

Asian Journal of
Applied
Sciences

Performance Analysis of Hybrid Optical Amplifiers for 64×10 Gbps DWDM System

¹J. Helina Rajini and ²S. Tamil Selvi

¹Department of Electronics and Communication Engineering, Sethu Institute of Technology, Pulloor, Kariapatti Taluk, Tamil Nadu, 626115, India

²Department of Electronics and Communication Engineering, National Engineering College, Kovilpatti, Tamil Nadu, India

Corresponding Author: J. Helina Rajini, Department of Electronics and Communication Engineering, Sethu Institute of Technology, Pulloor, Kariapatti Taluk, Tamil Nadu, 626115, India Tel: +919486927217

ABSTRACT

In Wavelength Division Multiplexed (WDM) transmission systems the following categories of optical amplifiers are used: Erbium Doped Fiber Amplifier (EDFA), Raman amplifier (RAMAN) and Semiconductor Optical Amplifier (SOA). A hybrid amplifier can be formed using these amplifiers to combine the merits and to compensate for the demerits of different amplifiers. In this study, the performance of different hybrid optical amplifiers (EDFA-EDFA-EDFA, RAMAN-EDFA-EDFA, EDFA-EDFA-RAMAN, RAMAN-EDFA-RAMAN, EDFA-EDFA-SOA) for 64×10 Gbps Dense Wavelength Division Multiplexed (DWDM) system has been compared. The performance has been analyzed on the basis of transmission distance from 80-200 km in terms of output power, Q-factor and bit error rate. The impact of modulation formats (NRZ and RZ) on hybrid optical amplifiers has been further investigated and it is found that EDFA-EDFA-EDFA provides the highest output power. The better Q value is provided by EDFA-EDFA-RAMAN up to 160 km. The least bit error rate is provided by EDFA-EDFA-RAMAN up to 160 km.

Key words: DWDM, EDFA, RAMAN, SOA, hybrid amplifier

INTRODUCTION

The growth of multimedia services and the rapid increase in the number of global internet users has led to the requirement for high capacity networks. Nowadays, use of Wavelength Division Multiplexing (WDM) is one of the most classic solutions for increasing transmission capacity. In WDM, multiple optical carriers at different wavelengths are modulated by independent electrical bit streams and are simultaneously transmitted over a single fiber. WDM systems are classified as being coarse or dense, depending on the value of the channel spacing. If the channel spacing is greater than 5 nm, then it is called as coarse WDM and if the channel spacing is less than 1 nm, then it is called as dense WDM (DWDM) system. Maintaining the required level of system performance over a longer transmission distance is vital. The transmission distance of a WDM system is limited by fiber losses.

For long-haul systems, the loss limitation is conventionally overcome using optoelectronic repeaters in which the optical signal is first converted into electric form and then regenerated. Such regenerators are quite complex and expensive for WDM systems. Another alternative to loss

management makes use of optical amplifiers which directly amplify the transmitted optical signal without conversion to electric form. It amplifies the signals simultaneously and decreases the attenuation (Agrawal, 2002).

In WDM systems the following categories of optical amplifiers are used: Erbium Doped Fiber Amplifier (EDFA), Raman amplifier (RAMAN) and Semiconductor Optical Amplifier (SOA). To compensate for the demerits and combine the merits of different amplifiers, a hybrid amplifier can be formed using these amplifiers.

The Erbium Doped Fiber Amplifier (EDFA) is an optical amplifier that uses erbium (Er^{3+}) ions which are doped in the host silica fiber. The EDFA is pumped by laser diodes which excite the erbium atoms to a higher energy level. The gain occurs through a process of stimulated emission which takes place when the signal passes through the amplifier due to interaction with the doped excited ions. The EDFA's gain is wavelength-dependent. The main drawback of EDFA is that its wavelength-dependent gain spectrum bandwidth is only 40 nm and also it is not flat. But it amplifies the individual channels of a multichannel WDM signal simultaneously, hence no cross-gain saturation occurs. Because of the relatively long spontaneous carrier lifetime in silica fibers, it accomplishes high gain for a weak signal with low noise figure (Agrawal, 2002).

A RAMAN amplifier uses Stimulated Raman Scattering (SRS) occurring in silica fibers when an intense pump beam propagates through it. Raman gain arises from the transfer of power from one optical beam (pump) to another (signal), that is downshifted in frequency. The peak amplifications correspond to the signal frequency that is 13.2 THz lower than the pump; this frequency difference is called the Stokes shift (Islam, 2004). The advantages of RAMAN amplifiers are very broad gain spectrum which can be tailored by varying the number of pumps and their wavelengths (Mustafa *et al.*, 2013) and relatively low noise figure. The disadvantages of RAMAN amplifiers are the poor pumping efficiency at lower signal power (Thyagarajan and Ghatak, 2007) and the requirement of expensive powerful lasers, capable of delivering high powers into single-mode fibers.

In SOAs, amplification is achieved via the stimulated recombination luminescence. To achieve the population inversion, the electrical energy is applied as a pump. The amplifier gain dynamics is determined by the quick carrier recombination lifetime of SOA. Consequently, SOA will respond quickly to the changes in the input optical signal power. This may cause severe signal distortions in multichannel WDM systems (Connely, 2004). The gain of a specific channel is saturated not only by its own power but also by the power of the neighboring channels, a phenomenon known as cross-gain saturation. It is undesirable in WDM systems. As a result, the amplified signal appears to fluctuate randomly which degrades the effective SNR at the receiver. The main advantages of SOAs are their broad amplification bandwidth (up to 70 nm), low power consumption and low cost (Agrawal, 2002).

Hybrid optical amplifiers are designed to enhance the bandwidth (Seo *et al.*, 2005), to maximize the span length (Chung *et al.*, 2005) and to achieve large gain bandwidth product with better gain flatness (Delavaux *et al.*, 1992). The amplifiers can be connected either in parallel or in series (Masuda, 2000). In here, hybrid amplifiers with series connections have been mainly concentrated. Seo *et al.* (2005) demonstrated the novel hybrid optical amplifier to increase the transmission capacity which covered S+C+L bands with 105 nm total bandwidth using a silica fiber.

Chang *et al.* (2006) compared the EDFA and Hybrid Fiber Amplifier (HFA) and reported that HFA is an alternative to improve the performance of line amplifier, instead of EDFA only. The HFA configuration that has low noise figure and high output power was described by them. The Q-factor and OSNR in the case of HFA is higher by more than 1 dB.

Singh *et al.* (2013) evaluated the performance of 16×10 , 32×10 and 64×10 Gbps WDM systems, using optical amplifiers with and without non-linearities and concluded that when the dispersion is 2 ps/nm/km and the number of channels are less, then SOA provides better results but as the number of channels are increased, it degraded the performance, because gain saturation problem crops up. If dispersion and number of channels are increased then EDFA provides better results than SOA.

Singh and Kaler (2013), compared the performance of optical/hybrid optical amplifier for 64×10 Gbps dense wavelength division multiplexed system and concluded that the hybrid optical amplifier (RAMAN-EDFA) provides the highest output power (20.18 dBm) and eye opening (0.00233) at 160 km for dispersion 2 ps/nm/km. The impact of modulation formats (NRZ, RZ and DPSK) on hybrid optical amplifier (RAMAN-EDFA) has been further investigated and found that RZ is more adversely affected by non-linearities, where as NRZ and DPSK are more affected by dispersion. RZ provides good quality factor (13.88 dB) and less eye closure (2.609 dB).

In this study, an attempt has been made to improve the performance of 64 channels DWDM system which is amplified by different hybrid optical amplifiers. Each channel has 10 Gbps data speed. Further, the performance of different hybrid optical amplifiers are compared in terms of output power, Q-factor and Bit Error Rate (BER) for different modulation formats (RZ, NRZ) and the maximum single span transmitted distance is optimized.

METHODOLOGY

Simulation set-up: The simulation setup of a 64 channel DWDM system is shown in Fig. 1. At the transmitter side, each section consists of a data source, an electrical driver, a CW laser source

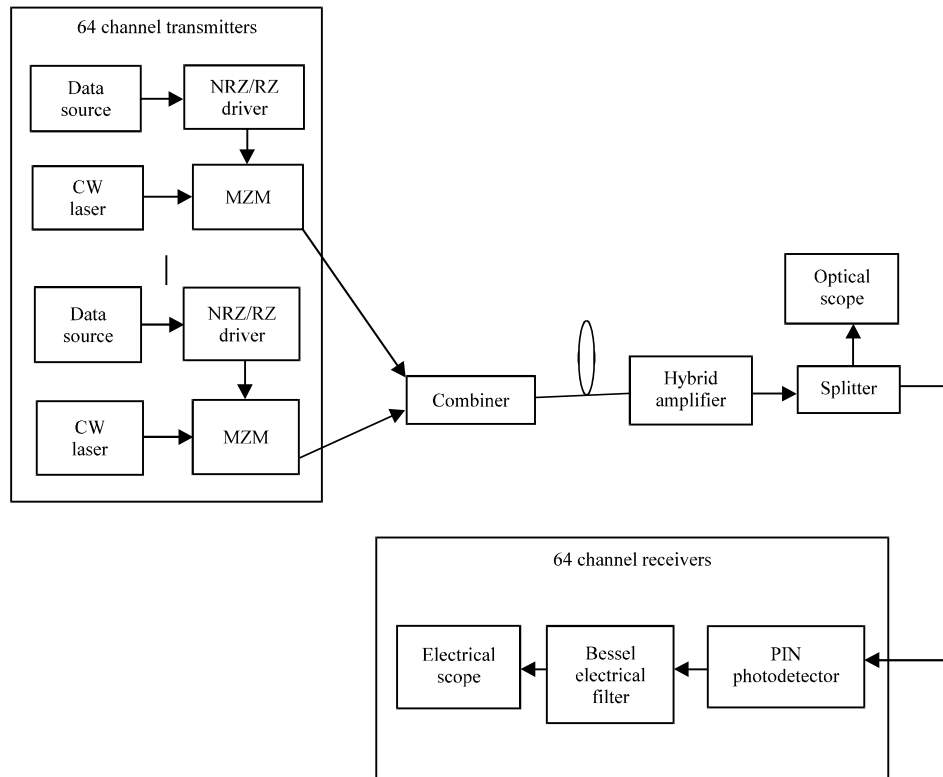


Fig. 1: Simulation set up for 64 channels DWDM system, MZM: Mach-Zehnder Modulator

and an external Mach-Zehnder modulator. A 10 Gbps pseudo random sequence is generated by the data source. The logical input signal (binary sequence of ones and zeros) is converted into an electrical signal by the electrical driver. Here NRZ and RZ electrical drivers are used. Sixty four laser beams in the range of 193.1-196.25 THz with 50 GHz channel spacing are generated by the CW laser source. The continuous optical signal from the laser source is externally modulated by the NRZ/RZ coded electrical pulses, using the Mach-Zehnder modulator. The laser power is set to 10 dBm. The input signal spectrum occupies a bandwidth of 3.15 THz. At the receiver side, modulated signals are converted into electrical signals with the help of PIN photo-detector and filtered by Bessel low pass filter. At the receiver section, the performance of one of the 64 channels is evaluated, based on the output power, Q value and BER measurement.

The operational parameters of different components are listed below. The DS anomalous fiber is set with reference frequency of 193.414 THz, attenuation of 0.2 dB km^{-1} and polarization mode dispersion of $0.2 \text{ ps/km}^{0.5m}$. The parameters of EDFA used for amplification are output power at 32 dBm and noise figure at 4.5 dB. The parameters for SOA are; injection current of 100 mA, amplifier length of $300 \times 10^{-6} \text{ m}$ and optical confinement factor of 0.35. The parameters for RAMAN are; Raman fiber length of 10 km, operating temperature of 300 K, pump wavelength of 1480 nm and pump power of 300 mW.

The optical signal is modulated by different modulation formats (NRZ and RZ) individually, transmitted and measured over different distances of 80, 100, 120, 140, 160, 180 and 200 km at 2 ps/nm/km dispersion. The performance of different hybrid optical amplifiers are evaluated in terms of output power, Q-factor and Bit Error Rate (BER) for different modulation formats (RZ, NRZ). The maximum single span transmitted distance was optimized.

RESULTS AND DISCUSSION

The performance of different hybrid amplifiers (EDFA-EDFA-EDFA, RAMAN-EDFA-EDFA, EDFA-EDFA-RAMAN, RAMAN-EDFA-RAMAN, EDFA-EDFA-SOA) have been compared for $64 \times 10 \text{ Gbps}$ DWDM system with different modulation formats in terms of output power, Q factor (dB) and BER.

Figure 2 shows the graphical representation of output power as a function of fiber length, for 64 channels DWDM system (NRZ modulation format). This graph shows that as the fiber length

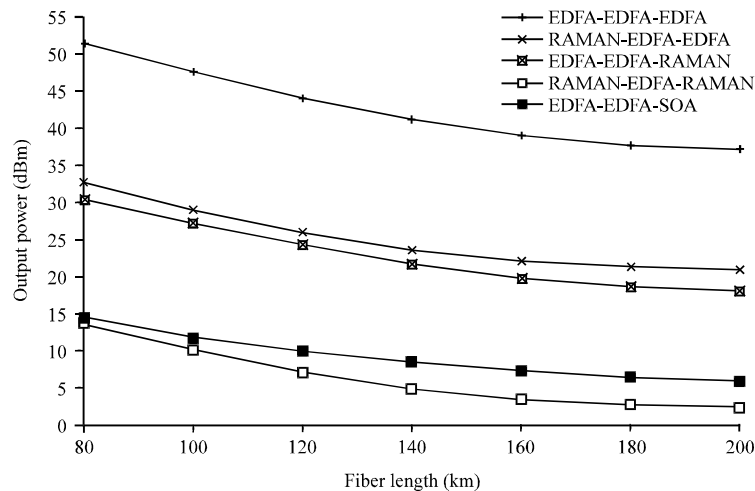


Fig. 2: Output power vs., fiber length for 64 channels DWDM system (NRZ)

increases from 80-200 km, the degradation of output power occurs. Degradation occurs due to continuous raise in ASE as the span distance increases. The variation in output power for the different hybrid optical amplifiers at dispersion of 2 ps/nm/km are 51.49 to 37.21 dBm for EDFA-EDFA-EDFA, 32.75 to 21.04 dBm for RAMAN-EDFA-EDFA, 30.46 to 18.16 dBm for EDFA-EDFA-RAMAN, 13.81 to 2.59 dBm for RAMAN-EDFA-RAMAN and 14.56 to 5.99 dBm for EDFA-EDFA-SOA. The EDFA-EDFA-EDFA hybrid amplifier provides the highest output power and it also provides an output power of 37.21 dBm for the worst case (at 200 km).

Figure 3 shows the graphical representation of output power as a function of fiber length for 64 channels DWDM system (RZ modulation format). This graph also shows that as the fiber length increases from 80-200 km, the output power decreases. The variation in output power for the different hybrid optical amplifiers at dispersion of 2 ps/nm/km are 48.52 to 36.98 dBm for EDFA-EDFA-EDFA, 29.91 to 20.92 dBm for RAMAN-EDFA-EDFA, 28.01 to 17.94 dBm for EDFA-EDFA-RAMAN, 11.04 to 2.48 dBm for RAMAN-EDFA-RAMAN and 12.4 to 5.7 dBm for EDFA-EDFA-SOA. The EDFA-EDFA-EDFA hybrid amplifier provides the highest output power and it also provides an output power of 36.98 dBm for the worst case (at 200 km).

From the above discussion, it is concluded that, EDFA-EDFA-EDFA hybrid amplifier provides the highest output power for NRZ (51.49 to 37.21 dBm) and for RZ (48.52 to 36.98 dBm) which is better than the output power provided by RAMAN-EDFA hybrid amplifier (32.9 to 13 dBm), reported by Singh and Kaler (2013). Also EDFA-EDFA-EDFA hybrid amplifier provides an output power of 37.21 dBm for NRZ and 36.98 dBm for RZ, for the worst case (at 200 km) which is better than the output power provided by RAMAN-EDFA which provided an output power of 20.18 dBm at 160 km.

Figure 4 shows the Q factor as a function of fiber length for 64 channels DWDM system (NRZ modulation format). As the length of the fiber increases from 50 to 180 km, Q factor decreases due to the fiber non-linearities. The variation in Q-factor for the various hybrid optical amplifiers are 23.96-8.26 dB for EDFA-EDFA-EDFA, 24.59-5.86 dB for RAMAN-EDFA-EDFA, 26.22-7.88 dB for EDFA-EDFA-RAMAN, 24.83-5.75 dB for RAMAN-EDFA-RAMAN and 16.88-7.84 dB for EDFA-EDFA-SOA. The better Q value is provided by EDFA-EDFA-RAMAN up to 160 km (26.22 dB at 50 km and 11.01 dB at 160 km).

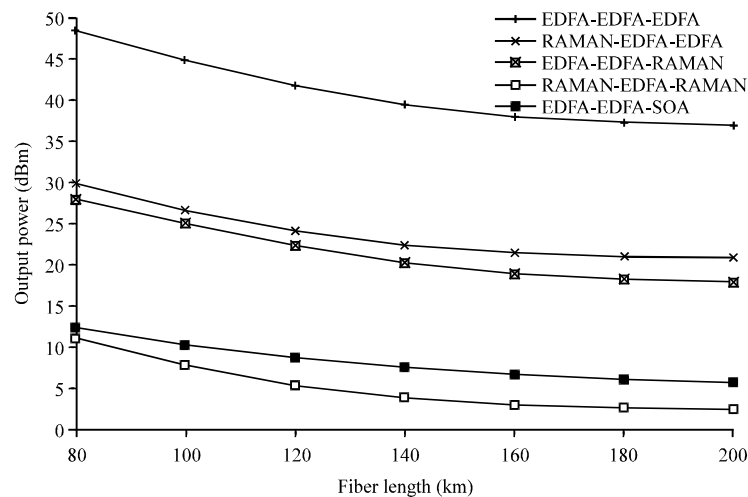


Fig. 3: Output power vs., fiber length for 64 channels DWDM system (RZ)

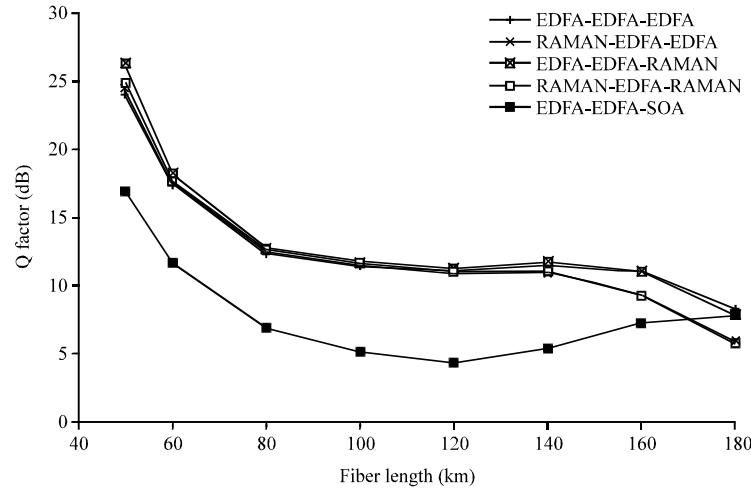


Fig. 4: Q factor vs., fiber length for 64 channels DWDM system (NRZ)

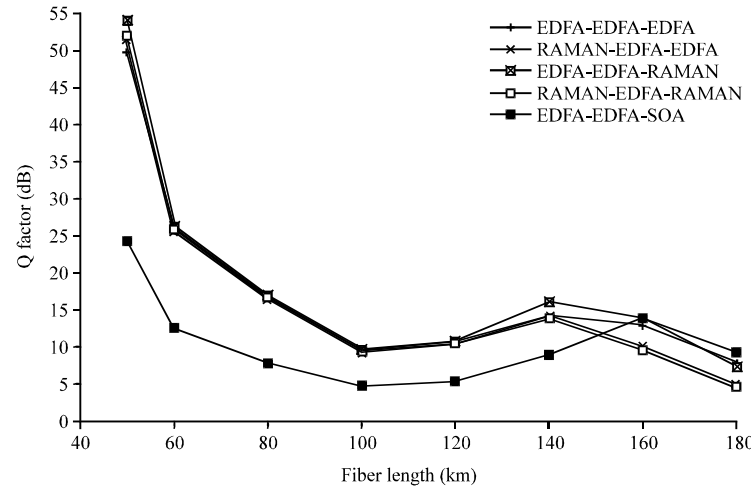


Fig. 5: Q factor vs., fiber length for 64 channels DWDM system (RZ)

Figure 5 shows the Q factor as a function of fiber length for 64 channels DWDM system (RZ modulation format). The variation in Q-factor for the various hybrid optical amplifiers are 49.57-7.74 dB for EDFA-EDFA-EDFA, 51.23-4.72 dB for Raman-EDFA-EDFA, 54.09-7.37 dB for EDFA-EDFA-Raman, 52.09-4.61 dB for Raman-EDFA-Raman and 24.29-9.22 dB for EDFA-EDFA-SOA. The better Q value is provided by EDFA-EDFA-Raman up to 160 km (54.09 dB at 50 km and 13.85 dB at 160 km).

From the above discussion, it is concluded that, the better Q value is provided by EDFA-EDFA-Raman for RZ (54.09 dB at 50 km) which is better than the Q value provided by Raman-EDFA hybrid amplifier (24.42 dB at 50 km), reported by Singh and Kaler (2013).

Figure 6 depicts BER as a function of fiber length for 64 channels DWDM system (NRZ modulation format). As the length of the fiber increases, the BER increases correspondingly. The variation in BER for the various hybrid optical amplifiers are 1.98×10^{-85} to 7.29×10^{-17} for

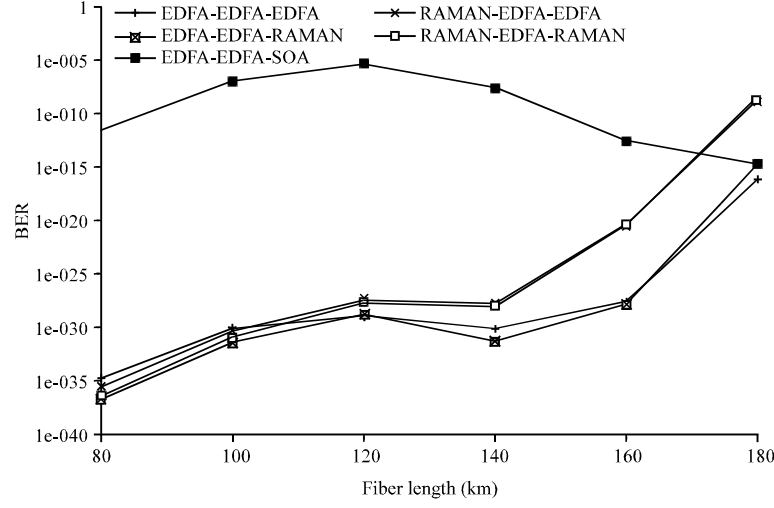


Fig. 6: BER vs., fiber length for 64 channels DWDM system (NRZ)

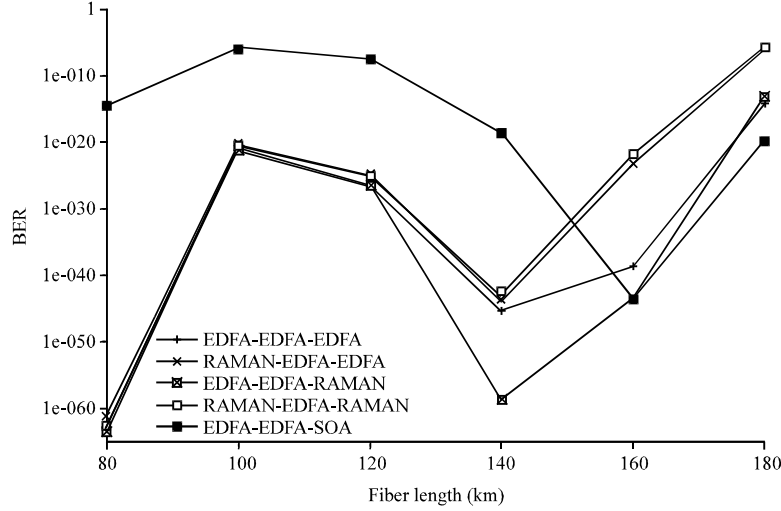


Fig. 7: BER vs., fiber length for 64 channels DWDM system (RZ)

EDFA-EDFA-EDFA, 2.39×10^{-36} to 2.27×10^{-9} for RAMAN-EDFA-EDFA, 2.22×10^{-37} to 1.58×10^{-15} for EDFA-EDFA-RAMAN, 5.09×10^{-37} to 4.46×10^{-9} for RAMAN-EDFA-RAMAN and 2.42×10^{-12} to 2.18×10^{-15} for EDFA-EDFA-SOA. The least bit error rate is provided by EDFA-EDFA-RAMAN (2.22×10^{-37} at 80 km) up to 160 km and for the worst case it becomes 1.58×10^{-15} (at 180 km) which is acceptable. At 180 km, EDFA-EDFA-EDFA provides the least BER (7.29×10^{-17}).

Figure 7 depicts BER as a function of fiber length for 64 channels DWDM system (RZ modulation format). As the length of the fiber increases, the BER increases correspondingly. The variation in BER for the various hybrid optical amplifiers are 3.3×10^{-62} to 4.99×10^{-15} for EDFA-EDFA-EDFA, 4.96×10^{-62} to 1.17×10^{-6} for RAMAN-EDFA-EDFA, 3.43×10^{-64} to 8.3×10^{-14} for EDFA-EDFA-RAMAN, 2.22×10^{-63} to 2.02×10^{-6} for RAMAN-EDFA-RAMAN and 2.81×10^{-15} to 1.46×10^{-20} for EDFA-EDFA-SOA. The least bit error rate is provided by EDFA-EDFA-RAMAN

(3.43×10^{-64} at 80 km) up to 160 km and for the worst case it becomes 8.3×10^{-14} (at 180 km) which is acceptable. At 180 km, EDFA-EDFA-EDFA provides the least BER (4.99×10^{-15}).

From the above discussion, it is concluded that, the least bit error rate is provided by EDFA-EDFA-RAMAN for RZ (3.43×10^{-64} at 80 km) which is better than the BER provided by RAMAN-EDFA hybrid amplifier for RZ (1×10^{-40}), reported by Singh and Kaler (2012). Also EDFA-EDFA-RAMAN hybrid amplifier provides a BER of 8.3×10^{-14} for RZ, for the worst case (at 180 km) which is better than the BER provided by RAMAN-EDFA which provided a BER of 3.89×10^{-9} at 180 km.

CONCLUSION

In this study, an attempt has been made to investigate the performance of different hybrid optical amplifiers (EDFA-EDFA-EDFA, RAMAN-EDFA-EDFA, EDFA-EDFA-RAMAN, RAMAN-EDFA-RAMAN, EDFA-EDFA-SOA) for 64×10 Gbps dense wavelength division multiplexed system. The performance has been analyzed on the basis of transmission distance from 80-200 km in terms of output power, Q-factor and bit error rate, when the dispersion is 2 ps/nm/Km. The impact of modulation formats (NRZ and RZ) on hybrid optical amplifiers has been further investigated and it is found that EDFA-EDFA-EDFA provides the highest output power (51.49 to 37.21 dBm for NRZ and 48.52 to 36.98 dBm for RZ). The better Q value is provided by EDFA-EDFA-RAMAN for NRZ (26.22 dB at 50 km and 11.01 dB at 160 km) and RZ (54.09 dB at 50 km and 13.85 dB at 160 km). The least bit error rate is provided by EDFA-EDFA-RAMAN for NRZ and RZ up to 160 km.

REFERENCES

- Agrawal, G.P., 2002. Fiber-Optic Communication Systems. 3rd Edn., John Wiley and Sons Inc., New York, USA., ISBN-13: 9780471215714, Pages: 576.
- Chang, S.H., J.S. Han, H.S. Chung and K. Kim, 2006. Transmission performance comparison of hybrid fiber amplifier. Proceedings of the Joint International Conference on Optical Internet and Next Generation Network, July 9-13, 2006, Jeju, pp: 274-276.
- Chung, H.S., J. Han, S.H. Chang and K. Kim, 2005. A Raman plus linear optical amplifier as an inline amplifier in a long-haul transmission of 16 channels $\times$ 10 Gbit/s over single-mode fiber of 1040 km. Opt. Commun., 244: 141-145.
- Connely, M.J., 2004. Semiconductor Optical Amplifiers. Kluwer Academic Publishers, Boston, MA.
- Delavaux, J.M.P., C.F. Flores, R.E. Tench, T.C. Pleiss and T.W. Cline *et al.*, 1992. Hybrid Er-doped fibre amplifiers at 980-1480 nm for long distance optical communications. IEEE Electron. Lett., 28: 1642-1643.
- Islam, M.N., 2004. Raman Amplifiers for Telecommunications 2: Sub-Systems and Systems. Springer, New York, USA., ISBN-13: 9780387406565, Pages: 432.
- Masuda, H., 2000. Review of wideband hybrid amplifiers. Proceedings of the Optical Fiber Communication Conference, March 7-10, 2000, Baltimore, MD., USA., pp: 2-4.
- Mustafa, F.M., A.A.M. Khalaf and F.A. Elgeldawy, 2013. Multi-pumped raman amplifier for long-haul UW-WDM optical communication systems: Gain flatness and bandwidth enhancements. Proceedings of the 15th International Conference on Advanced Communication Technology, January 27-30, 2013, PyeongChang, pp: 122-127.
- Seo, H.S., W.J. Chung and J.T. Ahn, 2005. A novel hybrid silica wide-band amplifier covering S+C+L bands with 105-nm bandwidth. IEEE Photonics Technol. Lett., 17: 1830-1832.

- Singh, S. and R.S. Kaler, 2012. Performance evaluation of 64×10 Gbps and 96×10 Gbps DWDM system with hybrid optical amplifier for different modulation formats. *Optik-Int. J. Light Electr. Opt.*, 123: 2199-2203.
- Singh, S. and R.S. Kaler, 2013. Hybrid optical amplifiers for 64×10 Gbps dense wavelength division multiplexed system. *Optik-Int. J. Light Electr. Opt.*, 124: 1311-1313.
- Singh, S., A. Singh and R.S. Kaler, 2013. Performance evaluation of EDFA, RAMAN and SOA optical amplifier for WDM systems. *Optik-Int. J. Light Electr. Opt.*, 124: 95-101.
- Thyagarajan, K.S. and A. Ghatak, 2007. *Fiber Optic Essentials*. John Wiley and Sons Inc., New Jersey, ISBN-13: 9780470152553, Pages: 344.