Journal of Engineering and Applied Sciences 12 (Special Issue 12): 9508-9513, 2017
ISSN: 1816-949X

Evaluation of Hybrid Optical Amplifiers EDFA-EDFA, SOA-EDFA and Raman-EDFA in Ultra Dense Wavelength Division Multiplexed System

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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 research, an ultra dense 16 channel WDM system is 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 and Raman-EDFA is less prone to FWM. Moreover, for distance 20-140 km, Raman-EDFA is optimal configuration for amplification and beyond 140 km, SOA-EDFA shows better performance. For prolonged link lengths such as more than 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.

Key words: Four Wave Mixing (FWM), Erbium Doped Fiber Amplifier (EDFA), Semiconductor Optical Amplifier (SOA), Raman amplifier, Bit Error Rate (BER), Optical Spectrum Analyzer (OSA)

INTRODUCTION

This document is a template. 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 networks. WDM has proved to be a major breakthrough for sufficing the need for increasing number of channels and transmission capacity of the system (Seo *et al*., 2005). 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 (Bobrovs *et al*., 2013). Semiconductor amplifier provides amplification in range of 1310-1550 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 (Anurag and Mayur, 2014; Chung *et al*., 2005). Employing Raman-EDFA hybrid amplifier, gain flatness of 90.5 nm has been achieved up to 50 km transmission distance (Mustafa *et al*., 2013). 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 (Masuda *et al*., 1998). Kaur *et al*. (2013) 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. J. Helina (Rajini and Tamil, 2015) 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. Singh *et al*. (2013) 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.

MATERIALS AND METHODS

Proposed architecture: An easy way for the realization of proposed system, Optiwave Optisystem™ a comprehensive simulation tool that allows to simulate, test and plan communication systems in modern optical transmission layer is used. A 16 channel WDM system is demonstrated at ultra dense channel spacings of 25 GHz in order to make system bandwidth efficient. Continuous wave lasers are operated in C-band (1530-1570nm) due to minimum attenuation and scattering in this particular optical frequency window. Laser frequencies for this work are considered from 193.1-193.475 THz. Launched power for each channel is kept low and fixed at 0 dBm as shown in Table 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/sec by pseudo random bit sequence generator in the form of 1 and 0's followed by non return to zero line coder. NRZ is a pulse form 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 is kept at 10 MHz to realize a practical WDM system and polarization is also 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 research, power meters, WDM analyzers and optical time domain visualize are incorporated in the system. 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. Figure 1 depicts the proposed model of 16 channel WDM system encompassing hybrid amplifier configurations. Also, four wave mixing is the major Kerr effect based nonlinearity that is analysed for different hybrid amplifier arrangements.

Table 1: Proposed architecture specifications

Parameters	Values
Input power	0 dBm or 1 mW
Frequencies	193-193.475 THz
Channel spacing	25 GHz
MZM extinction ratio	30 decibel (dB)
Data rate	10 Gbps
Sequence length	128
Amplifiers	EDFA, SOA, Raman

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. 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 in terms of output power, BER and quality of signal passed through joint combinations of amplifiers. Erbium doped fiber amplifier with 12 dB gain and 4.5 dB noise power is inserted in the system and values remained fixed throughout the research. SOA amplifier has several parameters values such as insertion loses (3 dB), injection current (0.1 A), length (3×10^{-6} m), width (3×10^{-6} m) and height (8×10^{-8} m). Raman amplifier of 10 km and pump power 250 mW with pumping 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.

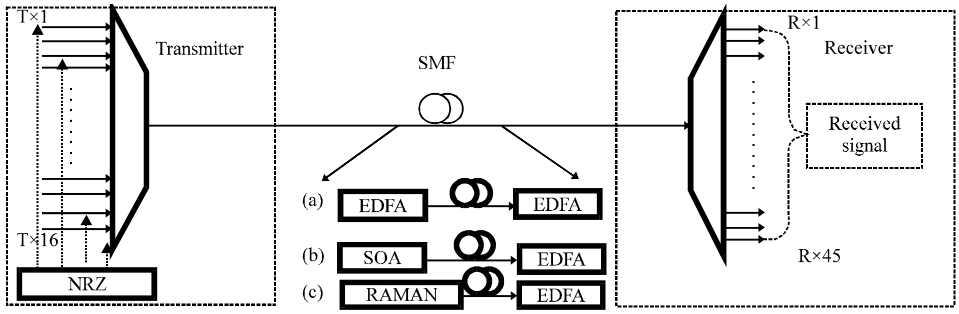

Fig. 1: Proposed 16 channels WDM system and hybrid amplifier configurations

RESULTS AND DISCUSSION

In proposed 16 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 1-300 km. SMF-28 is a single mode optical fiber with 0.2 dB/km attenuation for C-band wavelengths and effective area 80 μm^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 Fig. 2a-d.

FWM signals power is maximum in case of SOA-EDFA (-46.32 dBm) and minimum in Raman-EDFA (<-95 dBm). However, power of FWM signals is average in EDFA-EDFA and < and > 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 3 represents the effects of fiber link length on output power observed after hybrid amplifiers to evaluate their performances, the corresponding values for which are mentioned in Table 2. 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.

Table 2: Variation of Output power with SMF length for different hybrid amplifiers

Distance (km)	EDFA-EDFA (dBm)	Raman-EDFA (dBm)	SOA-EDFA (dBm)
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	-10.00
250	-10.33	-11.30	-11.22
300	-11.26	-11.37	-11.36

Table 3: Q-factor at different SMF link distances

Distance (km)	EDFA-EDFA	Raman-EDFA	SOA-EDFA
1	48.81	46.24	20.65
50	20.60	29.99	18.83
100	12.08	19.74	14.22
150	6.10	10.62	11.01
200	2.83	3.69	5.23
250	2.19	0.00	0.00
300	0.00	0.00	0.00

Output power in case of EDFA-EDFA observed maximum and exhibits best performance than 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.

Figure 4 depicts the variation of quality factor of the WDM system for different hybrid amplifiers at varied link length of SMF-28, the corresponding values of the same are tabulated in Table 3. For distances 20-150 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 Fig. 2c. 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 factor increase from 50-200 km and decreases for prolonged distances. Reason of better

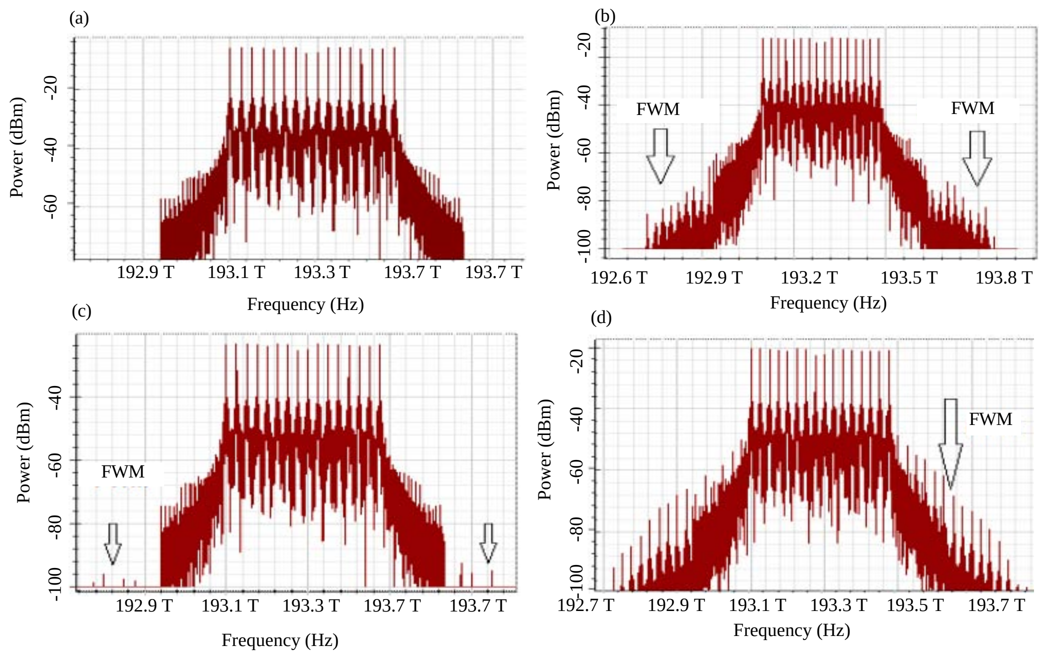

Fig. 2: Optical spectrum analyzer depictions for; a) WDM transmitter and after 150 km for; b) EDFA-EDFA; c) Raman-EDFA and d) SOA-EDFA

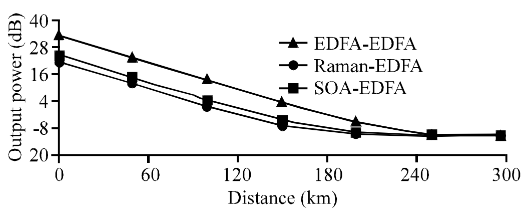

Fig. 3: Graphical representation of output power with variation of SMF length

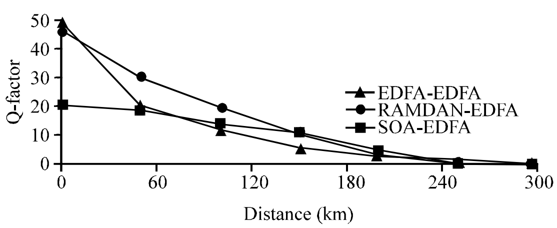

Fig. 4: Variation of quality factor with SMF length

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 inturn FWM also decreases. Table 3 listed the values of Q-factor at different link lengths. Figure 5 illustrates the power fluctuation of three different hybrid amplifiers at different wavelengths and depicts their gain flatness. To measure the gain fluctuations, a dual port WDM analyzer is incorporated in simulation and one port is attached

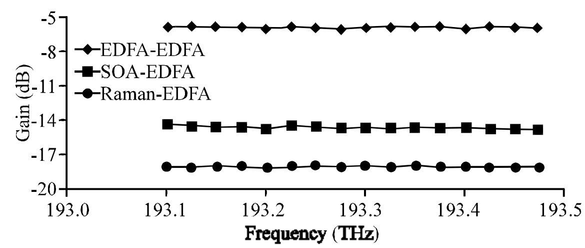

Fig. 5: Representation of gain for different hybrid amplifiers at 150 km

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 Fig. 4. Performance of EDF-EDFA is utmost in terms of gain and flatness too over different frequencies. Subsequent to this

Table 4: Performance of hybrid optical amplifiers

Parameters	EDFA-EDFA	Raman-EDFA	SOA-EDFA	Recommendations
Ouput power	Maximum	Minimum	Mild	EDFA-EDFA is optimal to use
Distance coverage (km)	>200 km	50-100 km	150-200 km	For maximum coverage E-E For mild coverage S-E For small coverage R-E
Four wave mixing	Moderate	Minimum	Maximum	R-E is optimal under FWM
Gain (dB)	Maximum	Moderate	Minimum	E-E is recommended
Gain flatness	±0.018 (dB)	±0.25 (dB)	±0.49 (dB)	For C-band, EDFA-EDFA is suggested

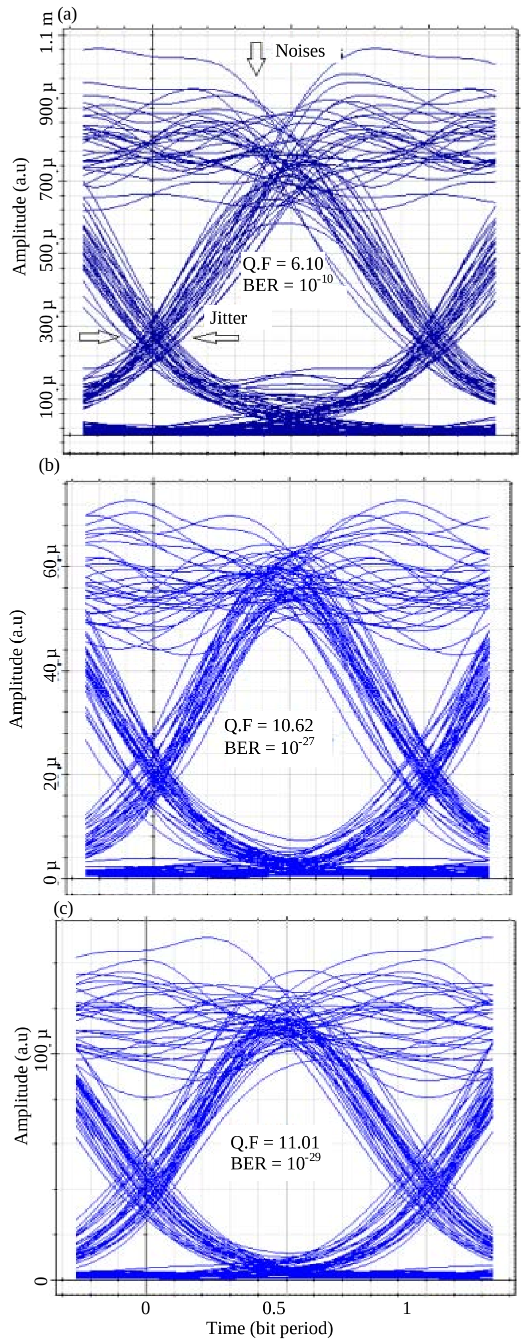

Fig. 6: Eye diagrams for: a) EDFA-EDFA; b) RAMAN-EDFA and c) SOA-EDFA at 150 km

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 6 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 andzeros with their quality factor and BER. 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 2.1×10^{-29}, respectively. In case of the other two arrangements, the results in terms of Q-factor and BER obtained as 6.10, 10^{-10} and 10.62, 10^{-27} for EDFA-EDFA and Raman-EDFA, respectively. Table 4 listed the important recommendations based on current investigation of different configuration of amplifiers in ultra dense WDM system. Suggestions are also reliant on performance of HOAs on the basis of Q-factor, gain flatness and BER.

CONCLUSION

This study demonstrated the performance of different hybrid optical amplifiers such as EDFA-EDFA, SOA-EDFA and RAMAN-EDFA in ultra dense 16×10 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 reveals that SOA-EDFA is more and Raman-EDFA is less susceptible to four wave mixing. Output power of 32.77, 24.15 and 21.23 dBm is calculated at 1 km after amplification through E-E, S-E and R-E, respectively. 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. Furthermore, for distance 20-140 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.

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