Performance analysis of different hybrid optical amplifiers under the effects of FWM

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Abstract : ***Amplification through Hybrid optical amplifiers (HOAs) is a propitious and proficient technology for high speed and high capacity dense wavelength-division-multiplexing (DWDM) systems. HOAs are intended to improve system reach and to accomplish wide gain bandwidth with enhanced flatness of gain. In this work, an ultra dense 16, 32 channel WDM systems are demonstrated and performance of diverse hybrid amplifiers is evaluated in terms of output power, Q-factor, Gain flatness and BER. Spacing among the WDM channels is 25 GHz in order to make system bandwidth efficient and scrutinized its effect on Four wave mixing in case of EDFA-EDFA, Raman-EDFA and SOA-EDFA. It is observed that SOA-EDFA is more prone and Raman-EDFA is less prone to FWM. Moreover, for distance 20 Km to 140 Km, Raman-EDFA is optimal configuration for amplification and from 150 Km to 200 Km, SOA-EDFA shows better performance. For prolonged link lengths such as beyond 200 Km, EDFA-EDFA is a right hybrid amplifier. In order to achieve maximum Gain flatness in proposed architecture, EDFA-EDFA is recommended to use. Moreover, analysis of different modulations formats such as non-return to zero (NRZ) and return to zero (RZ) also has been done.***

IndexTerms - HOA, NRZ, RZ, EDFA, SOA, Raman amplifier

I. INTRODUCTION

In today's age of technological advancement, an era marked by growth in multimedia services and multichannel communication systems, has given rise to high capacity optical net-works. WDM has proved to be a major breakthrough for sufficing the need for increasing number of channels and transmission capacity of the system [1]. Long distance transmission makes use of high speed data transmission and larger bandwidth to enlarge the area coverage, avoiding the use of repeaters by employing optical amplifiers. These networks are sensitive to fiber nonlinearities, dispersion and attenuations. Prior to the use of optical amplifiers, regenerators were used requiring the conversion of signals from one domain to the other. Such conversions required high speed electronic equipments, hence, not always feasible. Thus, Optical amplifiers were brought to use as they directly amplify optical signals without any conversion from optical to electrical, thus, maintaining the bandwidth by effectively enhancing the signal strength. RAMAN, EDFA and SOA are some examples of conventionally used amplifiers, each, with its own respective benefits and drawbacks. Amplification in case of Raman amplifier is achieved via. Stimulated Raman Scattering relying on the appropriate pump power and pump wavelength. Broad spectrum of Raman amplifier is established by alternating the number of pumps and their respective wavelengths [2,3]. Semiconductor amplifier provides amplification in range of 1310 nm–1550 nm contributing to their broad amplifications bandwidth with its operation limited to 10 Gbps. It is polarization dependent with whopping noise figure and cross talk. SOA gives reduced gain and large signal distortion, hence, used for small scale networks. EDFA amplifier provides amplifications in 1550 nm optical window. EDFA is used for ultra long distance transmission. In order to enhance the bandwidth utilization and maximize the transmission length, hybrid optical amplifiers are introduced [4,5]. Employing Raman-EDFA hybrid amplifier, gain flatness of 90.5 nm has been achieved up to 50 km transmission distance [6]. Hybrid amplifiers can be referred to as, integration of EDFA, SOA and Raman amplifier either in parallel or in series configurations. In case of parallel arrangement, signals are first demultiplexed using a coupler and thereafter amplified on individual basis after which, the signals are again multiplexed with a coupler. This configuration is relatively simple and conveniently applicable but it is marked with a demerit that the guard band for the coupler leads to unusable wavelength. In series configurations wide band spectrum is obtained with no requirement of couplers. Hybrid amplifiers can be configured as pre, post and symmetric, based on their respective placements [7]. In [8], author examined different WDM systems and established that SOA gives better performance at dispersion D = 2 ps/nm/km with less number of channels being used ,whereas, performance of the system deteriorates as the number of channels increase. For relatively large number of channels and dispersion EDFA gives better results as compared to SOA. In [9], author established that Raman-EDFA hybrid optical amplifier yielded maximum output power (20.18 dBm) for dispersion D = 2 ps/nm/km at 160 km and applying various modulation techniques on hybrid optical amplifier yielded that RZ provides good Q factor (13.88 dB) with minimal eye closure (2.609 dB). Author in [10], demonstrated the performance of different hybrid amplifier for 64 × 10 Gbps DWDM system and inferred that EDFA-EDFA gives maximum output power. EDFA-EDFA-Raman gives better Q-value 26.22 dB at 50 km for NRZ. In the research [11], they investigated WDM systems with EDFA, SOA and Raman amplifier and compared their performance on the basis of dispersion and distance. It was found that when dispersion is small and for less number of channels, SOA gives improved results. But as increased in the dispersion and number of channels, EDFA gives superior results as compared to SOA. Raman amplifier gives superior results for L band spectrum and low output power as compared to other amplifiers.

This paper emphasizes on the efficient bandwidth utilization by increasing the number of employed channels to 16, 32 and reducing the channel spacing to 25GHz. We accentuated on the performance of different configuration of amplifiers such as EDFA, SOA and Raman amplifier in ultra dense WDM system. Proposed architecture is high speed and has high capacity WDM system, also investigated for hybrid amplifications under the impact of Four wave mixing (FWM). Effects of different modulation formats and data rates are also studied..

II. SYSTEM SETUP

For the realization of proposed system, Optiwave OptisystemTM a comprehensive simulation tool that allows simulating, test and plan communication systems in modern optical transmission layer is used. A 16/32 channel WDM system is demonstrated at ultra dense channel spacings of 25 GHz in order to make system bandwidth efficient as shown in Figure 1.1. Continuous wave lasers are operated in C-band

(1530nm-1570nm) due to minimum attenuation and scattering in this particular optical frequency window. Laser frequencies for this work are considered from 193.1 THz to 193.475 THz. Launched power for each channel is kept low and fixed at 0 dBm as shown in Table 1.1. A low input power is less prone to fiber nonlinear effects and therefore, required for optical transmission systems. Binary data stream is generated at 10 Gb/s and 20 Gbps by pseudo random bit sequence generator in the form of 1's and 0's followed by Non return to zero/ Return to zero line coder. NRZ/RZ is the pulse forms and deliberate energy to binary data for further transmission. Electrical data is modulated with the drive of laser and the external peak point biased MZM (Mach zehnder modulator). In order to enhance carrier and suppress sidebands, a maximum point biased MZM is placed by adjusting its bias voltages. Laser line width kept at 10 MHz due to realize a practical WDM system and polarization is fixed. A WDM equally spaced multiplexer, multiplexes all the tributaries from transmitter that are operating at different wavelengths. Optical spectrum depicter shows the carrier signal frequency with respect to power and placed after multiplexer to observe the data signals. Architecture performance and signals are analyzed time to time and for this work, power meters, WDM analyzers and optical time domain visualize are incorporated in the system.

Table 1.1 Proposed architecture specifications

Parameter	Values
Input Power	0 dBm or 1 mW
Frequencies	193-193.475 THz
Channel spacing	25GHz
MZM extinction ratio	30 dB
Data rate	10 Gbps, 20 Gbps
Amplifiers	EDFA, SOA, Raman

A single mode fiber (SMF-28) is considered with attenuation, dispersion and all nonlinear effects to obtain near to practical system. Hybrid amplifiers are investigated in WDM system to get optimal combination of amplifiers for future generation ultra dense high capacity system. Also, Four wave mixing is the major Kerr effect based nonlinearity that is analyzed for different hybrid amplifier arrangements. A demultiplexer is to filter and route specific wavelength to respective port for the final assessment of the data signals. Receiver consists of photo detector p-i-n with 1 A/W responsivity and 10 nA dark current with the consideration of shot and thermal noises followed by low pass Bessel filter as shown Figure 1.2. A 3-R regenerator employed for re sampling, re shaping and re amplification of the received data. Bit error rate analyzer is decision making component which calculate the final received quality, error, signal to noise ratio etc of the signals. Different arrangements of amplifiers are considered such as EDFA-EDFA, RAMAN-EDFA and SOA-EDFA for proposed architecture and their performance is investigated on terms of output power, BER and quality of signal passed through joint combinations of amplifiers. Erbium doped fiber amplifier with 12 dB gain and 4.5dB noise power is inserted in the system and values remained fixed throughout the work. SOA amplifier has several parameters values such as insertion loses (3dB), injection current (0.1 Ampere), length (3e-006 meter), width (3e-006 meter) and height (8e-008 meter). Raman amplifier of 10 Km and pump of 250 mW and pump wavelength 1480 nm is examined for one hybrid arrangement. Amplifiers are place in pre and post configurations in each arrangement to mitigate the effects of attenuation and act as power booster.

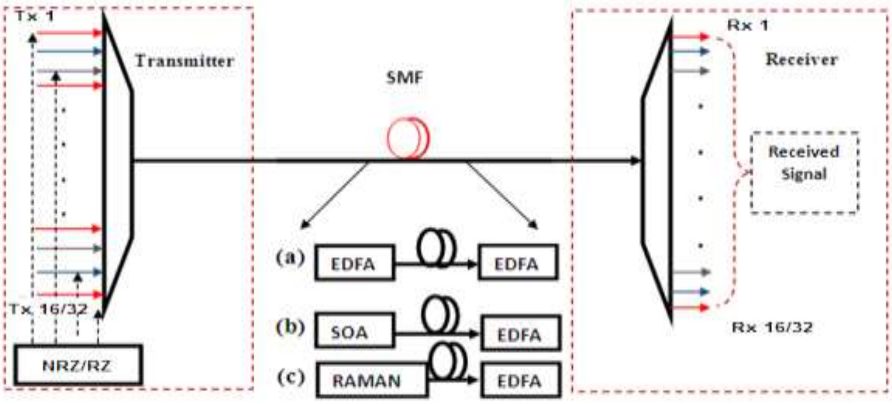


Figure 1.1 Proposed 16 channels WDM system and hybrid amplifier configurations

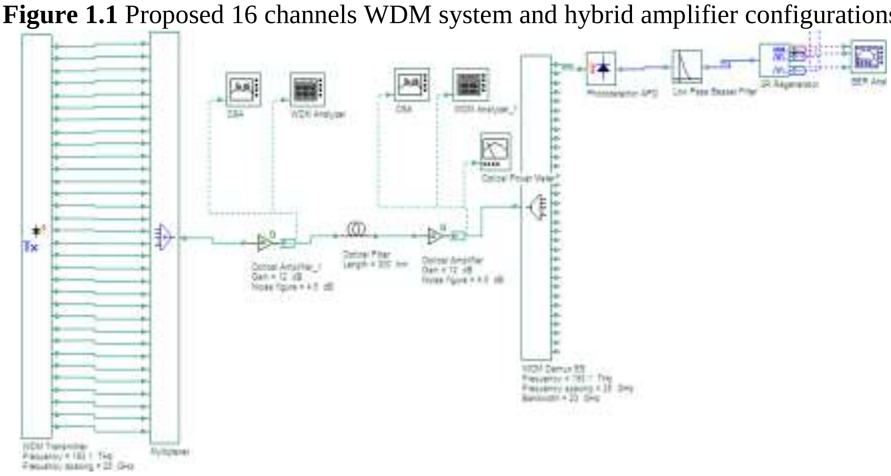


Figure 1.2 Simulation setup of WDM system and hybrid amplifier configuration

III. RESULTS AND DISCUSSIONS

In proposed 16 and 32 channels WDM architecture, performance of different configurations of EDFA, SOA and Raman amplifier is scrutinized as a hybrid power booster to perceive optimal configuration of amplifiers for prolonged distances. Investigation has been carried out to evaluate performance of hybrid amplifiers for ultra dense WDM system on the basis of output power, Q-factor and bit error rate. In order to examine the proposed architecture, distance of SMF-28 is varied from 1 Km to 300 Km. SMF-28 is a single mode optical fiber with 0.2 dB/Km attenuation at C- band and effective area 80µm^2. Optical spectrum analyzer (OSA) is incorporated after WDM multiplexer to analyze spectrum of carriers. OSA is a depiction tool that shows the carrier wavelength with respect to the power and placed both after multiplexer and amplifier stages to check FWM as shown in Figure 1.3 (a), (b), (c), (d) . FWM signals power is maximum in case of SOA-EDFA (-46.32dBm) and minimum in Raman-EDFA (less than -95 dBm). However, power of FWM signals is average in EDFA-EDFA and less than and greater than SOA-EDFA and Raman-EDFA respectively. It is recommended to use Raman-EDFA for high launched power systems for less four wave mixing because FWM is more at high powers as in case of WDM, where after multiplexing signal becomes very intense.

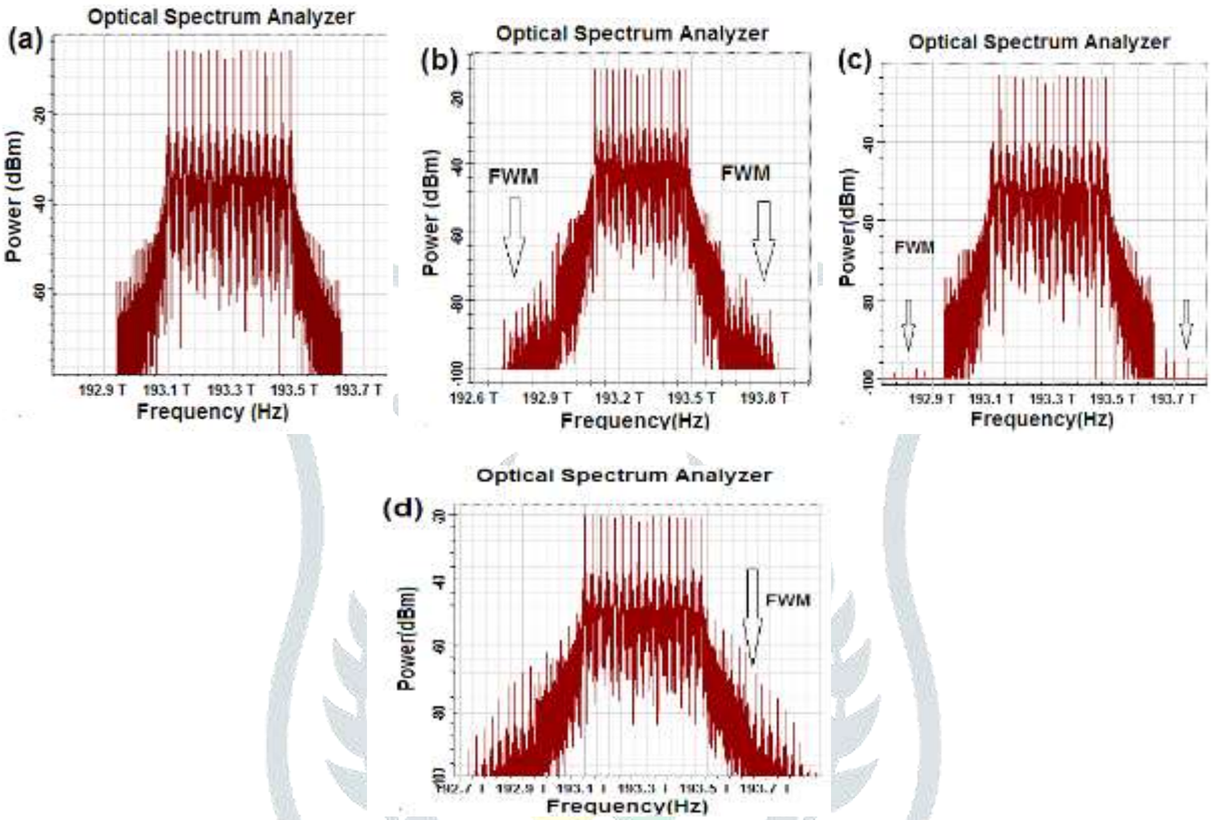


Figure 1.3 Optical spectrum analyzer depictions for (a) WDM transmitter and after 150 Km for (b) EDFA-EDFA (c) Raman-EDFA (d) SOA-EDFA

Figure 1.4 represents the effects of fiber link length on output power observed for 16 WDM channels after hybrid amplifiers to evaluate their performances. It is clearly seen that as the link length increases, there is reduction in output power for all arrangements of amplifiers. This is due to the linear and nonlinear effects that exist in optical fiber such as attenuation and Kerr's effects. Moreover, demonstrated WDM system is ultra dense and it is perceived that more interference and inter symbol crosstalk arouses as the decrease in spacing among adjacent channels of WDM. Output power in case of EDFA-EDFA observed maximum and exhibits best performance then other two arrangements of amplifiers. Raman-EDFA recommended for high power systems, however amplification of this hybrid amplifier is worst for demonstrated system. After 250 Km, all the hybrid amplifiers unveil nearly similar values of output power. EDFA is prominent and pioneering amplifier in C-band. In SOA, carrier density pulsation and refractive index change of medium is a major cause of nonlinear effects at high powers.

Table 1.2 Output power 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

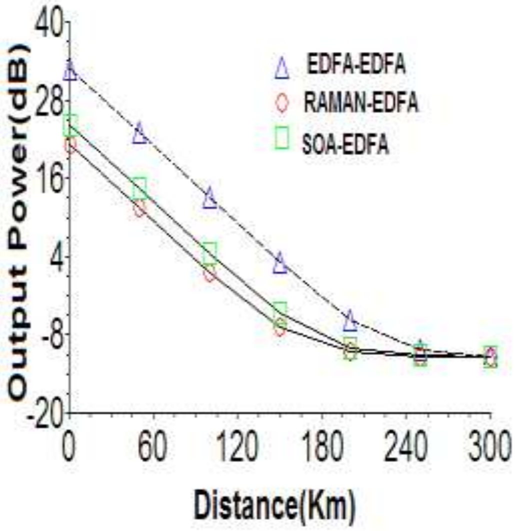


Figure 1.4 Output power versus distance

Evaluation is carried out to analyze quality factor of the WDM system for different hybrid amplifiers at varied link length of SMF-28. For distances 20 Km to 150 Km, Raman-EDFA is found out to be best amplifier due to combined effects of both the amplifiers and very less four wave mixing as illustrated in Figure 1.5. In order to achieve longer transmission reach, EDFA-EDFA is the optimal choice after 250 Km. Performance of SOA-EDFA in terms of Q-factor is not linear, quality increase from 50 km to 200 Km and decreases for prolonged distances. Reason of better performance of aforementioned hybrid amplifier is that it shows more FWM at higher powers and as the distance increase, power decreases because of attenuation and FWM also degenerated or declined. Table 1.3 listed the values of Q-factor at different link lengths.

Table 1.3 Q-factor at different SMF lengths in 16 Channels 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

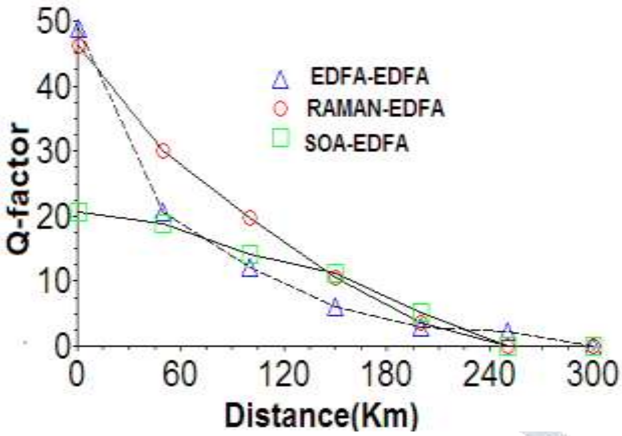


Figure 1.5 Variation of Q with distance in 16 Channels WDM system

To measure the Gain fluctuations, a dual port WDM analyzer is incorporated in simulation and one port is attached right after multiplexer and output of second amplification stage is fed to second port of analyzer. Link length is fixed at 150 Km and its effect is scrutinized on flatness of gain to find optimal Gain flattened arrangement of amplifiers. Optical communication is very much dependent on wavelengths/frequencies of light that are communicated over SMF. Each wavelength has its own level of power and speed inside single mode fiber, thus arouses fluctuations in power levels after amplification. Moreover, amplifiers suffered from a limitation that they cannot amplify all wavelengths in equal manner and consequently give rise to Gain variance. We accentuated on parameters of amplifiers in order to achieve Gain flatness and perceived it as illustrated in figure 1.6. Performance of EDF-EDFA is utmost in terms of Gain and flatness too over different frequencies. Subsequent to this amplifier is SOA-EDFA that provides Gain less than EDFA-EDFA but more than Raman-EDFA. It is concluded that for long distance transmission, EDFA-EDFA is optimal to use in C-band at dense channels spacing WDM system under the effects of FWM.

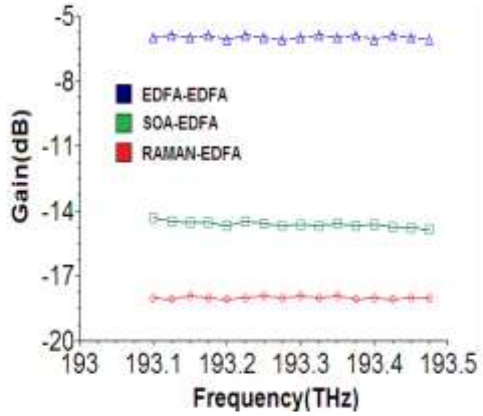
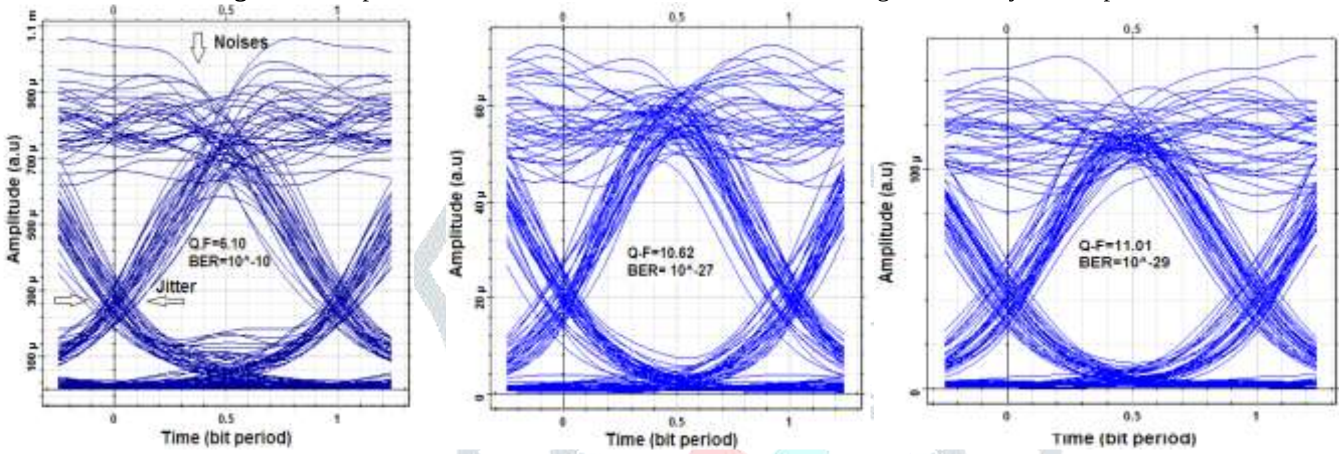


Figure 1.6 Representation of Gain for 16 WDM channels using different hybrid amplifiers at 150 Km



(a) (b) (c)

Figure 1.7 Eye diagrams for 16 channels WDM system using (a) EDFA-EDFA (b) RAMAN-EDFA (c) SOA-EDFA at 150 Km

Figure 1.7 shows the Eye diagram of system and is a decisive analyzer that compute the errors, Q-factor, SNR, eye closer, eye opening etc. It represents the average no. of ones and zeros with their Quality and bit errors. Noise can be attributed to the fluctuations observed on the peak of the broadened eye. Wide eye opening and high quality with fewer errors at 150 Km is perceived for SOA-EDFA. More the opening of eye, less are the errors and BER varies inversely with Q-factor and eye opening. Quality and BER observed in this case are 11.01 and $2.1\text{x}10^{-29}$ respectively. In case of the other two arrangements the results obtained are 6.10, 10^{-10} and 10.62, 10^{-27} for EDFA-EDFA and Raman-EDFA respectively. Figure 1.8 depicts the performance of NRZ and RZ modulation formats over different lengths of single mode fiber in terms of Q-factor. Results revealed that as the link length increases from 1 km to 300 km, Q of the received signal in both cases decreases. This is due the effects of attenuation, dispersion and nonlinear effects. It is evident that due to the bandwidth efficiency of NRZ modulation format, it surpasses the performance of RZ modulation format. It is clearly observed that system works for 250 km in case of NRZ within acceptable range of Q-factor and in case of RZ, It works for only 200 km.

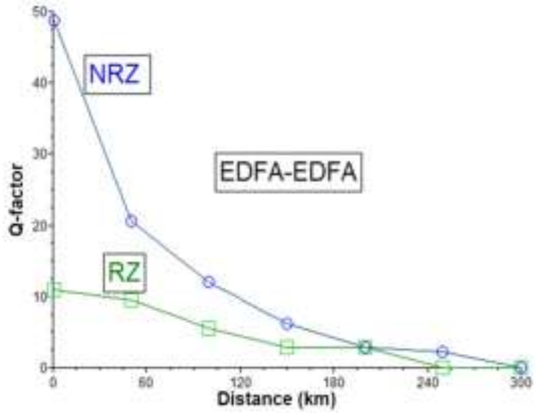


Figure 1.8 Q-factor versus distance

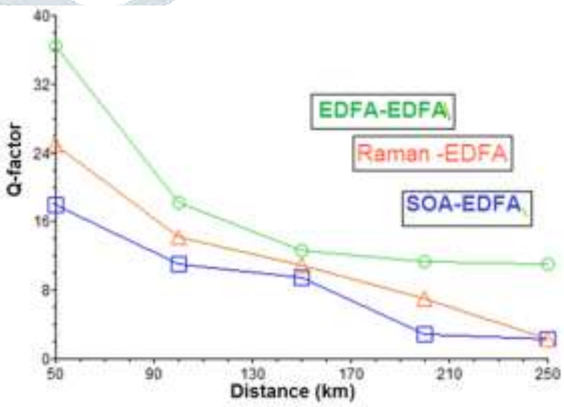


Figure 1.9 Q-factor versus distance for 32 WDM

Evaluation is carried out to analyze quality factor of the WDM system for different hybrid amplifiers at varied link length of SMF-28 by considering 32 WDM channels. For distances the entire distance range i.e from 50 Km to 250 Km, EDFA-EDFA is found out to be best amplifier due to combined effects of both the amplifiers as shown in Figure 1.9. In order to achieve longer transmission reach, EDFA-EDFA is the optimal choice even after 250 Km. Performance of SOA-EDFA in terms of Q-factor is not linear, quality decrease from 50 km to 250 Km. Reason of least performance of SOA-EDFA hybrid amplifier is that it shows more FWM at higher powers. Performance of Raman-EDFA falls in the middle of other two configurations. Thus, again EDFA-EDFA is an optimal choice to use in 32 WDM channels. Further, analysis of the performance of NRZ and RZ modulation formats over different lengths of single mode fiber for 32 WDM channels in terms of log (BER) has been done as shown in Figure 1.10. For distances the entire distance range i.e from 50 Km to 250 Km, EDFA-EDFA is found out to be best amplifier due to less BER is reported in this case. In order to achieve longer transmission reach with less number of errors, EDFA-EDFA is the optimal choice even beyond 250 Km. Performance of SOA-EDFA in terms of log (BER) is worst, BER increases from 50 km to 250 Km. Reason of least performance of SOA-EDFA hybrid amplifier is that it shows more FWM at higher powers. Log (BER) of Raman-EDFA falls in the middle of other two configurations. Figure 1.11 shows the effect of different data rates on the WDM system using optical configuration EDFA-EDFA. It is perceived that with the increase in the data rate, size of the bit slot reduces and it ultimately increase the errors due to dispersion and Q of received signal decreases. Time of bit slot calculation is given below:

$$T_B=1/\text{Data rate}$$

For 10 Gbps time of bit slot is 0.1 ns and for bit rate 20 Gbps, time of bit slot becomes half of that in 10 Gbps i.e. 0.05 ns. So, system performs better at 10 Gbps and results degrade at 20 Gbps.

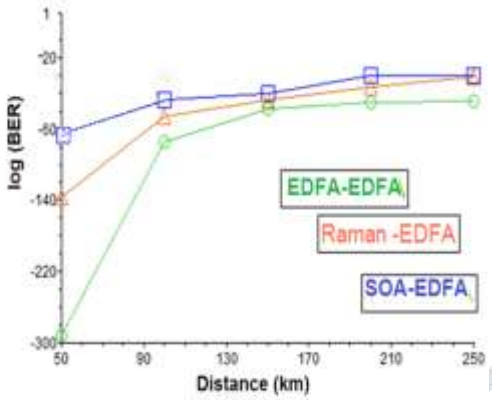


Figure 1.10 Log(BER) versus distance

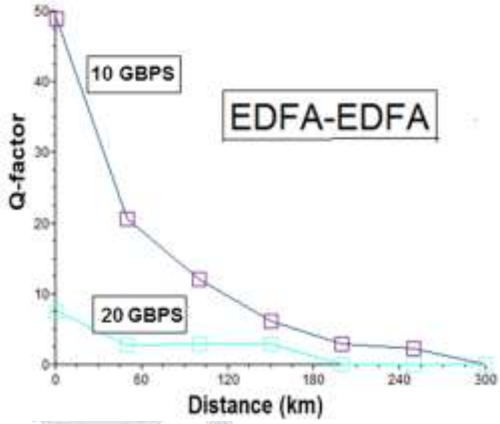


Figure 1.11 Q-factor vs distance at diff. data rate

IV. CONCLUSION

Work demonstrated the performance of different hybrid optical amplifiers such as EDFA-EDFA, SOA-EDFA and RAMAN-EDFA in ultra dense 16 x 10 Gbps, 32 x 10 Gbps WDM systems. Evaluation of hybrid amplifiers has been done in terms of Q-factor, Output power and BER. It is observed that Four wave mixing is prominent cause of signal degradation in WDM systems, thus an optimal amplifier arrangement is suggested due to less nonlinear impairments. Simulation results reveal that SOA-EDFA is more susceptible and Raman-EDFA is less susceptible to four wave mixing. Output power of 32.77dBm, 24.15dBm and 21.23dBm is calculated at 1 Km after amplification through E-E, S-E and R-E respectively in case of 16 WDM channels. Q-factor and BER for amplifiers is obtained as 6.1, 10^{-10} (EDFA-EDFA) , 10.62, 10^{-27} (RAMAN-EDFA) and 11.01, 2.1×10^{-29} (SOA-EDFA) at 150 Km using 16 WDM channels. Furthermore, distance 20 Km- 140 Km, Raman-EDFA is optimal configuration for amplification and for extended link lengths such as beyond 200 Km, EDFA-EDFA is a right hybrid amplifier. To accomplish maximum Gain flatness, EDFA-EDFA is suggested to incorporate in the WDM systems. With the increase in WDM channels from 16 to 32 and data rates from 10 Gbps to 20 Gbps, results degrades significantly and also NRZ is found out to be better modulation over RZ.

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