Investigation and Analysis of Hybrid Optical Amplifiers under Four Wave Mixing

[1]Daljinder Kaur, [2]Gurinder Singh

[1]M.tech Student, [2]Assistant Professor

[1]Department of electronics and communication,

[1]Ludhiana College of engineering and technology (LCET), India

Abstract : Amplification through Hybrid optical amplifiers (HOAs) is a promising and competent technology for pacy and high capacity DWDM (Dense wavelength-division-multiplexing) systems. Hybrid optical amplifiers are proposed to get better reach as well as to achieve wide gain bandwidth. In this work, diverse arrangements of amplifiers such as EDFA, SOA and RAMAN are considered for amplification in an ultra dense WDM system with channel spacings of 25 GHz. Investigation has been done for 16, 32 channels and performance is evaluated in terms of output power, Q-factor, and BER. Frequency spacing is 25 GHz to provide greater bandwidth efficiency and scrutinized its effect on FWM (Four wave mixing) in three different cases such as EDFA-EDFA, Raman-EDFA and SOA-EDFA. It is perceived that effect of FWM is greater on the SOA-EDFA arrangement and less on the Raman-EDFA. It is evident from the results that RAMAN-EDFA is best for the distance from 20 Km to 140 Km and SOA-EDFA exhibits best performance for distance of 150 Km to 200 Km. For large distances such as more than 200 Km, erbium doped amplifier-erbium doped amplifier (EDFA-EDFA) is optimal HOA Moreover, analysis of different modulations formats such as non-return to zero (NRZ) and return to zero (RZ) also has been done.

Keywords-Hybrid optical amplifier, Erbium doped fiber amplifier, Raman amplifier, Return to zero, Non-return to zero

I. Introduction

Nowadays, technological development, a period noticeable by augmentation of multimedia services and wavelength division multiplexing based communication systems, has set increase to high capacity WDM optical net-works. Also, multichannel technology has proved to be a most important advancement for sufficing the requirement for ever-increasing number of WDM channels as well as transmission reach [1]. Major advantage of the optical amplifiers is that they replace the need of repeaters in the optical transmission line. Repeaters basically perform electric to optical conversion and vice versa for the regeneration of the incoming signal, however, it deteriorates the performance due to E/O conversions. So, prolonged reach systems makes use of wide band optical amplifiers. Optical transmission systems suffer from mainly two types of issues such as linear and nonlinear. Linear issues are dispersion and attenuation and nonlinear are FWM (Four wave mixing), SPM (self phase modulation) etc. Optical amplifiers were came into use as they openly strengthen optical signals devoid of any alteration from O to E, consequently, keeping the bandwidth by successfully augmenting the strength of the signal. RAMAN, Erbium doped (EDFA) and semiconductor optical amp. (SOA) are some examples of typically used amplifiers, each one, by means of its own individual benefits as well as limitations. For the amplification, through Raman amplifiers, principle of Stimulated Raman Scattering is used which can be controlled through the pump power and the wavelength region [2,3]. SOA offers power boosting of weak signals in the range of 1310 nm–1550 nm. It is contributing to wide amplifications bandwidth but its action restricted to 10 Gbps. Crosstalk and dependency of SOA on polarization, prone it to the different noises. It was recommended in the literature that SOA should be used for small links because it provides less gain and large signal level fluctuations. For the conventional band region, EDFA is used for high speed and prolonged transmissions.

In order to improve the bandwidth use and make best use of the amplifiers, to cover the large transmission length, wideband HOAs (hybrid optical amplifiers) are demonstrated in [4,5]. By deploying RAMAN-EDFA configuration as a HOA, 90.5 nm flatness of gain has been attained till the link length of 50 km [6]. Configurations in HOA can be using SOA, Raman and EDFA parallel or in serial. HOA configurations can be employed in parallel, signals are separated first using a coupler and after that passed through amplifiers placed in each arm. This arrangement is comparatively uncomplicated and suitably appropriate but it is noticeable with a limitation that the guard band for the coupler leads to unusable wavelength. Series arrangements of amplifiers are also used and need no coupler. HOAs can be placed prior to fiber i.e pre, after fiber i.e post and middle of the link as symmetrical amplifier [7]. Numerous investigations has been done using optical amplifiers and HOAs as reported in [8] [9] [10] [11]. It was concluded that EDFA amplifier performs best in C-band multichannel systems and Raman amplifier performs good in L-band region.

This paper accentuated on the performance investigation and utilization of the available bandwidth by reducing frequency spacing to 25 GHz and increasing the number of channels to 16, 32. Moreover, different hybrid optical amplifiers are investigated in terms of performance under the effects of Four wave mixing.

II. System Setup

Figure 1 depicts the block diagram of proposed 16 channels and 32 channels wavelength division multiplexed system and is proposed at ultra dense frequency spacings of 25 GHz. Due to the several advantages of C-band region over other frequency bands, wavelengths from 1552.52 nm are used in the work. Continuous wave lasers are considered from 193.1 THz to 193.475 THz with input power of 0 dBm at each transmitter as shown in Table 1. In this work, power 0 dBm is taken because less nonlinear effects can occur at low incident power levels. Pseudo random bit sequence generator is employed to do a task of binary data generation at

10/20 Gbps. For the pulse shaping of binary data streams, linecoder such as non return to zero and return to zero are used in two different cases. Electrical to optical conversion is accomplished by using intensity modulator such as MZM which has two input ports. One port is getting drive from laser source and other from NRZ/RZ pulse format. MZM is operated in the peak point to get enhanced carrier and low sidebands. An ideal multiplexer combines the wavelength that comes from transmitters to one output signal. Diverse signal depicters are employed to access the signals and optical spectrum analyzer is one of them which is used to check the carrier signal.

Table 1.1 System parameters

Parameter	Values
Input Power	0 dBm
Frequencies	193-193.475 THz
Frequency spacing	25 GHz
Laser Linewidth	10 MHz
Data rate	10 Gbps, 20 Gbps
Amplifiers	EDFA, SOA, Raman
WDM channels	16 and 32
Linecodings	NRZ and RZ

Optical fiber standard model SMF-28 is considered for the work. Different combinations such as EDFA-EDFA, RAMAN-EDFA and SOA-EDFA are taken to accomplish the investigation of ultra dense high capacity system. Moreover, a kerr based nonlinear effect Four wave mixing is analyzed for different hybrid amplifier arrangements.

A de-multiplexer separates the signals according to the frequency of specific signal. Receiver consists of photo detector Avalanche with 1 A/W responsivity and 10 nA dark current. Low pass Bessel filter and it is followed by a 3-R regenerator. Bit error rate analyzer is decision making component that shows Q factor and BER. EDFA with 12 dB gain and 4.5dB noise power is used in the system and values kept fixed during the analysis. SOA amplifier has numerous parameters values such as length (3e-006 meter), insertion loses (3dB), height (8e-008 meter), injection current (0.1 Ampere), width (3e-006 meter). Raman amplifier with optical fiber length 10 Km as well as pump of 250 mW and pump wavelength 1480 nm is used. Pre and post configuration of amplifiers is considered in the work to combat with the attenuation issues.

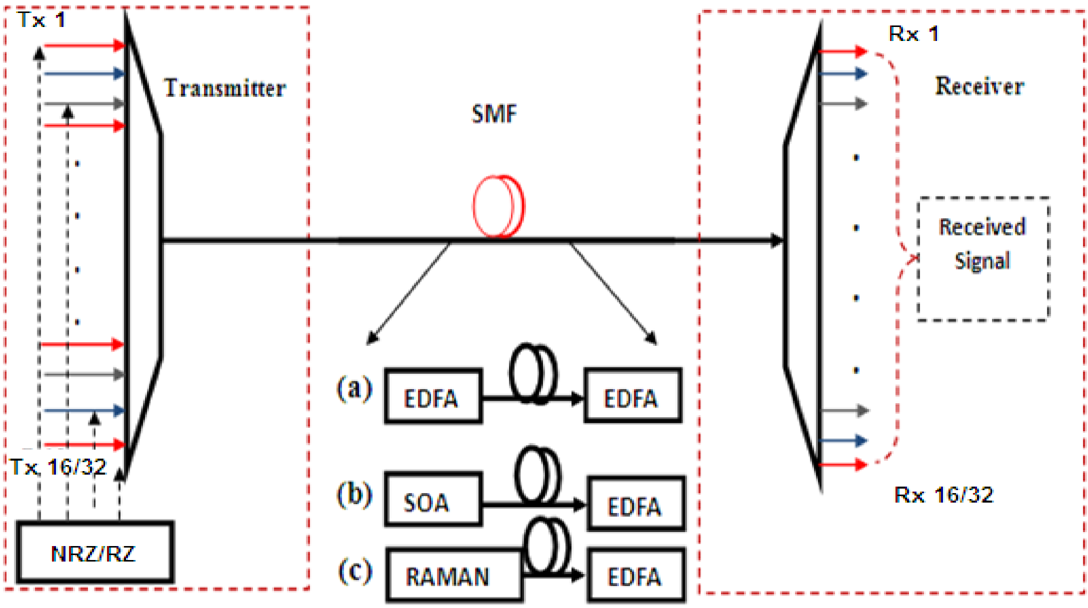


Figure 1 Block diagram of 16/32 channels WDM system with HOAs

III. RESULTS AND DISCUSSIONS

In investigation of WDM system at ultra dense freq. spacing for long reach has been performed with diverse hybrid optical amplifiers. Two cases of are considered by taking 16 channel in one and 32 channels in other. Results are analyzed in terms of output power of the diverse HOAs, Q factor and BER. As mentioned in the system setup, optical spectrum is incorporated in the system to check the carrier signals. It represents the power level of the carriers and also depicts the wavelengths of carriers. Two OSAs are employed in the link before and after the optical fiber. It is noteworthy that FWM is analyzed from the OSAs in diverse hybrid optical amplifiers as shown in Figure 2 (a), (b), (c), (d). Analyzed power of FWM peaks is greatest in case of SOA-EDFA arrangement (-46.32 dBm) and least for the Raman-EDFA (<-95 dBm). But EDFA-EDFA shows the moderate FWM peaks. It is suggested from the analysis that use of RAMAN-EDFA arrangement is beneficial in the systems where input power is high because this arrangement shows least FWM peaks.

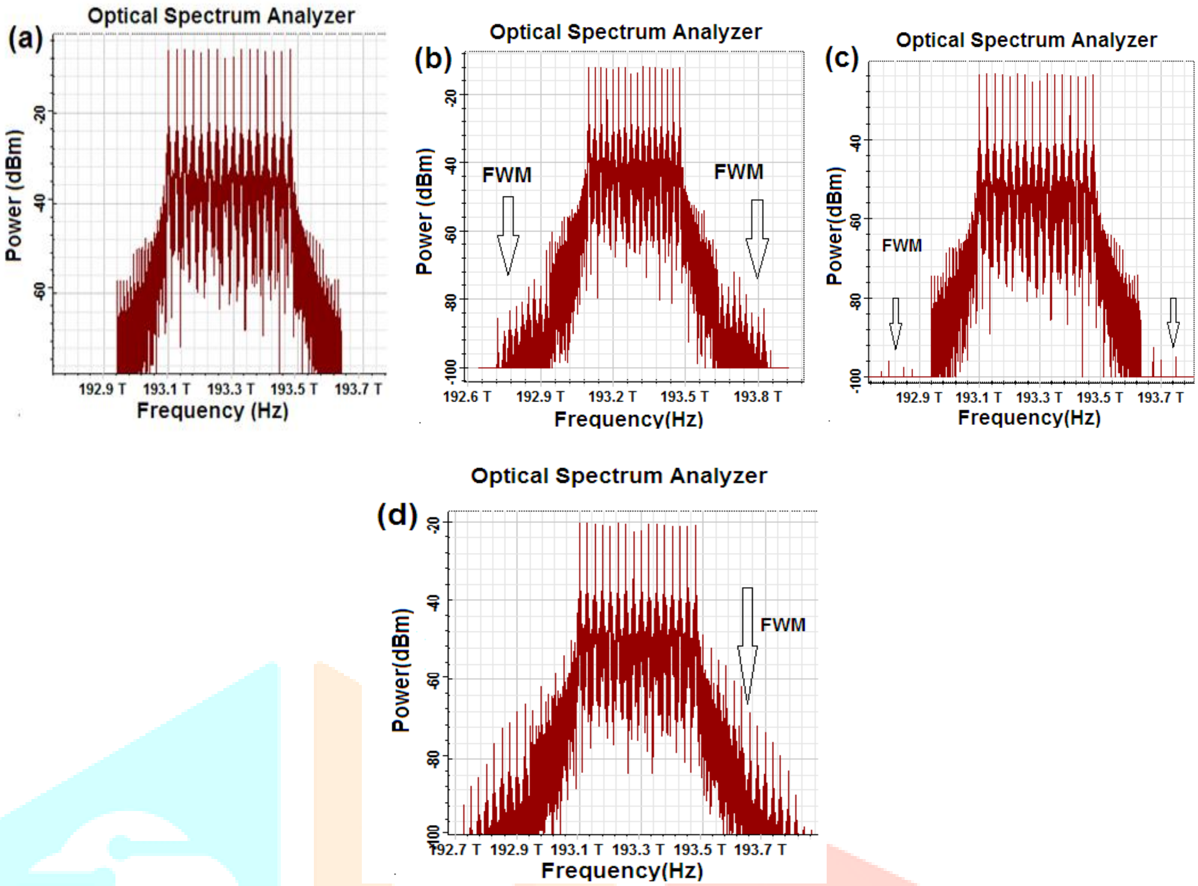


Figure 2 OSA for (a) WDM transmitter and after 150 Km for (b) E-E (c) R-E (d) S-E

Distance of the optical fiber is altered from 1 Km to 300 Km and attenuation of fiber is 0.2 dB/Km with effective area 80μm^2. Figure 3 depicts the distance variations effects on output power obtained for 16-channel WDM system using HOAs. Results revealed that with the distance enhancement, there is loss in the total output power for all hybrid optical amplifier configurations. Attenuation and pulse broadening is a major cause of the performance deterioration. Also, 25 GHz freq. spacing is too dense that it impacts the signal power due to power coupling. In terms of output power, EDFA-EDFA provides greatest output and Raman-EDFA gives least outputs. After distance of 250 Km, all arrangements of HOAs show almost close values of Pout (output power). EDFA is important and most suitable amplifier in Conventional-band. On the other hand, semiconductor optical amplifier shows fluctuations till 100 km due to carrier density pulsation and refractive index change and introduce nonlinear effects at high powers. After power loss due to attenuation, it amplifies the signal to better level but even then falls below EDFA-EDFA

Table 2 P_{out} vs distance for 16 WDM channels

Distance (Km)	EDFA-EDFA (dB)	RAMAN-EDFA (dB)	SOA-EDFA (dB)
1	32.77	21.23	24.15
50	22.97	11.45	14.36
100	12.99	1.65	4.46
150	3.13	-6.74	-4.62
200	-5.67	10.62	-10
250	-10.33	-11.3	-11.22
300	-11.26	11.37	-11.36

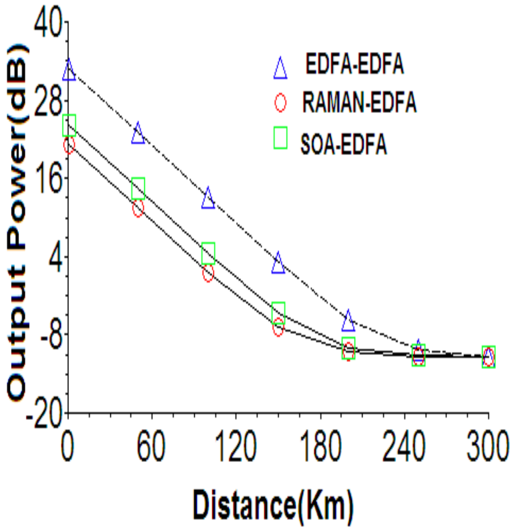


Figure 3 Output power of 16 WDM system at varied distances

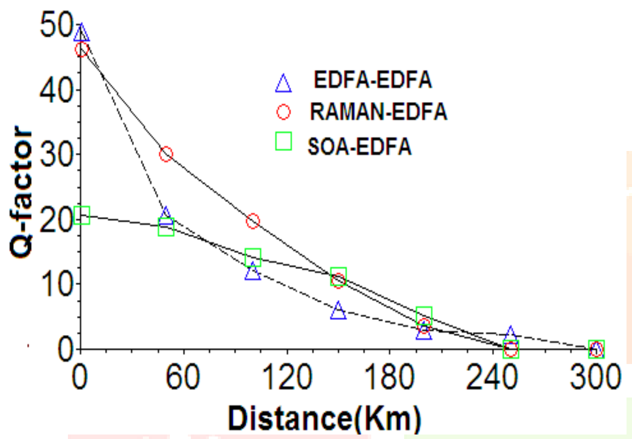
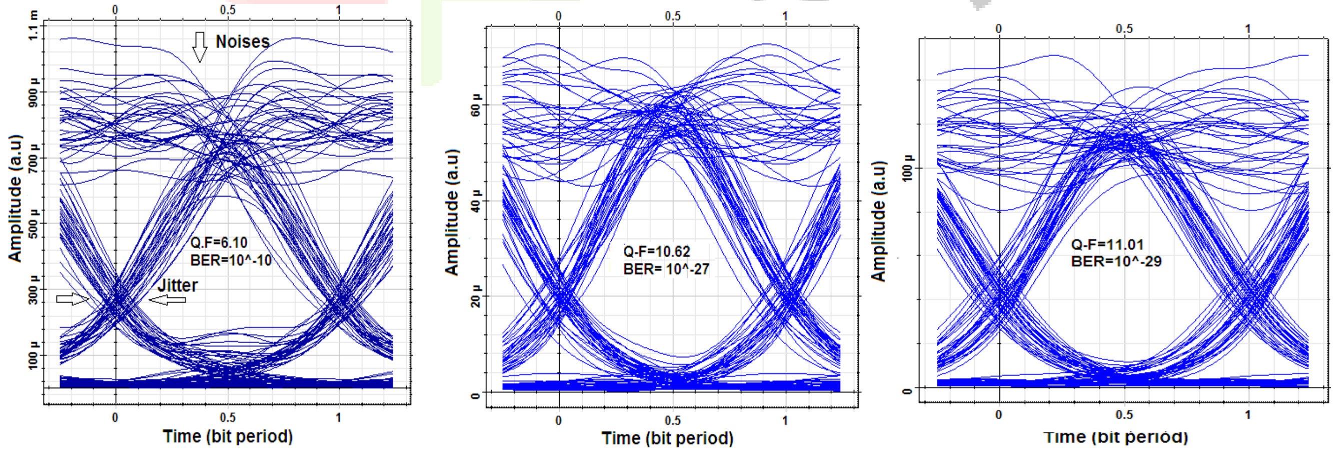


Figure 4 Variation of Q with distance in 16 Channels WDM system

Table 3 Q-versus distance in 16 WDM system

Distance(Km)	EDFA-EDFA	RAMAN-EDFA	SOA-EDFA
1	48.81	46.24	20.65
50	20.6	29.99	18.83
100	12.08	19.74	14.22
150	6.1	10.62	11.01
200	2.83	3.69	5.23
250	2.19	0	0
300	0	0	0

Investigation is performed to check the Q factor of the diverse amplifiers at varied link lengths of optical fiber. Investigation analysis reveals that Raman-EDFA provides highest Q factor owing to least FWM as depicted in Figure 4. In order to cover prolonged distances, EDFA-EDFA is the right choice. Performance of SOA-EDFA is fluctuating from 50 km to 200 Km and deteriorates for longer link lengths. This is due to nonlinear effects of SOA. Table 1.3 shows the values of Q-factor at different distances.



(a) (b) (c)

Figure 5 Eye diagrams for 16 channels WDM system using (a) E-E (b) R-E (c) S-E at 150 Km

Figure 5 shows the Eye diagram of system and is a decisive analyzer that compute the errors, Q-factor, SNR, eye closer, eye opening etc. Enhanced Q factor is obtained due to wide eye opening with lesser no. of errors at distance of 150 Km for SOA-EDFA. Values Form the analysis of aforementioned configuration, Quality and BER obtained is 11.01 and $2.1x10^{-29}$ respectively. In EDFA-EDFA and Raman-EDFA, Q, BER respectively observed are 6.10, 10^{-10} and 10.62, 10^{-27} at 150 km. Figure 6 shows the effect of NRZ and RZ linecodings on the proposed system over diverse link lengths of SMF-28 in terms of Q-factor. It is perceived that with the increase in the distance, from 1 km to 300 km, there is degradation in the Q factor of NRZ and RZ due to pulse broadening, nonlinear effects and attenuation. Because of the bandwidth efficiency of non return to zero, it surpasses the RZ linecoding performance. System can cover 200 km distance when RZ is used and it prolongs to 250 km in case of NRZ.

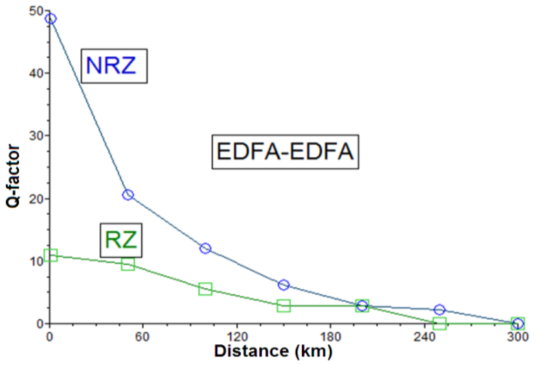


Figure 6 Q-factor vs distance of E-E using NRZ/RZ

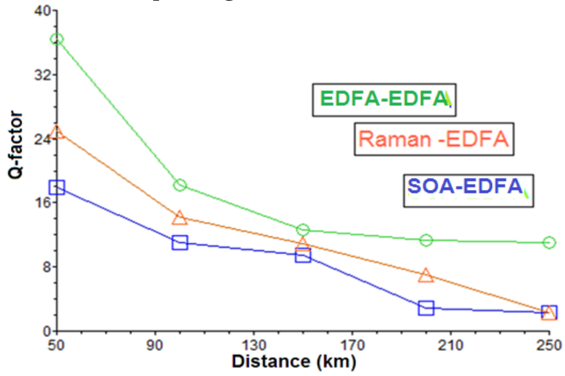


Figure 7 Q-factor vs distance for 32 WDM system

Figure 7 depicts the performance of 32 channels WDM system using diverse HOAs at distance from 50 km to 250 km. It is noteworthy that EDFA-EDFA configuration stands out and provide best Q factor over all the distance ranges followed by the Raman-EDFA performance. SOA-EDFA is least performing configuration. Therefore, again best choice of HOA in 32 WDM system comes out to be EDFA-EDFA.

Figure 8 represents the impact of diverse bit rates on the ultra dense WDM system using best HOA arrangement i.e. EDFA-EDFA. It is evident that bit rate increase, reduces the time slot of thebits and due to this, errors increases. At short bit slots, dispersion made very serious degrading effects. Time of bit slot can be calculated as:

$$T_B = \frac{1}{Bit\ rate}$$

Let us consider an example that time slot for 10 Gbps is 0.1 ns and if double the bit rate to 20 Gbps, time slot reduces to its half i.e. 0.05 ns. Therefore, it is observed that performs of system is better at 10 Gbps as compared to 20 Gbps.

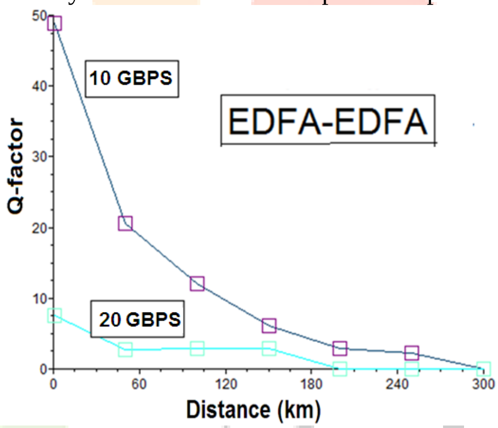


Figure 8 Q-factor vs distance WDM system at different bit rate for EDFA-EDFA

IV. CONCLUSION

Work is accomplished for the performance evaluation of diverse HOAs such as EDFA-EDFA, SOA-EDFA and RAMAN-EDFA in UWDM system using the capacity 16 x 10 Gbps and 32 x 10 Gbps. Parameters for the investigation are considered Q-factor, BER, Output power. Four wave mixing is well-known cause of signal deprivation in multi-channel systems, therefore a best suited amplifier configuration is recommended in this work. It is perceived that SOA-EDFA arrangement system is extra prone to FWM and Raman-EDFA is less vulnerable to the nonlinear effect. Output power in three different cases is observed as 32.77dBm (E-E), 24.15dBm (S-E) and 21.23dBm (R-E) at 1 Km for 16 WDM channels. Q factor and BER in three different cases is attained as 6.1, 10^{-10} (E-E), 10.62, 10^{-27} (R-E) and 11.01, 10^{-29} (S-E) at 150 Km. It is also observed that EDFA-EDFA is best amplifier for longer distances. Out of the comparison of NRZ and RZ, former one came out to best and also 10 Gbps data rate provides better results as compared to 20 Gbps.

REFERENCES

[1] H.S. Seo, J.T. Ahn, W.J. Chung, A Noval Hybrid silica wide band amplifier covering S + C + L bands with 105 nm bandwidth, Photon. Technol. Lett. 17 (9) (2005) 1830–1832.
[2] N. Singh, M. Kumar, A. Verma, “Automatic Gain-Controlled HOA with Residual Pumping”, Journal of optical communications, https://doi.org/10.1515/joc-2017-0185, 2017.
[3] V. Bobrovs, A. Alsevska, S. Olonkins, L. Gegere, G. Lvanovs, Comparative performance of Raman-SOA and Raman-EDFA hybrid optical amplifiers in DWDM transmission systems, Int. J. Phys. Sci. 8 (39) (2013) 1898–1906.
[4] Surinder Singh, R.S. Kaler, Placement of hybrid optical amplifier in fiber optical communication system, Optik 119 (6) (2011) 296–302.
[5] H.S. Chung, J. Han, K. Kim, S.H. Chang, A Raman plus linear optical amplifier as an inline amplifier in a long-haul transmission of 16 channels × 10 Gbps over single mode fiber of 1040 km, Opt. Commun. (2005) 141–145.

[6] Fathy M. Mustafa, Ashraf A.M. Khalafand, F.A. Elgeldawy, Multi pumped Raman amplifier for long haul UW-WDM optical communication system: Gain flatness and bandwidth enhancements, Proceedings of the 15th International Conference on Advanced Communication Technology (2013) 122–127.
[7] H. Masuda, K. Aida, S. Kawai, Ultra wideband hybrid amplifier comprising distributed Raman amplifier and erbium doped fibre amplifier, Electron. Lett. 34 (13) (1998) 1342–1344.
[8] S. Singh, R.S. Kaler, Amanpreet Singh, Performance evaluation of EDFA, RAMAN and SOA optical amplifier for WDM systems, Optik 124 (2013) 95–101.
[9] S. Singh, R.S. Kaler, Hybrid optical amplifiers for 64 × 10 Gbps dense wavelength division multiplexed system, Optik 124 (2013) 1311–1313.
[10] J. Helina Rajini, S. Tamil Selvi, Performance analysis of hybrid optical amplifier for 64 × 10 Gbps DWDM systems, Asian J. Appl. Sci. 8 (1) (2015) 46–54.
[11] Ramandeep Kaur, Rajneesh Randhawa, R.S. Kaler, Performance evaluation of optical amplifier for 16 × 10, 32 × 10 and 64 × 10 Gbps WDM system, Optik 124 (2013) 693–700.