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Performance Evaluation of Optical Amplifiers for High-Speed Optical Networks

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Abstract: Optical networks were invented by the developing and developed nations in order to extend the capacity required for communication systems in a worthwhile way. In this paper, the attempt is done to improve the capacity and performance of semiconductor optical amplifier, Raman and erbium-doped fiber amplifier (EDFA) amplifiers used in optical networks. The potential of different optical amplifiers operating at 8×10 Gbps has been examined and their performance was compared on behalf of different parameters, viz. eye opening, eye closure, jitter, quality factor and transmission distances. It was observed that EDFA provided the consistent good quality of communication for long-distance transmission up to 150 km along with better eye opening and eye closure with acceptable jitter performance. Further, it is observed on the basis of quality factor and bit error rate that EDFA gives comparably better performance than Raman amplifier. Moreover, it is seen that as the data rate of the system increases, the quality of communication signals starts decreasing.

Keywords: EDFA, SOA, Raman amplifier, optical networks

1 Introduction

Optical amplifiers (OAs) allowed an impressive growth in the capacity of optical transmission systems while reducing system costs. This is due to high output power afforded by optical amplifiers that support higher bit rates and handling of multichannel operations. But these advantages cause the degradation of signal to noise ratio due to accretion of large dispersion and amplifier noise over the length of the fiber [1]. Initially, in optical communication systems, the conversion of

signal from one domain to another domain required optoelectronic regenerator. But this procedure was expensive in compared to optical amplifiers because optical amplifier does not require any conversion from one domain to another. Before optical amplifiers, use of optical repeater for WDM (wavelength division multiplexing) transmission was not a practical means so WDM system with short distance was in focus before development of optical amplifiers. OAs made it possible to construct long-distance transmission. There are two types of OAs: semiconductor optical amplifier (SOA) and doped fiber amplifier (DFA). Functioning of SOAs was below the lasing threshold value as they are basically semiconductor lasers. They are used for long-haul optical transmission as a functional device [2]. Innovation of optical communication occurs through erbium-doped fiber amplifier (EDFA). Unlike optoelectronic regenerators, optical amplifiers do not require elevated speed electronic component and also are translucent to data format and data rate. EDFA also has low noise figure approximated to 3 dB and also it provides high gain. It was particularly useful in WDM as it allows amplification of multiple signals which are carried on a fiber in high-speed optical networks [3].

EDFA practically has two windows of wavelength. These are C & L band. C band ranges from 1,530 nm to 1,560 nm and L band from 1,560 nm to 1,610 nm. EDFA is appropriate to operate at C band. OAs in L band are used to extend the number of WDM channels and optical bandwidth. C band has less noise figure than L band [4]. Behero et al. [5] proposed a cost-effective solution that optical fiber itself can be used as a gain medium called Raman amplifier for optical amplification under high pump power phenomena without using expensive doped ions. Raman amplification was used for long-distance optical transmission system. In the late 1990s, Raman amplifier was introduced, but that was relatively poor as they amplify signals in the range of 1 to 5 W in comparison to EDFA as they amplify signals in range of 1 to 10 mW. Therefore, Raman amplifier with more power was used to realize large gain of 20 dB or more [6]. Hwang et al. [7] demonstrated a wider gain bandwidth and high-capacity Raman fiber amplifier (RFA), which was the enabling and promising technology for long-haul WDM

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network. Depending on the usage of pumped wavelengths and pump power, it was used to amplify not only C band also L and S bands.

Singh et al. [8] investigated a WDM system operated at 10 Gbps for 16, 32 and 64 channels with SOA, EDFA and Raman amplifiers. It was found that SOA gives better performance when numbers of channels are less. EDFA gives better results in terms of power and bit error rate (BER) when dispersion was increased. For gain flattening and L band amplification, Raman amplifier gives better results. Performance of that network was investigated with or without the presence of nonlinearities and dispersion was varied from 2 to 10 ps/nm/km. Kim et al. [9] transmitted 10 Gbps signal over 80 km using single mode fiber (SMF) using SOA as a booster. Amit Wason et al. [10] proposed a new rerouting algorithm (LRRA) for WDM networks that reduces the blocking and improves the performance of WDM networks. Singh et al. [11] proposed semiconductor optical amplifier in dispersion compensated fiber for 10 Gbps nonreturn to zero format. It describes different locations of SOAs through diverse compensation methods (post, pre, symmetrical) in optical fiber. These compensation methods were compared with reference to eye diagram, eye closure penalty, BER and output power. It was seen that when SOA was used, postcompensation method gives better results to other compensation methods. Kaur et al. [12] investigated the performance of WDM systems operated at 10 Gbps for 16, 32 and 64 channels with SOA, EDFA and Raman amplifiers. It was found that SOA gives better performance when numbers of channels are less. EDFA gives better results in terms of power and bit error rate (BER) when dispersion was increased. For gain flattening and L band amplification, Raman amplifier gives better results. Performance of that network was investigated with or without the presence of nonlinearities.

Anu et al. [13] investigated 16-channel DWDM network with channel spacing of 25 GHz over a distance of 1,450 km using MDRZ, CSRZ and DRZ modulation format. Jeenanjyoti et al. [14] determined the different modulation formats in a single-channel light-wave system and also found the effects of amplified spontaneous emission (ASE) on CSRZ, RZ and NRZ.

Singh et al. [15] proposed semiconductor optical amplifier in dispersion compensated fiber for 10 Gbps nonreturn to zero format. It describes different locations of SOAs through diverse compensation methods (post, pre, symmetrical) in optical fiber. These compensation methods were compared with reference to eye diagram, eye closure penalty, BER and output power. It is seen that when SOA was used, postpower compensation method was better to other compensation methods.

Malik [16] investigated the performance of conventional and hybrid amplifiers at reduced channel spacing of 0.4 nm. It is concluded that for a distance of 100 km, Raman-EDFA configuration proved to be better than SOA-EDFA. For distance more than 100 km, the case was reversed and SOA-EDFA configuration produced better results for small number of channels.

Singh et al. [17] proposed a novel flat gain amplifier for 100×10 Gbps DWDM system using hybrid constitution of Er-Yb co-doped waveguide amplifier and semiconductor optical amplifier with 0.2 nm channel spacing. The resultant was a flat gain > 14 dB with gain deviation less than 0.75 dB without including any gain clamping scheme.

Singh et al. [18] proposed a two-stage hybrid optical amplifier with reduced channel spacing of 0.2 nm in DWDM system. The simulation results showed that as input power was increased, gain variation also increased. At input power 3 mW, 10 dB flat gains were obtained with gain variation less than 4.5 dB without using any gain flattening scheme.

In this paper, optical amplifiers with eight channels are used and determined their performance in the terms of eye opening, eye closure, jitter, quality factor and BER by changing the communication distance. This paper is organized in four sections. In Section 2, optical simulation model is explained. In Section 3, simulation results have been described for different transmission distance and in Section 4, conclusion is reported.

2 Investigated model

Simulation setup for eight-channel optical amplifier is exposed in Figure 1. Each transmitter module consists of source of data, electrical driver, amplitude modulator and source of laser. Data source reproduces a pseudo-random logical signal and the corresponding pseudo-random signal has a period length of $2^D - 1$ bit. Electrical driver is an important component which translates

Figure 1: Simulation setup for eight-channel WDM system.

binary sequence of one's and zero's into an electrical signal and generates the desired data. Signals of different wavelength are multiplexed and transmitted over the fiber at different communication distances. These signals are transmitted at a data rate of 10 Gbps. These signals are in the range of 1,531.01 nm to 1,601.56 nm and with channel spacing of 0.8 nm. Laser power is setup at "0" dBm because higher power wavelengths lead to nonlinear effects such as four wave mixing (FWM) and cross phase mixing (XPM). Transmission distance was varied from 20 to 160 km. At the receiver end, output signals are demodulated in original form. Output was detected with the help of photodiode and observed on the electrical scope. We have used the Optisim for the simulation of our model. Table 1 defined the parameter used for SOA in WDM system. Parameters for EDFA used in WDM system is shown in table 2. Table 3 defined the parameter for Raman amplifier in WDM system.

Table 1: Parameters for SOA in WDM system.

Parameters	Value
Amplifier length (10^{-6} m)	300
Bias current	100 mA
Input/output insertion loss	3 dB
Confinement factor	0.35
Carrier lifetime	0.3 ns
Active large thickness (10^{-6} m)	0.15
Active large width (10^{-6} m)	1.5

Table 2: Parameters for EDFA in WDM system.

Parameters	Value
Noise figure	5
Output power	32 mW
Gain shape	Flat

Table 3: Parameters for Raman amplifier in WDM system.

Parameters	Value
Raman fiber length	9 km
Pump wavelength	1,453 nm
Pump power	500 mW
Pump attenuation	0.2 dB/km
Reference frequency for dispersion	1,550 nm
Operating temperature	300 K

3 Results and discussion

In this paper, the performance of various optical amplifiers has been analyzed with transmission distance in the terms of eye diagram, jitter, BER and quality factor for SOA, EDFA and Raman amplifier.

The variation in eye opening and closing for SOA, EDFA and RAMAN amplifier at 100 km is shown in the Figures 2–4, respectively, and similarly at 5, 6 and 7 for

Figure 2: Eye diagram for SOA at 100 km.

Figure 3: Eye diagram for EDFA at 100 km.

Figure 4: Eye diagram for Raman amplifier at 100 km.

150 km. The eye diagram indicates the quality of the received signals, i.e. better the eye opening, better will be the communication quality. Eye diagram of respective amplifiers indicated that eye started closing with increase in distance due to continuous rise in distortion, ASE and other nonlinearities along the length of the fiber.

It was observed that as the distance was increased up to 150 km, SOA amplifier showed improved eye diagram and provided the best quality of signals, whereas Raman amplifier gave the maximum distortion at the same distance. On varying the distance for SOA from 20 to 200 km, the variation in eye opening was 0.00177405 to 4.14×10^{-5} with best acceptable value 4.14×10^{-5} at 150 km and the optimized eye closure value was 0.569117 dB. In Figure 2, X-axis represents the time interval and Y-axis represents the amplitude of the signal.

The variation in eye opening and eye closing for SOA at 150 km is shown in figure 5. The eye diagram indicates the quality of the received signals. It was observed that as the distance was increased up to 150 km, SOA amplifier showed improved eye diagram and provided the best quality of signals. The variation in eye opening and eye closing for EDFA at 150 km is shown in figure 6. EDFA amplifier gives better eye opening at 150 km as shown in figure 6.

Figure 5: Eye diagram for SOA at 150 km.

Figure 6: Eye diagram for EDFA at 150 km.

Like SOA, EDFA amplifier also gives better eye opening at 150 km (6.78106×10^{-7}) with good quality of signals. Further, on increasing the transmission distance from 20 to 170 km, the eye opening started decreasing with the variation of 0.00971545 to 7.2229×10^{-7} . Moreover, it was observed that eye started closing with distance due to increase in distortion and other nonlinearities along the length of the fiber. The variation in eye closure from 50 km to 150 km was 0.202558 dB to 1.701827 dB. For Raman amplifier, the better eye opening was shown at maximum 100 km distance with acceptable value of 9.0417×10^{-6} . ASE noise power was the main reason behind the major variation in eye closure from 100 km to 150 km. In addition to this, Jitter variation was attributed to nonlinear effects and cross-phase modulation between the adjacent bits. The units of Y-axis in Figure 7 are [a.u], which represent the amplitude of the digital signal. The eye opening corresponds to one bit period and is called unit interval (UI) width of the eye diagram. Eye diagram represents BER and signal to noise ratio (SNR) of the signal received. Eye amplitude is the difference between the “1” and “0” levels. The receiver circuit will determine whether the received signal bit is a “0” or “1” based on the eye amplitude. The noise on the eye will cause the eye to close. As a result, the eye height measurement determines the eye closure due to noise.

As shown in Figure 8, SOA has the largest eye opening. Larger the eye opening, better will be the communication quality. Eye opening varied from 3.19×10^{-4} to 4.14×10^{-5} , 9.01×10^{-5} to 6.78×10^{-6} and 9.04×10^{-6} to 7.93×10^{-9} for SOA, EDFA and Raman amplifiers, respectively. Further, it was observed that at 100 km, SOA gave an eye closure of 0.48 dB while EDFA and Raman amplifier gave 0.50 dB and 1.124 dB, respectively. Figure 9 shown the graph between the eye closure and the

Figure 7: Eye diagram for Raman amplifier at 150 km.

Figure 8: Eye opening vs. transmission distance.

Figure 9: Eye closure vs. transmission distance.

transmission distance. Larger the eye closure, lesser will be the quality of communication. It was seen that SOA gave the much consistent good quality of communication for long distance transmission. Larger the eye closure, lesser will be the quality of communication. The variations in eye closure for 100 km to 150 km are from 0.48 dB to 0.56, 0.50 dB to 1.70 dB and 1.124 dB to 22.07 dB for SOA, EDFA and Raman, respectively. It was concluded that SOA gave the much consistent good quality of communication for long-distance transmission.

Jitter variations for all the optical amplifiers are shown in Figure 10. It was observed that EDFA gave improved results. Jitter variation is attributed to the non-linear effects and cross-phase modulation between adjacent bits. As shown in Figure 11, the quality factor decreases with increase in transmission distance for different hybrid amplifiers. The maximum quality factor for all the three amplifiers was at lower transmission distances and EDFA was the one with the highest quality

Figure 10: Jitter vs. transmission distance.

Figure 11: Quality factor vs. transmission distance.

factor. At 20 km, EDFA amplifier gave the maximum quality factor of 36.34 dB. Further, as the distance increased up to 100 km it was observed that the quality factor for SOA was 14.98 dB, for Raman amplifier was 19.12 dB and for EDFA was 27.25 dB. It was concluded that for the small number of channels, EDFA amplifier gave better and consistent performance as compared to Raman and SOA amplifiers. Moreover, EDFA provides the least amount of jitter (0.02066 ns) with eye opening of 9.01×10^{-5} at 100 km.

Figure 12 illustrates the graph between BER and transmission distance for different optical amplifiers. It was seen that as the transmission distance increased from 20 to 180 km, there was a rise in the BER. It may be due to nonlinear effects that degraded the performance of the system. Further, it was observed that beyond 80 km, EDFA gave the best performance than other optical amplifiers. At 100 km, BER for EDFA was 1×10^{-40} , for Raman was 9.57084×10^{-20} and for SOA was 8.11526×10^{-9} . Acceptable BER for SOA at 70 km was 9.07975×10^{-13} .

Figure 12: BER vs. transmission distance.

Figure 13: Q factor vs. transmission distance for EDFA with varying data rate.

In Figure 13, it was noticed that the quality of WDM system decreases with increase in the transmission distance. EDFA at 2.5 and 5 Gbps gives almost the same quality of signals. It was observed that up to 170 km EDFA optical amplifier at 10 Gbps was more suitable than 20 Gbps EDFA amplifiers. At 170 km, the observed quality factor for EDFA at 10 Gbps was 15.40 dB and for 20 Gbps it was 9.923 dB. From the simulation results, it was concluded that EDFA at 10 Gbps is preferred for long-distance transmission. But as we increase the distance, signal quality starts decreasing. Figure 14 represents the graph between the jitter and transmission distance for EDFA at varying data rate. It was observed that jitter decreases with increases the data rate.

Figure 14: Eye closure vs transmission distance for EDFA with varying data rate.

Figure 15: Jitter vs. transmission distance for EDFA with varying data rate.

Figure 15 demonstrates the graph between eye closure and fiber distance. From the simulation results, it is observed that with increase in transmission distance, eye closure starts increasing. Up to 170 km EDFA at 10 Gbps gave acceptable eye closure. Minimum the eye closure, better will be the quality of signal. At 170 km, eye closure for EDFA at 10 Gbps was 3.259831 dB and that at 20 Gbps was 6.606919 dB.

4 Conclusion

From the simulation results, it is concluded that EDFA provided consistent good quality of communication for long-distance transmission up to 150 km along with better eye opening and eye closure with acceptable jitter performance. Further, it is observed on the basis of quality

factor and BER that EDFA gives comparably better performance than Raman amplifier. Moreover, it is seen that as the data rate of the system increases, the quality of communication signals starts decreasing.

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