to this point and with further increase in launched power it goes on increasing until the launched power was 10 dBm where the BER on the first channel became 0.7078×10^{-6}.

4.2 64 channels and 100 GHz spacing:

The data representing BER and Q-factor vs received power per channel are given in table 2 and figure 3. BER and Q-factor were observed at two channels for this setup. These were 197.7THz (highest OSNR, channel no. 47) and 194.8 THz (lowest OSNR, ch #18). When the launched power was increased, the BER went on improving until it reached a minimum of 0.99×10^{-40} at received power of -28.563 and -28.596 dBm. When compared with [16], this system transmits 24 more channels and produces a BER 10^{31} times smaller with nearly 13 dBm lesser received power. The BER performance is again better as compared to [15] with nearly 5.8 dBm lesser power. The BER rose above 10^{-9} mark and became 0.2647×10^{-8} for a launched power of 7.5 dBm (received power -15.62 dBm), which is lower as compare to 10 dBm power in case of 32 channels. So, non linear effects are dominating in higher number of channels.

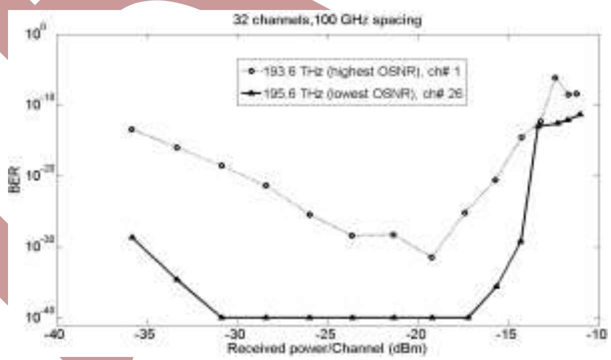

Figure 2: BER vs eceived optical power at 32 channels and 100GHz spacing for ch#1 nd ch# 26

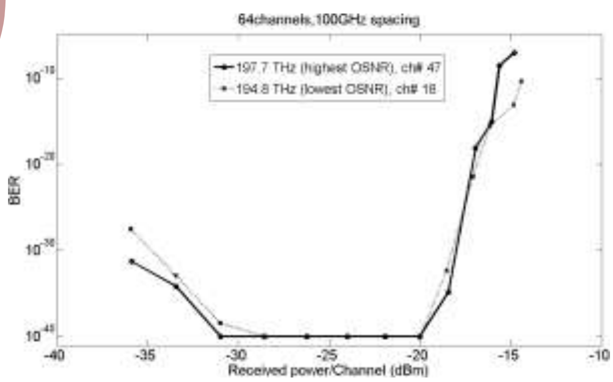

Figure 3: BER vs received optical power at 64channels and 100GHz spacing for ch# 47 and ch# 18.

Table 1: BER and Q-factor for 32 channels, 100 GHz spacing

L.P (dBm)	193.6THz (highest OSNR), channel no.1			195.6 THz (lowest OSNR), channel no.26		
	R.P(dBm)	BER	Q-factor	R.P(dbm)	BER	Q-factor
-20	-35.844	0.3554×10^{-13}	7.48	-35.83	0.21×10^{-28}	11.19
-17.5	-33.359	0.1107×10^{-15}	8.21	-33.345	0.2396×10^{34}	12.35
-15	-30.886	0.2882×10^{-18}	8.89	-30.87	0.99×10^{-40}	13.31
-12.5	-28.433	0.4331×10^{-21}	9.59	-28.416	0.99×10^{-40}	13.31
-10	-26.015	0.3411×10^{-25}	10.52	-25.995	0.99×10^{-40}	13.31
-7.5	-23.656	0.3785×10^{-28}	11.14	-23.63	0.99×10^{-40}	13.31
-5	-21.392	0.4975×10^{-28}	11.12	-21.357	0.99×10^{-40}	13.31
-2.5	-19.248	0.3435×10^{-31}	11.75	-19.237	0.99×10^{-40}	13.31
0	-17.435	0.6251×10^{-25}	10.46	-17.256	0.99×10^{-40}	13.31
2.5	-15.744	0.2591×10^{-20}	9.40	-15.683	0.2331×10^{-35}	12.53
5	-14.297	0.2719×10^{-14}	7.81	-14.337	0.507×10^{-29}	11.32
7.5	-13.246	0.4438×10^{-12}	7.14	-13.375	0.92×10^{-13}	8.23
10	-12.441	0.7078×10^{-6}	4.82	-12.303	0.25011×10^{-12}	7.22
12.5	-11.703	0.2979×10^{-8}	5.81	-11.746	0.7824×10^{-12}	7.06

** L.P Launched power, R.P Received power

Table 2: BER and Q-factor for 64 channels, 100 GHz spacing

L.P (dBm)	197.7THz (highest OSNR),channel no. 47			194.8THz(lowest OSNR),channel no. 18		
	R.P (dBm)	BER	Q-factor	R.P (dBm)	BER	Q-factor
-20	-35.887	0.5356×10^{-31}	11.71	-35.92	0.307×10^{-27}	10.95
-17.5	-33.418	0.6506×10^{-34}	12.27	-33.45	0.1141×10^{-32}	12.03
-15	-30.971	0.99×10^{-40}	13.31	-31.003	0.3636×10^{-38}	13.04
-12.5	-28.563	0.99×10^{-40}	13.31	-28.596	0.99×10^{-40}	13.31
-10	-26.22	0.99×10^{-40}	13.31	-26.254	0.99×10^{-40}	13.31
-7.5	-23.983	0.99×10^{-40}	13.31	-24.018	0.99×10^{-40}	13.31
-5	-21.905	0.99×10^{-40}	13.31	-21.942	0.99×10^{-40}	13.31
-2.5	-20.019	0.99×10^{-40}	13.31	-19.98	0.99×10^{-40}	13.31
0	-18.434	0.1518×10^{-34}	12.38	-18.533	0.4799×10^{-32}	11.91
2.5	-16.944	0.64511×10^{-18}	8.80	-17.075	0.3475×10^{-21}	9.61
5	-16.056	0.7778×10^{-15}	7.97	-16.171	0.2508×10^{-15}	8.11
7.5	-15.62	0.2647×10^{-8}	5.83	-14.856	0.7432×10^{-13}	7.38
10	-14.807	0.8221×10^{-7}	5.23	-14.431	0.4244×10^{-10}	6.49

** L.P Launched power, R.P Received power.

4.3 32 channels, 50 GHz channel spacing:

The data representing the BER and Q-factor vs received power per channel are shown in table 3 and figure 4. Here the BER and Q-factor were observed at two channels, these were 193.35 THz (lowest OSNR, channel no. 6) and 194.65 THz (highest OSNR, channel no. 12). When -20 dBm power was launched, the BERs recorded were 0.2366×10^{-11} and 0.9379×10^{-18}. Then, as the launched power was further increased in steps of 2.5 dBm, the BER goes on decreasing down until the channel no. 12 touched the lowest limit of 0.99×10^{-40} (Q factor of 13.31). The other channel had a BER of 0.113×10^{-17} (Q factor of 8.743). The corresponding values of jitter were 0.0176 (194.65 THz) and 0.023(193.35 THz). At this point the received power was -19.308 and -19.252 dBm respectively. At channel no. 12, the BER performance is 10^{31} times smaller with 4.2 dBm lesser power as compared to [16]. Similarly, the BER performance is 10^{31} times smaller, but requires 3.5 dBm more power as compared to [15]. After this with further increase in launched power, the BER started to increase until it became higher than 10^{-9} for a launched power of 12.5 dBm (for a received power of -11.7 dBm on channel no. 12).

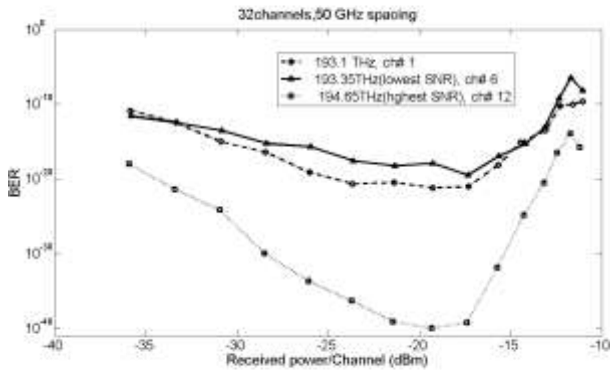

Figure 4: BER vs received optical power at 32 channels and 50 GHz spacing for ch# 1, 6, 12

Table 3: BER and Q-factor for 32 channels and 50 GHz spacing

L.P(dBm)	193.1 THz , channel no. 1			193.35 THz (lowest OSNR), ch#6			194.65 THz (highest OSNR),ch#12		
	R.P(dBm)	BER	Q	R. P(dBm)	BER	Q	R.P(dBm)	BER	Q
-20	-35.842	$0.136x10^{-10}$	6.66	-35.789	$0.236x10^{-11}$	6.91	-35.888	$0.9379x10^{-18}$	8.764
-17.5	-33.357	$0.3325x10^{-12}$	7.18	-33.304	$0.341x10^{-12}$	7.18	-33.403	$0.4084x10^{-21}$	9.597
-15	-30.884	$0.93772x10^{-15}$	7.94	-30.832	$0.273x10^{-13}$	7.52	-30.931	$0.6624x10^{-24}$	10.239
-12.5	-28.432	$0.3742x10^{-16}$	8.33	-28.38	$0.536x10^{-15}$	8.018	-28.479	$0.9969x10^{-30}$	11.464
-10	-26.015	$0.7308x10^{-19}$	9.04	-25.965	$0.197x10^{-15}$	8.14	-26.062	$0.2059x10^{-33}$	12.17
-7.5	-23.658	$0.217x10^{-20}$	9.42	-23.61	$0.256x10^{-17}$	8.65	-23.706	$0.4413x10^{-36}$	12.679
-5	-21.395	$0.3233x10^{-20}$	9.38	-21.333	$0.53x10^{-18}$	8.82	-21.447	$0.7434x10^{-39}$	13.16
-2.5	-19.249	$0.6362x10^{-21}$	9.55	-19.252	$0.113x10^{-17}$	8.74	-19.308	$0.99x10^{-40}$	13.31
0	-17.306	$0.891x10^{-21}$	9.51	-17.332	$0.321x10^{-19}$	9.13	-17.383	$0.3213x10^{-19}$	9.13
2.5	-15.669	$0.7522x10^{-18}$	8.78	-15.62	$0.114x10^{-16}$	8.47	-15.709	$0.1362x10^{-31}$	11.83
5	-14.459	$0.7621x10^{-15}$	7.97	-14.191	$0.446x10^{-15}$	8.04	-14.263	$0.1405x10^{-24}$	10.38
7.5	-13.072	$0.3063x10^{-13}$	7.5	-13.108	$0.766x10^{-13}$	7.38	-13.171	$0.28x10^{-20}$	9.39
10	-12.273	$0.54371x10^{-10}$	6.45	-12.332	$0.527x10^{-9}$	6.1	-12.421	$0.3094x10^{-16}$	8.36
12.5	-11.569	$0.9383x10^{-10}$	6.37	-11.675	$0.304x10^{-6}$	4.98	-11.7	$0.1167x10^{-13}$	7.63
15	-11.045	$0.2128x10^{-9}$	6.24	-11.044	$0.65x10^{-8}$	5.68	-11.194	$0.1698x10^{-15}$	8.15

** L.P Launched power, R.P Received power

4.4 64 channels, 50 GHz channel spacing:

The data representing BER and Q-factor vs received power for 64 channels and 50 GHz spacing are shown in table 4 and figure 5.The values of BER and Q-factor were observed for two channels 193.1 (highest OSNR, channel no. 1) and 195.65 (lowest OSNR, channel no. 52). The BER for lowest launched power of -20dBm was found to be $0.3576x10^{-9}$ and $0.7566x10^{-18}$ respectively. The lowest value of BER was recorded for a received power of -21.828 dBm on the channel no. 52. It was $0.6271x10^{-25}$ with a Q- factor of 10.4651 while on the other channel BER was $0.3237x10^{-15}$ with a Q-factor of 8.08 for a received power of -21.852 dBm. This system transmits 24 more channels and BER performance is 10^{16} and 10^{6} times smaller with nearly 6 dBm lesser power as compared to [16]. When compared with [15], the BER performance is again better, but requires nearly 2 dBm more received power. As the launched power was increased, the BER goes on increasing and finally a threshold was reached at a launched power of 7.5 dBm (received power of -15.147 on first channel) when the BER of $0.1616x10^{-6}$ was recorded and the system can no longer be used beyond that. It is to be noted that the lowest amount of BER for 64 channels is higher than lowest BER obtained for 32 channels. Also, highest power that can be launched into fiber is lower for 64 channels (7.5dBm) as compare to 32 channels (12.5dBm). The reason for this is cross gain modulation, in which a channel is saturated not only by its power but also due to powers of other channels. As the number of channels increase, this effect becomes more dominant.

4.5 32 channels, 35 GHz channel spacing:

The data representing BER and Q-factor for 32 channels and 35 GHz spacing are shown in table 5 and figure 6. The BER and Q-factor were observed for two channels viz 193.275 THz (highest OSNR, channel no.5) and 193.8 (lowest OSNR, channel no. 17). Here, for lowest launched power of -20 dBm the BERs at two channels were $0.18503x10^{-11}$ and $0.1085x10^{-7}$ making it useless. With further increase in power the BER decreased at a slow rate and went down to a minimum of $0.4291x10^{-16}$ and $0.7202x10^{-11}$ on the channel no. 5 and 17 respectively. The corresponding Q-factor and jitter were (8.3232 and 7.7542) and (0.02436 and 0.02029). This happened at a launched power of 0 dBm and received power of -17.366 dBm and -17.265 dBm respectively. Here the BER performance is 10^{7} and 10^{2} times smaller than [16] and needs nearly 2.2 dBm lesser power, but as compared to [15], the BER performance is better but needs nearly 5.5 dBm more power.

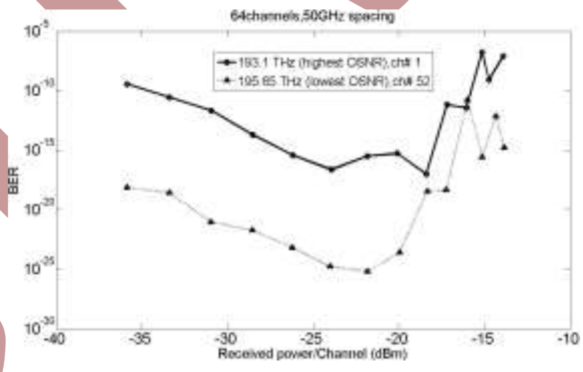

Figure 5: BER vs received optical power at 64 channels, 50 GHz spacing for ch#1, 52

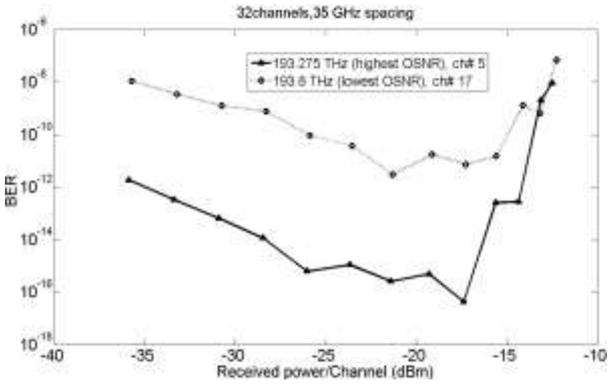

Figure 6: BER vs received power at 32 channels, 35 GHz spacing for ch# 5, 17

Table 4: BER and Q for 64 channels and 50 GHz spacing

L.P(dBm)	193.1 THz (highest OSNR),channel no, 1			195.65 THz (lowest OSNR),channel no. 52		
	R.P(dBm)	BER	Q-factor	R.P(dBm)	BER	Q-factor
-20	-35.871	$0.3576x10^{-9}$	6.16	-35.881	$0.7566x10^{-18}$	8.78
-17.5	-33.401	$0.28x10^{-10}$	6.55	-33.412	$0.2546x10^{-18}$	8.91
-15	-30.952	$0.2108x10^{-11}$	6.93	-30.968	$0.9125x10^{-21}$	9.51
-12.5	-28.542	$0.1966x10^{-13}$	7.563	-28.565	$0.1874x10^{-21}$	9.678
-10	-26.195	$0.377x10^{-15}$	8.061	-26.23	$0.6376x10^{-23}$	10.018
-7.5	-23.95	$0.2331x10^{-16}$	8.39	-24.008	$0.1726x10^{-24}$	10.36
-5	-21.852	$0.3237x10^{-15}$	8.08	-21.828	$0.6271x10^{-25}$	10.4652
-2.5	-20.085	$0.5197x10^{-15}$	8.022	-19.973	$0.2404x10^{-23}$	10.113
0	-18.412	$0.9691x10^{-17}$	8.497	-18.358	$0.3466x10^{-18}$	8.876
2.5	-17.204	$0.6811x10^{-11}$	7.4003	-17.247	$0.4426x10^{-18}$	8.84
5	-16.072	$0.3737x10^{-11}$	6.848	-16.002	$0.1575x10^{-10}$	6.639
7.5	-15.147	$0.1616x10^{-6}$	5.1085	-15.136	$0.2641x10^{-15}$	8.1052
10	-14.749	$0.7975x10^{-9}$	6.034	-14.335	$0.7271x10^{-12}$	7.079
12.5	-13.912	$0.7753x10^{-7}$	5.245	-13.852	$0.1555x10^{-14}$	7.8871

** L.P Launched power, R.P Received power.

Table 5: BER and Q for 32 channels and 35 GHz spacing

L.P(dBm)	193.275THz (highest OSNR),channel no. 5			193.8 THz (lowest OSNR),channel no.17		
	R.P(dBm)	BER	Q-factor	R.P(dBm)	BER	Q-factor
-20	-35.866	$0.18503x10^{-11}$	6.948	-35.701	$0.1085x10^{-7}$	5.597
-17.5	-33.381	$0.3335x10^{-12}$	7.1868	-33.216	$0.3509x10^{-8}$	5.79
-15	-30.908	$0.6549x10^{-13}$	7.4031	-30.744	$0.1263x10^{-8}$	5.959
-12.5	-28.456	$0.1154x10^{-13}$	7.632	-28.293	$0.77x10^{-9}$	6.039
-10	-26.038	$0.6286x10^{-15}$	7.999	-25.877	$0.9304x10^{-10}$	6.372
-7.5	-23.68	$0.1121x10^{-14}$	7.928	-23.523	$0.3641x10^{-10}$	6.515
-5	-21.412	$0.26305x10^{-15}$	8.1057	-21.298	$0.3052x10^{-11}$	6.8775
-2.5	-19.287	$0.4972x10^{-15}$	8.0284	-19.119	$0.1728x10^{-10}$	6.6256
0	-17.366	$0.4291x10^{-16}$	8.3232	-17.265	$0.7202x10^{-11}$	6.7542
2.5	-15.606	$0.2545x10^{-12}$	7.2229	-15.568	$0.1551x10^{-10}$	6.6424
5	-14.333	$0.2844x10^{-12}$	7.207	-14.089	$0.1297x10^{-8}$	5.9553
7.5	-13.111	$0.2087x10^{-8}$	5.87	-13.169	$0.64601x10^{-9}$	6.06
10	-12.477	$0.9242x10^{-8}$	5.625	-12.256	$0.6945x10^{-7}$	5.266

**L.P Launched power, R.P Received power.

4.6 64channels, 35 GHz channel spacing:

The data representing BER and Q for 64 channels and 35 GHz spacing are shown in table 6 and figure 7. The BER and Q-factors were observed for two channels at frequencies 195.305 THz (highest OSNR, channel no.26) and 194.325 THz (lowest OSNR, channel no.16). For lowest value of launched power, the recorded BERs at two channels were $0.2364x10^{-13}$ and $0.1092x\ 10^{-10}$ respectively. The lowest BER was observed for a launched power of -2.5 dBm and at a received power of -20.215 dBm which was $0.8258x10^{-18}$, with a Q-factor of 8.778 and a jitter of 0.01732. The BER at other channel was $0.1837x10^{-12}$, with a Q-factor of 7.268 and a jitter of 7.268. This system transmits 24 more channels and its BER performance 10^6 and 10^3 times smaller as compared to [16] and needs nearly 5.2 dBm lesser power. Similarly, the system has a same better BER performance as compared to [15], but needs 2.5 dBm more power. With further increase in launched power the BER performance degraded and finally at a received power of -16.026 dBm (launched power 5 dBm), the BER became $0.4189x10^{-8}$ on the 194.325 THz channel.

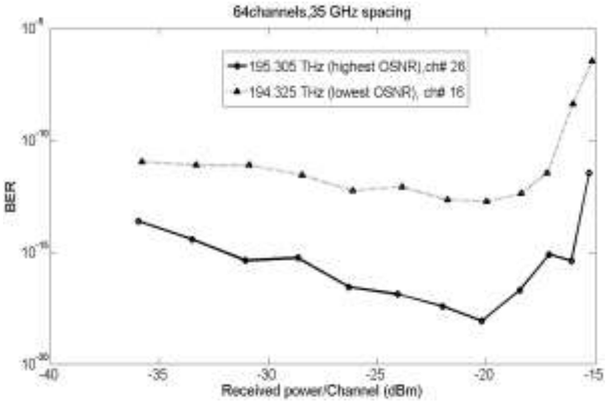

Figure 7: BER vs received power at 64 channel 35 GHz spacing for ch# 26, 16

Table 6: BER and Q for 64 channels, 35 GHz spacing

L.P(dBm)	195.305 THz(highest OSNR),ch#26			194.325 THz (lowest OSNR),ch#16		
	R.P(dBm)	BER	Q-factor	R.P(dBm)	BER	Q-factor
-20	-35. 957	$0.2364x10^{-13}$	7.5395	-35.791	$0.1092x10^{-10}$	6.693
-17.5	-33.488	$0.3665x10^{-14}$	7.779	-33.32	$0.76003x10^{-11}$	6.746
-15	-31.042	$0.4227x10^{-15}$	8.04	-30.872	$0.7588x10^{-11}$	6.746
-12.5	-28.635	$0.549x10^{-15}$	8.016	-28.461	$0.2718x10^{-11}$	6.893
-10	-26.295	$0.2721x10^{-16}$	8.3773	-26.115	$0.5575x10^{-12}$	7.116
-7.5	-24.061	$0.1308x10^{-16}$	8.463	-23.870	$0.8252x10^{-12}$	7.0621
-5	-21.99	$0.3785x10^{-17}$	8.6067	-21.777	$0.2158x10^{-12}$	7.245
-2.5	-20.215	$0.8258x10^{-18}$	8.778	-19.976	$0.1837x10^{-12}$	7.268
0	-18.47	$0.194x10^{-16}$	8.417	-18.395	$0.4072x10^{-12}$	7.159
2.5	-17.109	$0.7819x10^{-15}$	7.972	-17.198	$0.3418x10^{-11}$	6.8616
5	-16.096	$0.3969x10^{-15}$	8.056	-16.026	$0.4189x10^{-8}$	5.7598
7.5	-15.274	$0.3363x10^{-11}$	6.863	-15.149	$0.3374x10^{-6}$	4.968

** L.P Launched power, R.P Received power.

4.7 32 channels on different channel spacing:

The corresponding curve showing the BER vs received power per channel for 32 channels on different channels is shown in figure 8. The following channels 26, 12, 5 were plotted for 100 GHz, 50 GHz, 35 GHz respectively. It was analyzed that to reach the same BER, the lower channel spacing required more amount of received power (comparing 50 GHz to 100 GHz). 32 channel communication system at 100 GHz spacing reached the lowest BER of $0.99x10^{-40}$ at a received power of-30.87 dBm, while the same system at 50 GHz. spacing reached the lowest BER of $0.99x10^{-40}$ at a received power of -19.308 dBm. This clearly shows that 50 GHz spacing requires somewhat 11.5 dBm more power to obtain a very low BER. The increased requirement of received power can be interpreted as; the receiver now requires more photons per bit for their correct detection to overcome the crosstalk induced penalty. The 35 GHz spacing system could not reach such low BER, its lowest value was of the order of 10^{-16} for a received power of -26.295dBm. So, it can be concluded that the 32 channels at 100 GHz is best in terms of receiver sensitivity, it can obtain very low BER for a much less received power as compared to other channel spacing.

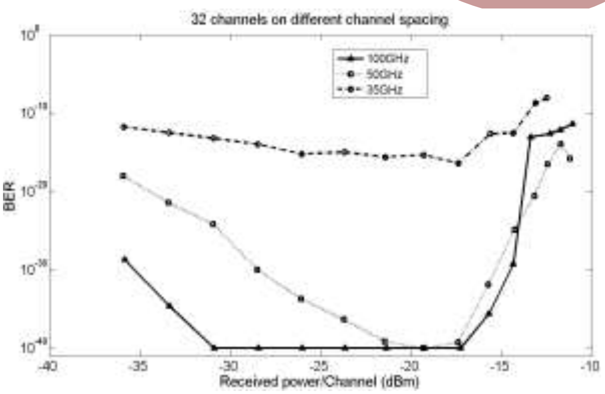

Figure 8: : BER vs received power at 32 channels on different channel spacing

The50 GHz spacing can obtain the same lowest BER but requires higher number of photons per bit for correct detection to counter the effects of crosstalk due to FWM and other nonlinearities. The 35 GHz system has much poorer receiver sensitivity although acceptable in terms of BER as compared to 100 GHz system.

4.8 64 channels on different channel spacing:

The corresponding curve of BER vs received power per channel is shown in figure 9. The following channels 18, 52, 16 are plotted for 100 GHz, 50 GHz, 35 GHz spacing. As the numbers of channels are increased to 64, the dependence on channel spacing was slightly different from 32 channels. The system with 100 GHz is highly sensitive. Its lowest BER is $0.99x10^{-40}$, for a received power of -30.971 dBm which is nearly the same as the 32 channel system with 100 GHz spacing. But as the spacing is decreased to 50 GHz, the lowest BER obtained was $0.6271x10^{-25}$ for a received power of –21.828 dBm. The lowest BER for 50 GHz system is of the order of 10^{15} times greater than 100 GHz system but still requires nearly 9 dBm more power than latter. The BER on 100 GHz spacing for lowest power sent was of the order of 10^{-27} (on the channel plotted, although it is more smaller on the other channel) for a received power of -35.9 dBm, is 10^{2} times smaller as compared to lowest BER on the 50 GHz spacing, however receiver sensitivity required to maintain such a performance was 14 dBm lesser for the latter. The 50 GHz spacing can obtain the same lowest BER but requires higher number of photons per bit for correct detection to counter the effects of crosstalk due to FWM and other nonlinearities. The 35 GHz system has much poorer receiver sensitivity as compared to 100 GHz system although it is acceptable in terms of BER. The system at 35 GHz spacing was poor out of the out of the three in terms of receiver sensitivity. The FWM and other nonlinearities have played their part on low channel spacing and cross talk induced due to them is the major reason for degradation of receiver sensitivity, while failing to maintain a low BER. So, it can be concluded that the 64 channel system at 100 GHz spacing is best in terms of receiver sensitivity. It can produce very low BER for very less received power, the sensitivity degrades with further decrease in channel spacing.

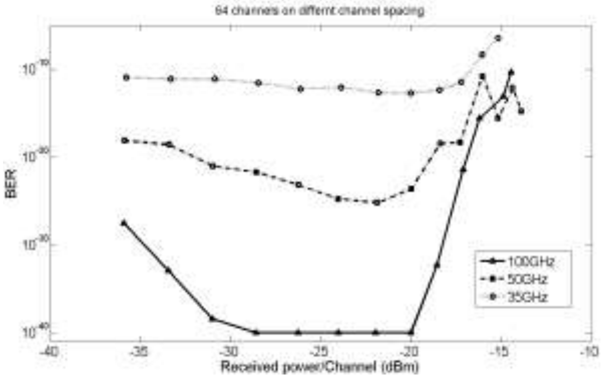

Figure 9: BER vs received power at 64 channels on different channel spacing

4.9 Important observation:

It was seen in every graph that with increase in launched power, the BER decreases, reaches a lowest level and then increases and eventually increases above 10^{-9}. This behavior can be explained as follows.

The BER of an optical communication system is given by

$$BER = 1/2\, erfc\sqrt{\eta N_P/2}$$

Where η is quantum efficiency and N_P is is number of photons per bit for correct detection.

Clearly it can be observed from the above equation, the BER decreases as number of photons per bit increases. As the input launched power is increased, the number of photons incident on the receiver increases which results in decrease in BER in the initial part of the curves and the system reaches the lowest value of BER attained by the system.

After the lowest BER attained, as the input launched power is increased. There are two counter acting effects. One is increase in number of photons per bit, which tends to decrease the BER and the other are the various non linear effects. These effects includes saturation induced self phase modulation, Four wave mixing (FWM) and cross gain modulation. In saturation induced self phase modulation, the gain saturation leads to time dependent phase shift across the pulse, this leads to self phase modulation and results in chirping. In cross gain modulation, the saturation of one channel while transmission through an SOA depends not only on the channel itself but on the optical powers in other neighboring channels also. Thus saturation of a channel depends on the bit pattern of neighboring channels. This leads to gain fluctuations and degrades the effective SNR at the receiver. The combination of all these effects leads to degradation of BER at the receiver with increase in input launched power.

5. CONCLUSION:

We started with a goal to see the performance of the optimized SOA as a preamplifier for different channel spacing and number of channels. It was seen that very low BERs are achievable with this pre amplifier. 100 GHz channel spacing is highly receiver sensitive, the system based on the preamplifier can easily achieve BER of 0.99×10^{-40} for very low received powers of around -30.9dBm (launched power of -15 dBm) for both 32 and 64 channels. Similarly for 50 GHz spacing, the system was again able to achieve the BER of 0.99×10^{-40} for a received power of -19.3 dBm (launched power -2.5 dBm), although only for 32 channels, 50 GHz; the system achieved a BER of 0.6271×10^{-25} for a received power of -21.8dBm (launched power of-5 dBm), although larger than 32 channels, but still an impressive performance. For 35 GHz spacing, the system was not able to achieve very low BERs but still of the order of 10^{-18} for a received power of -20.2 dBm (launched power -2.5 dBm) at 64 channels. Similarly the lowest BER for 32 channels and 35 GHz spacing was of the order of 10^{-16} for a received power of -17.3 dBm (0 dBm launched power). In every channel spacing the performance of the system was better as compared to work reported in [15], [16]. It was seen and intuitively expected that as the channel spacing was decreased the BER increased and required higher amount of power to achieve low BERs especially for 32 channel system. The system with 100 GHz spacing was best in terms of receiver sensitivity, it can obtain very low BERs with very less received powers, but as the channel spacing is decreased, the receiver sensitivity degrades. For 64 channels, the 100 GHz system is again best in terms of receiver sensitivity while 50 GHz system has higher BERs and is poorly sensitive as compared to the latter. With further increase in power the system indicated an increase in BER due to non-linear effects. The system with lower channel spacing and higher channels became useless (BER more than 10^{-9}) for a lesser launched power. If the system set up is operated on 25 GHz spacing the performance deteriorated due to large non linear effects. The best performance can be obtained up to 35 GHz channel spacing.

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