

Performance evaluation of hybrid optical amplifiers in WDM system

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Abstract There is a huge demand of bandwidth and gain in today's high tech era. To fulfil this demand proper amplification is required. Hybrid Optical Amplifier made a remarkable change in present optical networks in order to amplify the signals for better performance of a system. In this paper, we have proposed the different configurations of hybrid optical amplifiers for better performance of Wavelength Division Multiplexed (WDM) systems. This paper also provides a crucial insight into the performance of different configurations of hybrid optical amplifiers (such as EDFA–Raman, EDFA–EDFA and SOA–EDFA) at 10 Gbps in WDM systems with 0.4 and 0.8 nm channel spacing. Work capacities of the systems were compared on the basis of various parameters viz., fiber length, dispersion, bit error rate, quality factor, eye diagram and output power. Attempts were taken to design 8×10 Gbps Dense Wavelength Division Multiplexed system with reduced channel spacing and 16×10 Gbps WDM system with 100 GHz channel spacing. It was assessed that for WDM system with 16 inputs and channel spacing of 0.8 nm, Raman–EDFA configuration gives better results as compared to EDFA–EDFA and SOA–EDFA configurations. Further, it was observed that SOA–EDFA configuration with reduced channel spacing (0.4 nm) provided maximum output power and better eye opening with lowest BER at a distance of 100 km. Moreover, it was seen that with

increase in channel dispersion from 2 to 8 ps/nm/km, the quality of the signal started decreasing.

Keywords BER · Hybrid optical amplifier · Output power · Quality factor

Introduction

The Dense Wavelength Division Multiplexed (DWDM) with high flexibility, transparency and reliability has become the preferred technique these days to cover the longer distances along with large number of channels [1, 2]. Using this technology number of channels can be increased on demand. Conventional amplifiers such as Raman amplifier, Erbium Doped Fiber Amplifier (EDFA) and Semiconductor Optical Amplifier (SOA) are the major components of WDM optical networks [3, 4]. Among the above-mentioned amplifiers, Raman optical amplifier has grabbed huge attention due to its transparency to amplify any wavelength by adjusting pump wavelength [5]. Additionally, Raman amplifier reduces the non-linearity by improving overall performance of the system [6]. On the other hand, EDFA was used for long distance transmission due to its high on–off ratio. Simultaneously, it can also amplify large number of signals of different wavelengths. Singh and Kaler [7] reported a 20×10 Gbps WDM transmission system using cascaded inline semiconductor optical amplifier by using 100 GHz channel spacing with OOK and DPSK modulation formats. It was found that DPSK system performs best for 1190 km transmission distance with bit error rate observed $< 10^{-10}$ and quality factor of 15 dB for all channels. In comparison with Raman amplifier and EDFA, SOA is low cost, requires less power and has wide spectrum amplification that can amplify all

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signals in that range [8]. These conventional amplifiers (such as SOA, EDFA, and Raman amplifier) have their own advantages and disadvantages. They can be used individually for particular application limited small number of channels. To improve the performance of amplifiers, hybrid optical amplifiers are designed using the amplifiers as a sub system. They can be used for the ultra-long distance transmission with large dispersion. These amplifiers are arranged in different configuration (series or parallel) depending upon the configuration applications. Hybrid amplifiers are used for multichannel, multiterabit WDM systems with reduced channel spacing. Kaur et al. [9] examined SOA, EDFA and Raman amplifier individually and compared their performance. Results proved that SOA proved to be better for small number of channels, whereas EDFA proved better for large number of channels and large dispersion. Raman amplifier was used for flat gain and long distance transmission. Malik et al. [10] investigated the performance of conventional and hybrid amplifiers at reduced channel spacing of 0.4 nm. It is concluded that for the distance 100 km, SOA–EDFA configuration proved to be better than other configurations. Singh and Kaler [11] determined the performance of hybrid amplifier and found that Raman–EDFA configuration gave better outcomes in contrast to conventional amplifiers. The effect of modulation format on hybrid optical amplifier was also verified. Singh and Kaler [12] determined the performance of Raman–EDFA hybrid optical amplifier configuration using differential phase shifting keying at different channel spacing for 16×10 Gbps system and found that hybrid optical amplifier gave lesser crosstalk with good signal quality and better gain. Singh and Singh [13] determined the performance of Raman–EDFA, EDFA–SOA and Raman–SOA hybrid amplifiers configurations at 10 Gbps at reduced channel spacing for 120×10 Gbps DWDM systems. It was found that Raman–EDFA configuration gave better solution for WDM system in comparison to Raman–SOA and EDFA–SOA configurations. Singh and Kaler [14] 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 was obtained with gain variation < 4.5 dB without using any gain flattening scheme. Singh and Kaler [15] evaluated hybrid optical amplifiers for high capacities dense wavelength division multiplexed systems and summarize the different state-of-the-art configurations with the rapidly growing schemes. Also discuss the various issues such as gain bandwidth, cross talk, gain flatness and transient effect. Unfortunately, the previous designed hybrid optical amplifiers either used large channel spacing or complex components in the system to improve the performance of the system. However no focus was given

on the WDM system for channel ranging from 0.4 to 0.8 nm. In this paper, hybrid optical amplifiers are designed for wavelength division multiplexed system at 0.4 and 0.8 nm with reduced channel spacing for multichannel communication systems without using any complex components with an aim to propose hybrid optical amplifiers for next generation WDM optical communication systems.

Proposed models

The work (various models) might have been investigated before, but the model designed in this paper is a hybrid optical network which is different from that of the predecessors in terms of its configuration. We have used different parameters to evaluate the performance of the WDM system which are given in Table 1, 2 and 3. The designing and simulation of the models is done with the Optsim software.

We have proposed investigating models for multichannel (8/16 channels) WDM optical network using hybrid optical amplifier configurations. Proposed configurations can easily be illustrated from Fig. 1. In Fig. 1a, we have proposed SOA–EDFA configuration, in which

Table 1 Parameters for SOA

Parameters	Value
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

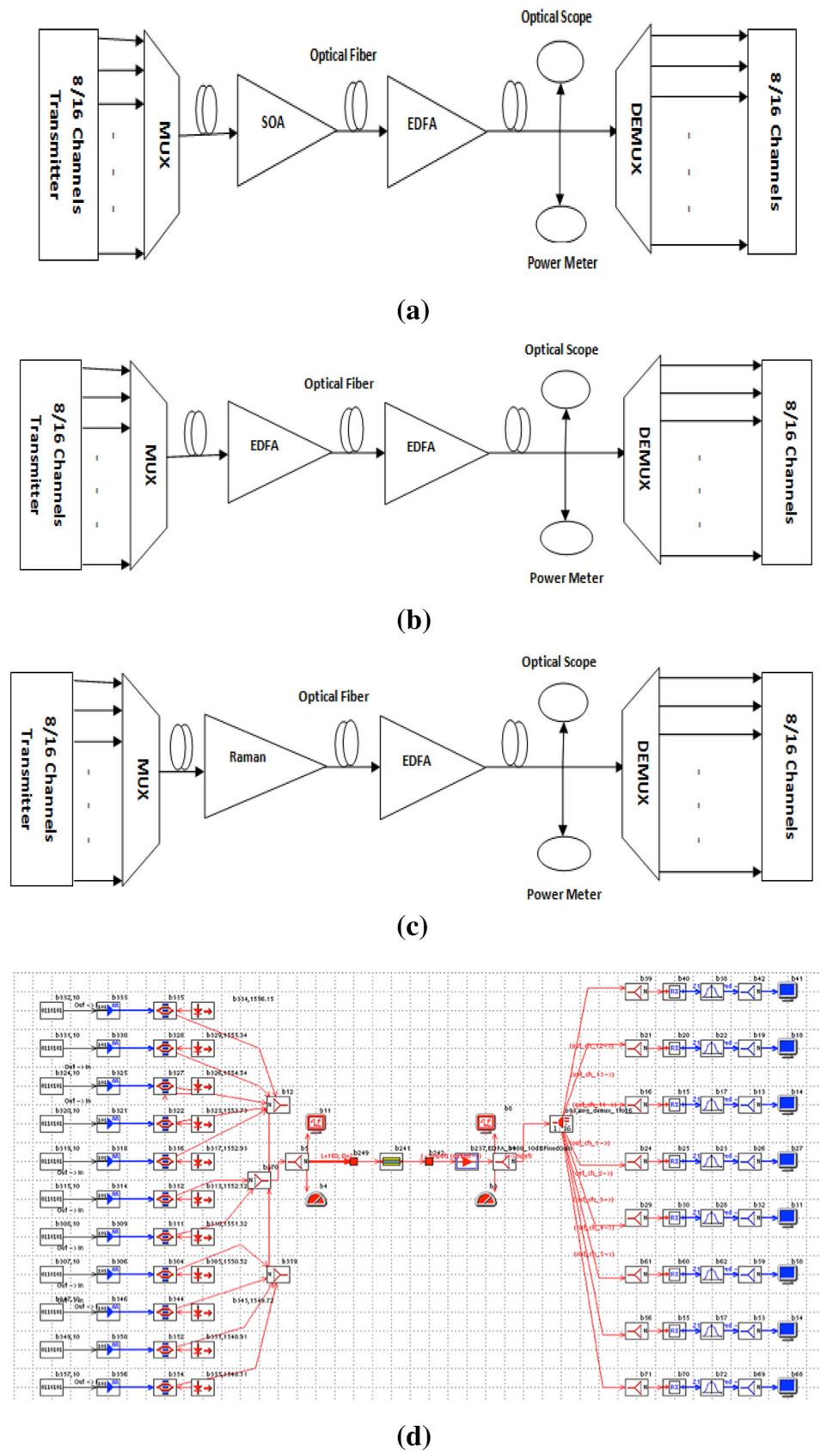
Table 2 Parameters for Raman amplifier

Parameters	Value
Raman fiber length	9 km
Pump wavelength	1452.23 nm
Pump power	100 mW
Pump attenuation	0.2 dB/km
Reference frequency for dispersion	1550 nm
Operating temperature	300 K

Table 3 Parameters for EDFA

Parameters	Value
Noise figure	4.5 dB
Output power	32 mW
Gain shape	Flat

Fig. 1 Proposed models for 8/16 channels, 10 Gbps WDM network **a** SOA–EDFA HOA configuration, **b** EDFA–EDFA HOA configuration, **c** Raman amplifier–EDFA HOA configuration, **d** simulation model for 16 channel configuration



amplification is done in two stages. In first stage, SOA is used as pre-amplifier followed by EDFA as post-amplifier. Figure 1b explains EDFA–EDFA configuration, where we have used EDFA on both the stages. Whereas in Fig. 1c Raman–EDFA hybrid optical amplifier configuration is shown where Raman amplifier is followed by EDFA. We have transmitted the data with channel spacing of 50 GHz in 8 channel configurations and channel spacing of 100 GHz for 16 channels configurations. The numerical aperture and fiber length of 0.23 and 5 m respectively are used in case of EDFA; whereas 10 mA bias current; 3 dB output insertion and 3 dB insertions loss are these parameters which are taken into consideration for SOA. Parameters which are used for Raman amplifier are 1480 nm pump wavelength, 9 km amplifier fiber length and 300 K operating temperature. The modulation scheme which is being used for both the channels configuration is NRZ with data rate of 10 Gbps. The transmitter section consists of data source, electrical driver, modulator and CW laser. In 8 channels 10 Gbps WDM system, 8 different sources are used with channel spacing of 50 GHz varying in the range of 1552.80–1555.60 nm, whereas in 16 channel, 10 Gbps WDM system, 16 different sources are used with channel spacing of 100 GHz varying in the range of 1545.20–1557.20 nm.

Results and discussion

In this section we will cover and discuss the results obtained for proposed models depending upon output power, quality factor, eye diagram and BER. We have covered and analyzed the results for different hybrid amplifier configurations.

Figures 2, 3, 4 and 5 cover the results for 16 channels, 10 Gbps WDM optical networks with channel spacing of 100 GHz. Figure 2 shows the variation of output power for

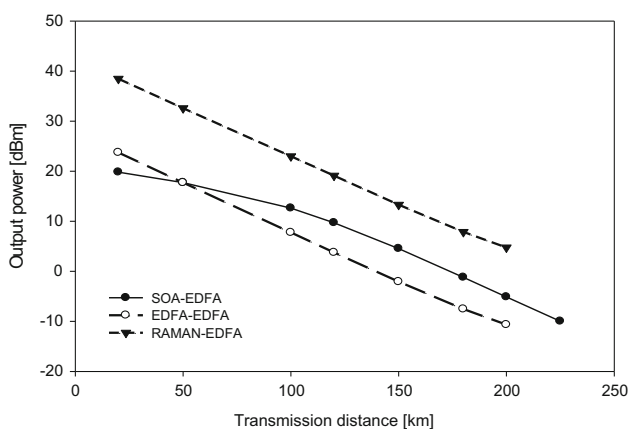


Fig. 2 Output power versus transmission distance for 16 channels with channel spacing of 100 GHz

different transmission distance. The output power (dBm) decreases with increase in transmission distance. It is clear from the figure that the output power received in Raman–EDFA amplifier configuration is always better than the other two configurations, whereas the quality factor (dB) of EDFA–Raman configuration is better for smaller transmission distance. Below transmission distance of 100 km its value is comparable with EDFA–EDFA configuration and is better than SOA–EDFA configuration. However, at any transmission distance above 100 km the SOA–EDFA configuration proved to be better than both the other configurations.

Keeping in view the results shown in Fig. 3, SOA–EDFA is preferred for distance larger than 100 km. Eye opening can be seen from results shown in Fig. 5, this figure shows the relationship between eye opening and transmission distance. It is cleared from the results that eye opening decreases for all the amplifier configurations with increase in transmission distance. This may be due to non-linearities and dispersion included in fiber through the length.

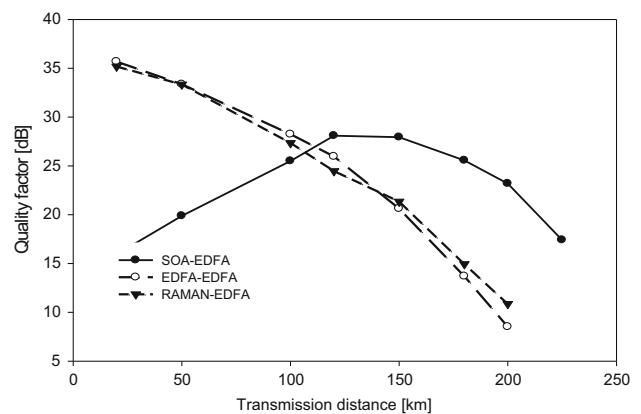


Fig. 3 Quality factor with transmission distance for 16 channels with channel spacing of 100 GHz

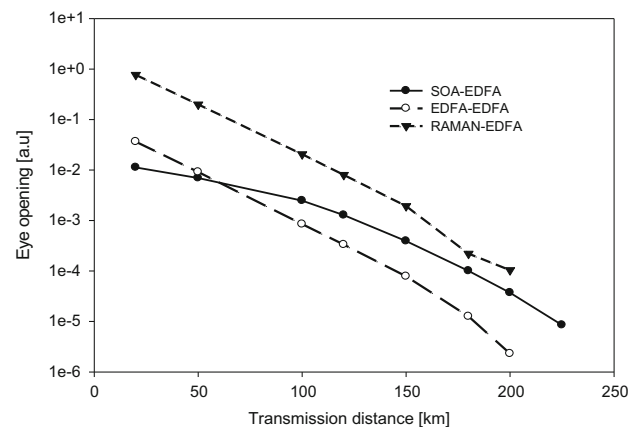
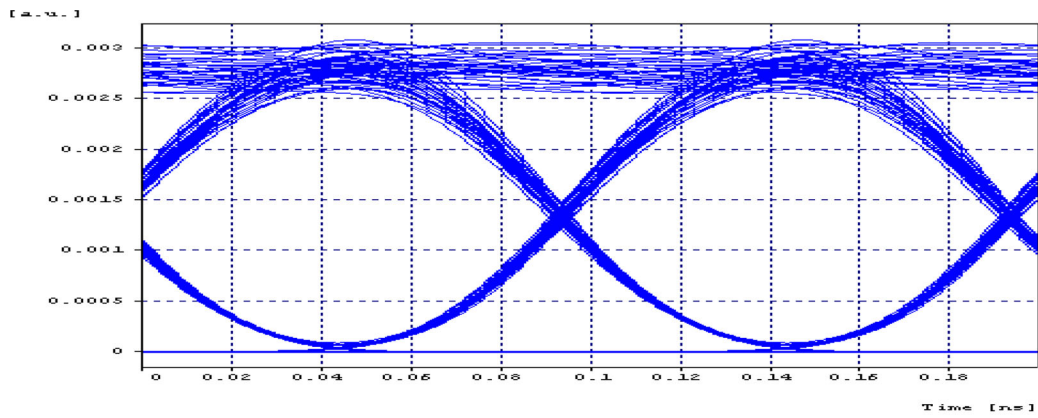
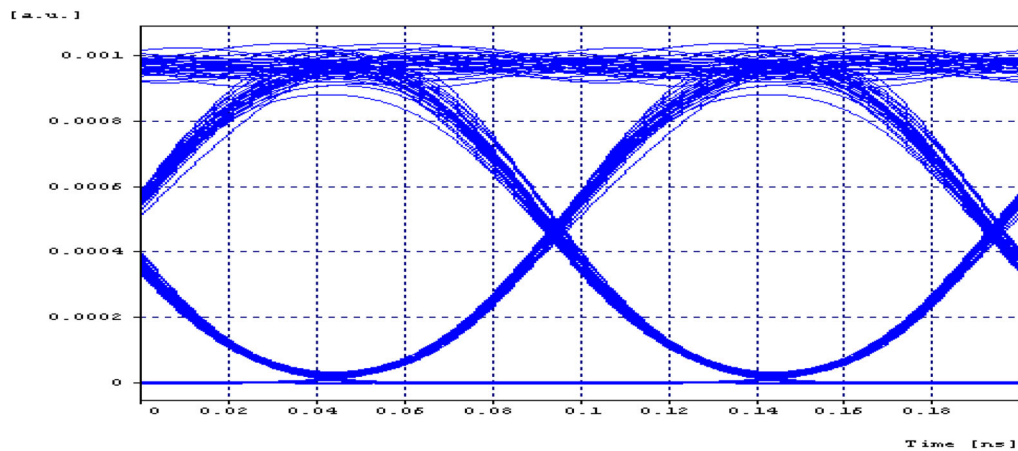


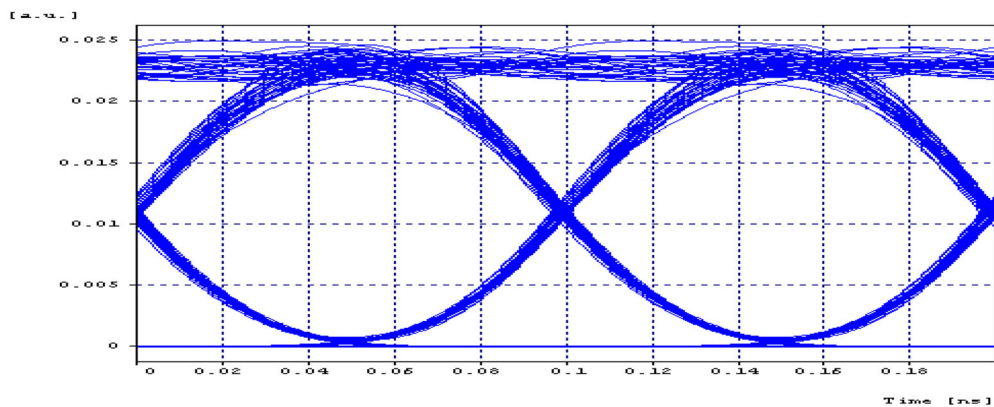
Fig. 4 Eye opening versus transmission distance for 16 channels with channel spacing of 100 GHz



(a)



(b)



(c)

Fig. 5 **a** Eye diagram for SOA-EDFA at 100 km for 16 channels with channel spacing of 100 GHz channel spacing. **b** Eye diagram for EDFA-EDFA at 100 km for 16 channels with channel spacing of

100 GHz. **c** Eye diagram for Raman-EDFA at 100 km for 16 channels with channel spacing of 100 GHz

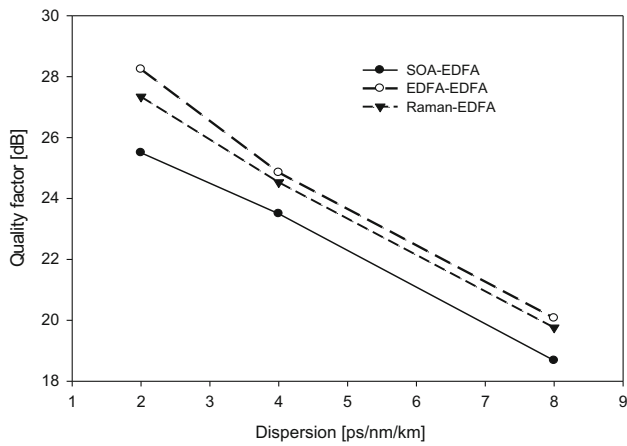


Fig. 6 Dispersion versus quality factor

Generally, larger eye opening signifies the smaller bit error rate and better quality of service. The results give a clear picture about these configurations; it can easily understand that Raman–EDFA configuration takes a lead amongst other configurations when comparing in line with eye opening.

Figure 5 shows the pattern for the eye diagram for all configurations. Eye diagram for SOA–EDFA configuration is shown in Fig. 5a, b covers the pattern for EDFA–EDFA configuration whereas eye diagram pattern for Raman–EDFA is covered in Fig. 5c. These patterns are shown for transmission distance for 100 km for 16 channels with channel spacing of 100 GHz. It is clear from the results and patterns shown in Figs. 4 and 5 that Raman–EDFA amplifier configuration is larger than both the other configurations which means better quality of service and BER.

The variation of quality factor with respect to dispersion for all configurations is shown in Fig. 6. It is clear from the results that quality of signal decreases with increase in the

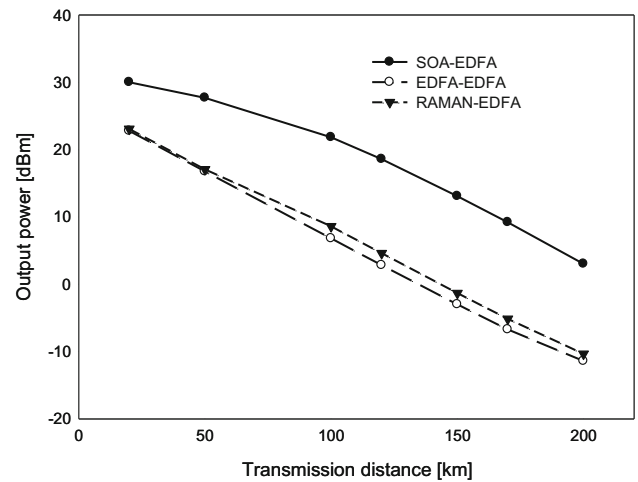


Fig. 8 Output power with transmission distance for 8 channels with channel spacing of 50 GHz

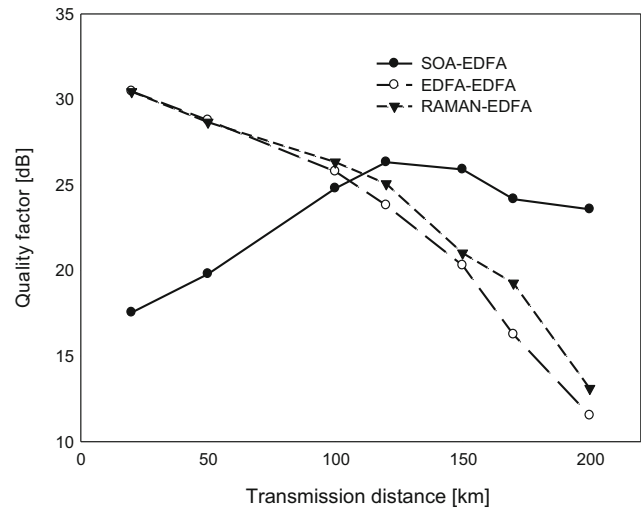


Fig. 9 Quality factor with transmission distance for 8 channels with channel spacing of 50 GHz

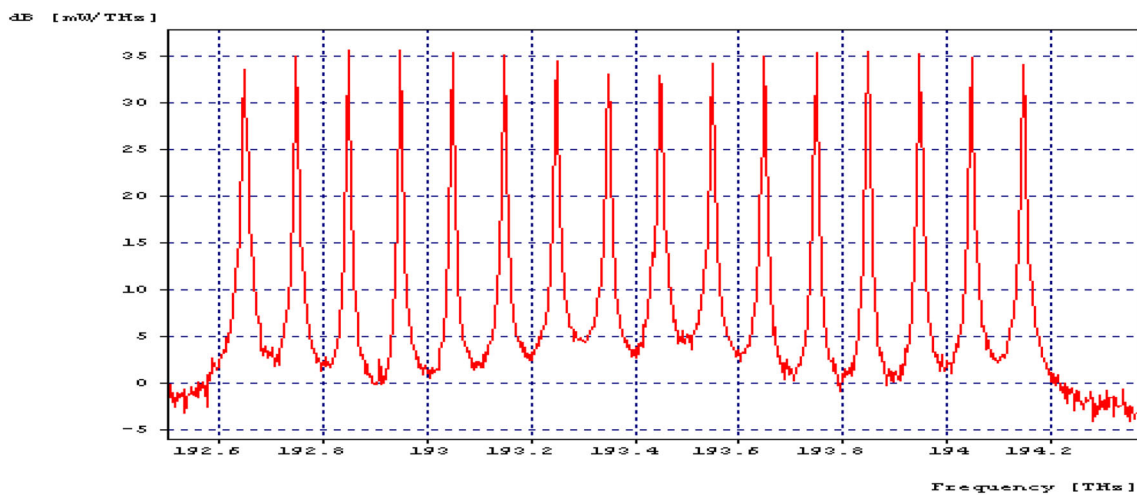
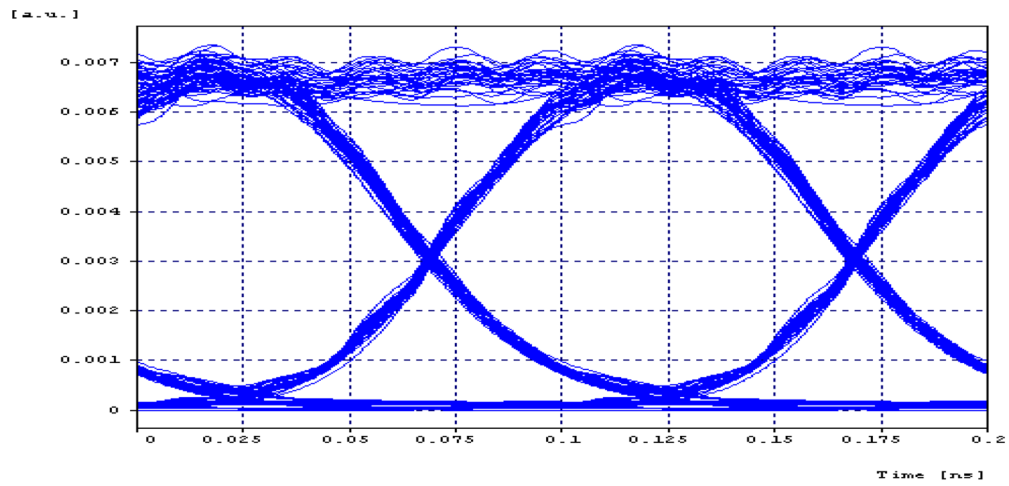
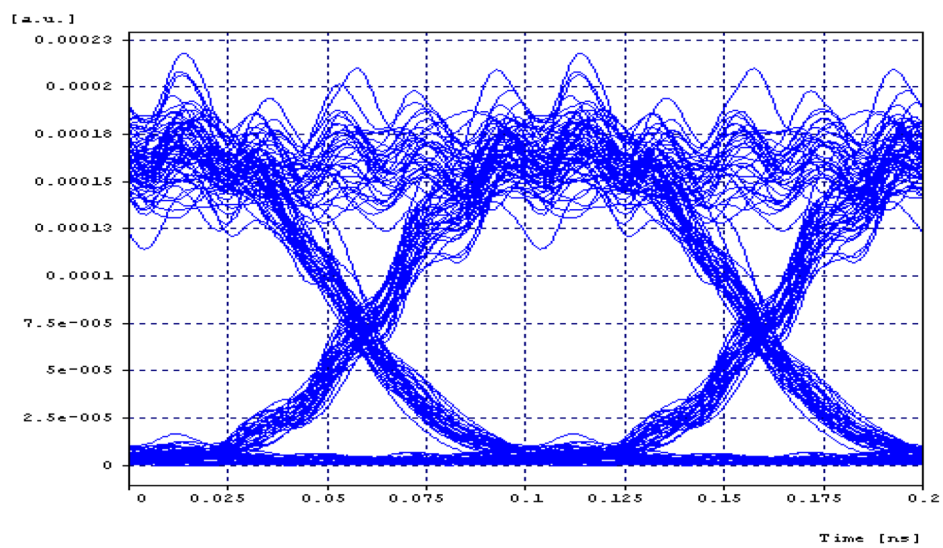


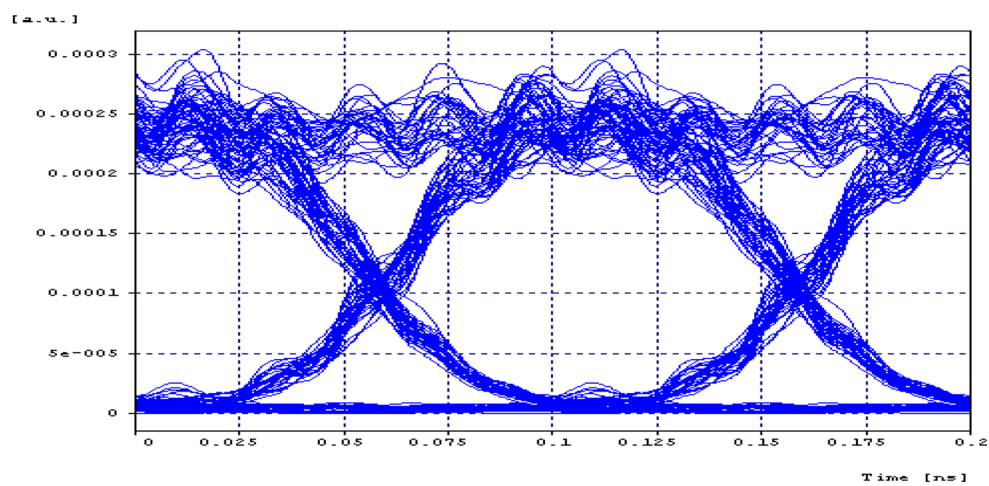
Fig. 7 Optical spectrum for Raman–EDFA hybrid amplifier at 100 km for 16 channels WDM system



(a)



(b)



(c)

Fig. 10 **a** Eye diagram for SOA-EDFA at 150 km for 8 channels with channel spacing of 50 GHz. **b** Eye diagram for EDFA-EDFA at 150 km for 8 channels with channel spacing of 50 GHz. **c** Eye diagram for Raman-EDFA at 150 km for 8 channels with channel spacing of 50 GHz

Table 4 Comparison of proposed models with the earlier models

Parameters	Singh and Kaler [7]	Kaur et al. [9]	Malik et al. [10]	Proposed hybrid optical amplifiers
Amplifiers	SOA inline	SOA, EDFA, Raman amplifier	SOA, EDFA, Raman amplifier and Hybrid optical amplifiers	Hybrid optical amplifiers
Number of channels	20	Parameters taken for 16 channels	8	16 channels
Modulation format	OOK, DPSK	NRZ	NRZ	NRZ
Maximum quality factor	More than 15 dB	26.19 dB	~ 24.80 dB for SOA–EDFA hybrid optical amplifier	~ 35 dB for Raman–EDFA hybrid optical amplifier
BER	~ 10 ⁻¹⁰	~ 10 ⁻¹⁰ (For SOA at 200 km)	–	9.506 × 10 ⁻⁹ (at 180 km for Raman–EDFA hybrid optical amplifier)
Maximum output power	–	12.040 dB (EDFA)	21.84 dB for SOA–EDFA hybrid optical amplifier	~ 38 dB for Raman–EDFA hybrid optical amplifier

channel dispersion further, EDFA–EDFA hybrid optical amplifier configuration improved to be better than other hybrid amplifiers configurations. Keeping in view the results shown in Figs. 2, 3, 4, 5 and 6 it is concluded that besides the better performance of all the amplifier configurations over conventional amplifiers, EDFA–Raman amplifier configuration take an edge over other configurations. If we ignore the performance of EDFA–EDFA configuration over Raman–EDFA configuration than the later proved to be better as compared to the other configuration in term of all the parameters for any distance < 100 km. However we can conclude that for any transmission distance above 100 km SOA–EDFA configuration is better in terms of every parameter.

Considering Raman–EDFA hybrid optical amplifier configuration better than the other configuration we have plotted the optical spectrum for this configuration which is shown in Fig. 7. This spectrum is shown for 16 channels WDM system with channel spacing of 100 GHz and is plotted for frequency of 192.65–194.15 THz.

Results shown in Figs. 8, 9 and 10 cover the comparison of hybrid amplifier configurations for different parameters depending upon for 8 channels with channel spacing of 50 GHz. Figure 8 covers the relationship of optical output power with transmission distance, whereas, quality factor is covered in Fig. 9. Eye diagram for different configurations for 8 channels with channel spacing of 50 GHz are covered in Fig. 10. From the Fig. 8 it is clear that output power decreases with increasing transmission distance. It is also observed that for lower number of channels SOA–EDFA configuration has better output power as compared to other two configurations. Figure 9 shows the variations of quality factor with respect to transmission distance. Once again it has observed that the Raman–EDFA configuration gives better quality of

service below transmission distance of 100 km. And as the transmission distance is increased above 100 km SOA–EDFA configuration give better results. It can also be observed that the quality factor is independent of number of transmission channels but mainly depends on transmission distance. Figure 10 shows the patterns for eye diagrams for different configurations with 8 channels at reduced channel spacing. Eye opening for EDFA–EDFA, Raman–EDFA and SOA–EDFA configuration at a distance of 150 km is 0.000157655 a.u., 0.000229118 a.u and 0.00636113 a.u respectively. BER for SOA–EDFA, EDFA–EDFA, Raman–EDFA configurations are calculated to be 1e–040, 2.39004e–025, and 1.96501e–028 respectively. It is cleared from the results that SOA–EDFA configuration has better eye opening. From the above results shown in Fig. 8, 9 and 10 it can be concluded that for 8 transmission channels with channel spacing of 50 GHz SOA–EDFA in every aspect.

Table 4 represents the consequence of currently investigated optical amplifiers with the earlier models. It was observed that the proposed hybrid amplifier showed enhancement over the contemporary optical amplifiers in different parameters. Raman–EDFA gives maximum quality factor and maximum output power among all the configurations at lower transmission distances.

Conclusion

In this paper, we proposed the different configurations of hybrid optical amplifiers for better performance of WDM systems. We also compared the performance of different configurations of multichannel (8/16 channels) hybrid optical amplifiers (such as Raman–EDFA, EDFA–EDFA & SOA–EDFA) at 10 Gbps in WDM systems for 100 GHz

and 50 GHz channel spacing. This comparison is made in terms of output power, quality factor, BER and eye diagram. It is concluded that the proposed hybrid optical amplifier configurations are better than conventional amplifiers; however, Raman–EDFA amplifier configuration take an edge over other configurations. Raman–EDFA configuration proved to be better as compared to the other configuration in term of all the parameters for any distance < 100 km for large number of channels. It was also concluded that for any transmission distance above 100 km SOA–EDFA configuration is better in terms of every parameter for small number of channels. It is also seen that the quality factor is independent of number of transmission channels but mainly it is dependent upon transmission distance.

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