Open Access Journal of Physics
Volume 2, Issue 1, 2017, PP 44-49

Analysis of Hybrid Optical Amplifiers for Dense Wavelength Division Multiplexing (DWDM) Systems Using Adequate Channel Spacing

Swati Tyagi[1], Dr. Amit Kumar Garg[2], Riya Sinha[3]

[1,3]*MTech. Scholar, Department of Electronics and Communication Engineering, DCRUST, Murthal*
[2]*Professor, Department of Electronics and Communication Engineering, DCRUST, Murthal*

***Corresponding Author:** Swati Tyagi , *MTech Scholar, Department of Electronics and Communication Engineering, DCRUST, Murthal*

ABSTRACT

The entire network system makes use of Dense Wavelength Division Multiplexing (DWDMs) has emerged through optical amplifier implementation. The further performance of DWDM network is improved through exploiting Hybrid Optical Amplifiers. This paper proposed an idea of various hybrid optical amplifiers for dense wavelength division multiplexed system at decreased channel spacing (<0.2 nm) to achieve higher gain and reduced crosstalk. Here, a semiconductor optical amplifier (SOA), and Raman amplifier, both in combination with a erbium doped fibre amplifier that is Raman-EDFA(R-E) and EDFA-Semiconductor Optical Amplifier (E-S) are investigated for the first time at 0.05 and 0.1nm channel spacing. We exhibit that the R-E (HOA) gives better gain (23.9 dB) and bring around reduced cross-talk (-14.1dB) by using minimum bandwidth. Based on the simulation results, it is concluded that 70 km is the finest span distance at which R-E accomplish a 2450 km transmission distance in terms of performance.

Keywords: *HOA, DWDM, Q-factor, BER, R-E and E-S.*

INTRODUCTION

The evolved multimedia services and the increase in the number of worldwide internet users have raised the demand for high capacity networks; this in turn evolved the optical transmission system. In today's era, the accepted solution for transmission capacity for increasing transmission capacity is by using the wavelength division multiplexing (WDM) to keep the required level of system's performance over longer transmission distance. Adversely this kind of multichannel system along with linear effects like optical attenuation and chromatic dispersion is more sensitive to fibre non-linearity which results in signal distortion and thus causes dramatic degradation in the performance of the system. Primarily, the effect that puts the limitation on distance of transmission is optical signal attenuation. To compensate this optical signal attenuation, one of the way is to by making use of signal repeaters and the other is by amplifying the optical signal. For WDM systems the former solution was not the best choice because it requires de-multiplexing, conversion, processing and regenerating the signals of all the 16 channels; thus, it was quite complex and expensive. Simultaneously when optical signals were being amplified their power also gets increased during transmission without any conversion. Thus, this method is way simpler and cheaper than those using repeaters. Optical Amplifiers used in WDM transmission are Semiconductor optical amplifiers (SOAs), doped fiber amplifier (DFAs), Raman amplifiers(RAs). But the major drawback of SOAs is that they produce large amount of ASE and serious signal distortion that is caused through their gain dynamics. Irrespective of SOA case DFA provides signal amplification with less signal impairments, but their frequency is highly dependent on the gain spectrum because of the doped material. Also, SOA-EDFA are being attractive now-a-days as they have high on-off ratio and thus increase the transmission distance. Moreover most of the noiseless amplifications are provided by the Raman amplifiers; in such cases the gain spectrum can be changed by varying the number of pumps and their frequencies to achieve higher gain. Thereby it causes the need of powerful pump which is not much reasonable. For combining the benefits and to compensate the drawbacks of different amplifiers we can use them together, forming a hybrid amplifier. Hence hybrid amplifiers are designed to increase the span length, to reduce the impairments introduced through non-linearity of fibre and thus these are capable of enhancing the bandwidth of the optical communication system. A good variety of such pairs can be used in modern transmission systems.

In the literature, numerous experiments have been performed using hybrid optical amplifiers for a compact and long-haul transmission in DWDM system. In [11], by combining Raman amplifier and linear optical amplifier as an in-line HOAs a long-haul transmission of 16*10 g bit/sec over a single mode fiber (SMF) of 1040 km was demonstrated. But the major drawback associated to this is that it was limited to number of channels having 100 GHz of channel spacing. In [12], with a channel spacing of 50 GHz without any in-line dispersion compensation DWDM transmission of 43Gbit/sec differential phase shift keying was presented over 1200 km of Non-zero dispersion shifted fibre. Inadequately, this experiment was also limited due to a channel spacing of 50 GHz. In recent past, a solution of this problem comes out by analyzing the super DWDM technologies and carrying out the transmission experiments with 12.5Ghz (0.1 nm) channel spacing over 320 km that is 4 spans of 80 km of a standard single mode fiber without any dispersion. Unfortunately, this was also limited because of the transmission distance and span numbers.

Still, these models were not appropriate to be used for the designing ultra-high capacity DWDM systems, since the achieved results were restricted to the number of channels or channel spacing of (>0.2nm). Additionally, analysis of hybrid optical amplifier for the channel spacing of less than 0.2nm has not been done yet. The main aim of this paper is to provide a capacity system which uses less bandwidth and a reduced channel spacing. Recently, an effective gain flattened L-band optical amplifier was proposed which make use of hybrid combination of the Raman amplifier and EDFA for 160*10 gbps DWDM system at 25GHz interval [13].

In this paper, previous work is extended by taking advantage of Raman and EDFA amplifier at reduced channel spacing. Further, the performance of multi-span of R-E HOA for long-haul communication systems is investigated.

In section 2, setup is explained. Result and characterization from numerical simulations are presented in sec.3 and the conclusion is summarized in sec.4.

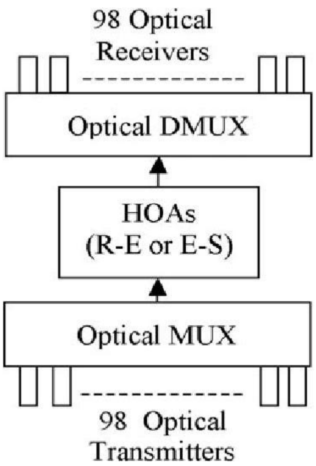


Fig1. *DWDM system with hybrid R-E and E-S. amplifier [9] On (top) and EDFA-SOA (bottom).[9]*

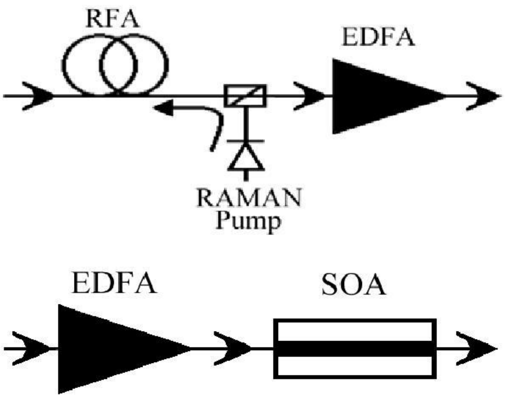


Fig2.*Configurations of HOAs: R-E with Raman fiber*

THE NUMERICAL SIMULATION SYSTEM

The system which is proposed is shown in figure-1. Figure-2 shows two different schemes of Raman fiber amplifier (RFA), EDFA and SOA. The numerical simulations are carried out at 1448.2nm as used in [13]. In the (1) configuration of the hybrid amplifier as shown in fig-2(top), before amplification the signal first enters into the Raman stage by the cascaded EDFA, called hybrid R-E. In the II configuration of the hybrid amplifier as shown in fig-2(bottom), the amplification in this configuration occurs twice by the EDFA followed by SOA, called hybrid E-S. In R-E configurations, due to smaller pump-noise coupling onto the signal, the Raman stage is operated in the counter pumped geometry.

In this, output power of EDFA is considered fixed with a gain of 25 dB and a noise figure of 4dB. A PIN photo detector with a responsivity of 0.875 A/W and a dark current of 0.1nA is used at the receiver's side. For the amplification, channel spacing of 0.8nm is required for the system which consist (C+L) band of EDFA. The parameters of RFA and SOA are given in table 1 and table 2.

Table1. *Raman Fibre amplifier parameters*

Parameters	Value
Fibre Length	15 km
Fibre attenuation	0.2 dB/km
Dispersion	16ps/nm/km
Operating Temp.	300k
Pump Wavelength	1448.2nm
Pump Power	650 MW

Table2. *Semiconductor Optical Amplifier*

Parameters	Value
Amplifier Length	750μm
Active layer width	2.0μm
Active layer thickness	0.21μm
Confinement factor	0.41
Saturation power	20.8mW

Here, 98 CW lasers are exploited as the transmitter source with carefully selected frequency. Each signal has an input power of -10mW, thus the quality of the signal gets decreased with the increase in input power. The transmitter and receiver both are made up of SMF of 60 km with 10 Ps/nm/km dispersion and 4 km DCF with -96 Ps/nm/km dispersion.

RESULTS AND DISCUSSION

Impact of Reduced Channel Spacing for Hoas

In this case, 98 NRZ modulated signal channels are used to cover the area of 1546.725 to 1551.575 nm at 0.05 nm channel spacing. In the same way, the spectra of 1536.9 to 1556.3, 1523.8 to 1526.6, 1510.7 to 1568.9, and 1497.6 to 1575.2 nm are taken for 0.1, 0.2, 0.4, and 0.8 nm of channel spacing, respectively. The HOAs are characterized in terms of gain and Q-factor. To illustrate the performance of HOAs, the results from the first channel are considered for their corresponding channel spacing. Fig 3 shows the optical spectrum at transmitter side for different channel spacing such as 0.05 and 0.1 nm.

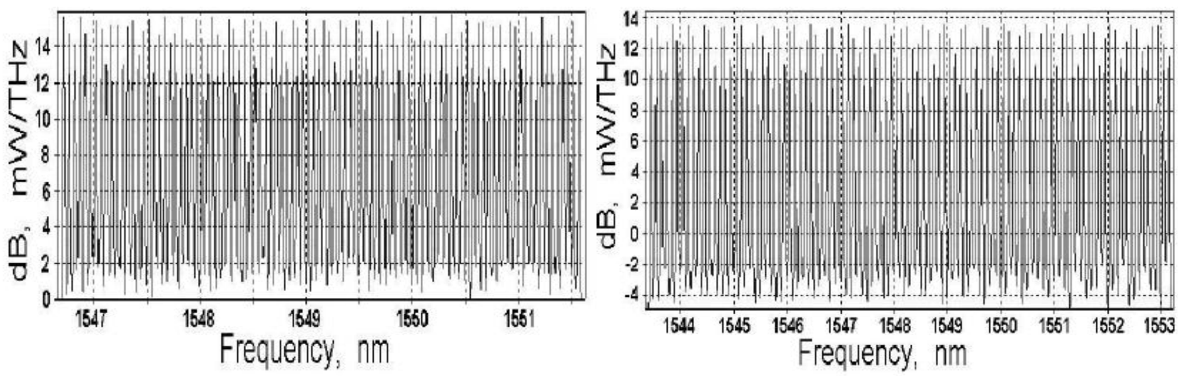


Fig3. *Optical spectra for 0.05 nm (left) and 0.1 nm (right) spaced DWDM signals.[9]*

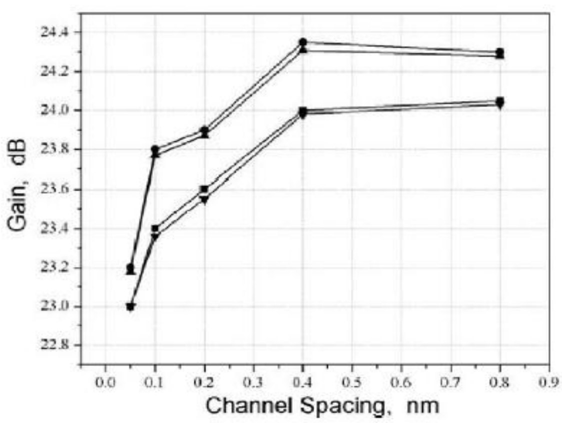


Fig4. *Gain variations at reduced spacing [7]*

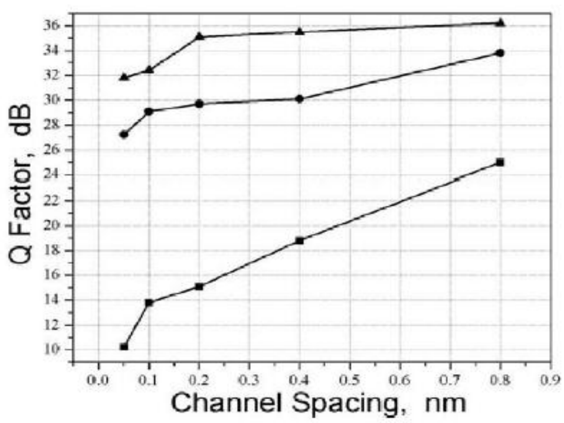


Fig5. Q-factor variations at reduced channel spacing [7]

Here, the gain variations for different channel spacing's are observed. From fig-4 it is seen that R-E provides larger gain(>23.2 dB) for all cases as compared to E-S. This is because in E-S HOA, SOA contributes to non-linear effects and inter channel crosstalk at smaller channel spacing. In R-E and E-S HOA, a larger gain is observed that is 24.35 and 24.02 dB at 0.4 nm of channel spacing.In fig-5 the quality of different optical signals has been shown for different channel spacing's. The quality of the received signal gets decreased with the decrease in the channel spacing's, it occurs because each amplifier contributes to some non-linear effects and inter-channel cross talk of DWDM channels. Then it was observed that R-E increases the quality factor by 4dB from the corresponding input quality. Whereas, SOA contributes to a degraded performance.

From the above results, it seems that the R-E HOA provides better results as compared to the E-S HOA. So further crosstalk induced by the R-E HOA is determined and illustrated for a long- haul communication system.

Cross-Talk Induced by R-E HOA.

Here, the cross-talk induced by the R-E HOA is presented for different input laser powers and then the numerical simulations are compared with the calculated results. Crosstalk amplifiers can be calculated by various methods. One approach to calculate cross-talk is to use two input signals, one of which is modulated. The other method is to use two signals, when both the input signals are modulated. In this case, we make use of second method to calculate the cross-talk induced by HOAs. Then the cross-talk here can be defined as the variation in the output power at λ_1= (1536.9 nm) caused by the addition of another signal at λ_2= (1527.1 nm). Thus, the cross-talk can be written as:

$$\boxed{\text{Crosstalk} = \frac{\text{P1, out(P2, IN = OFF)} - \text{P1, out(P2, IN = ON)}}{\text{P1, out(P2, in = OFF)}}}$$

Where, P_2 ,in is the input power, $P_{1,}$ out is the amplified output power, and indices 1 and 2 indicates the two wavelength signals. And P_1, P_2 are modulated signals. Figure 6 further shows the dependence of the crosstalk induced by the R-E HOA on the input power. The crosstalk induced is in the range of -14 to -11.2dB. Also, due to saturation when input power gets increased, the crosstalk also gets increased.

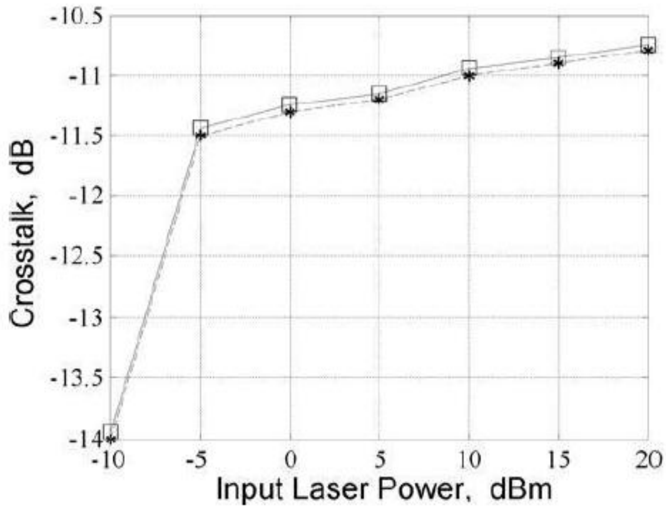
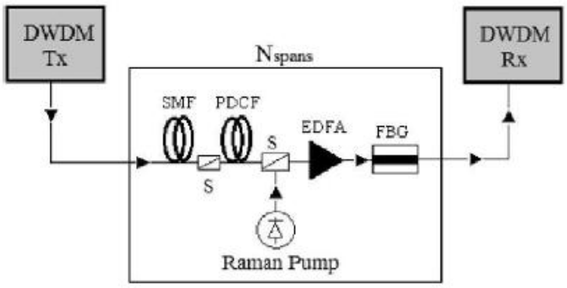


Fig6. *Crosstalk variations with different input laser power using the R-E HOA, where the results of simulations are shown by squares, and the results of calculations by stars.[13]*

Long-Haul Communication Using R-E HOA at Different Span Distances

A setup for long-haul communication is shown in figure-7. Each transmitter transmits 98 optical channels with a channel spacing of 0.2 nm, where each individual channel's speed is 2.488 G bit/s. Here, a long-haul system is considered which is composed of N spans; each span length for different cases is shown in Table 3. Each span consist a stretch of SMF with 16ps/nm/km dispersion, DCF with 96ps/nm/km dispersion, a fixed output power of EDFA with 22 dB of fixed gain and a fibre brag grating with –550ps/nm of compensating dispersion. The fibre length parameters for SMF and DCF are L span and L_{DCF}. The total link can be written as:

$$\text{Ltotal} = \text{Nspans} \cdot (\text{Lspan} + \text{LDCF})$$



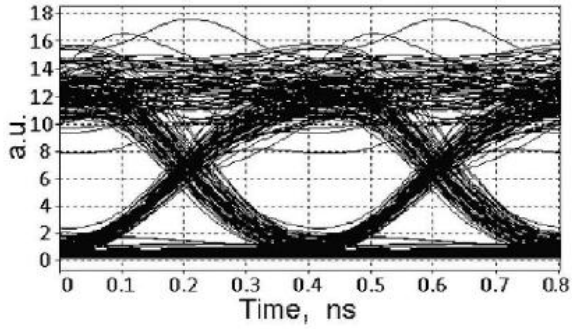


Fig.7. *Setup for long haul communication using the R-E HO[13].* **Fig8.** *Eye Diagram after 2450 km using the R-E as in Line amplifier. [13]*

As figure 7 depicts that DCF is backward pumped at 1448.2 nm with a power of 650 MW, called as pumped DCF, to provide Raman amplification and dispersion compensation in parallel [23]. Length of SMF and DCF is obtained by the below equation:

$$L_{DCF} = \frac{-Dspan}{Ddcf} Lspan$$

Where *D span* and D_{dcf} are the dispersion parameters for SMF and DCF.

Table 3: Different variations of SMF and DCF

No.	DCF km	SMF km
1	4	24
2	6	36
3	8	48
4	10	60
5	12	72
6	14	84

Table 4: Variations in output parameters when R-E is used

No.	Spans	L_{max}, km	Q Factor, dB	BER
1	23	644	15.19	$9.07 \cdot 10^{-9}$
2	29	1218	15.20	$5.92 \cdot 10^{-9}$
3	24	1344	15.41	$2.7 \cdot 10^{-9}$
4	35	2450	15.63	$1.09 \cdot 10^{-9}$
5	28	2352	15.47	$2.19 \cdot 10^{-9}$
6	23	2254	15.43	$1.61 \cdot 10^{-9}$

Table 4 shows the maximum distance L max as a function of L_{span} at a target Q-factor >15 dB and bit rate of<10^{-9}. At L_{span} of 70 km (NO.4), the L_{total} is around 2450 km (35 spans of No.4) when R-E is used. By observing these results R-E HOA is recommended for long-haul communication at large L_{span} for better performance. The received eye diagrams for the DWDM system consisting of R-E is shown in figure 8 above.

Conclusion

R-E and E-S HOA were investigated as 98 channel DWDM systems with channel spacing of 0.05, 0.1, 0.2, 0.4 and 0.8 nm. It has been shown, that by making use of minimum bandwidth (19.4 nm), (R-E) HOA gives better gain (23.9 dB) with less crosstalk of (-14.1 dB).On other hand, E-S gives a degraded performance. The combination of R-E covers a transmission distance of 2450 km by using a span distance of 70 km with an acceptable BER and Q-factor. Thus, by observing the results, we recommend R-E HOAs to be used in high capacity long haul communication systems at a reduced rate of channel spacing with large span distance.

References

[1] A. N. Z. Rashed and M. A. Metawe'e, J. Russ. Laser Res., 34, 255 (2013).

[2] F. M. Abbou, C. C. Hiew, H. T. Chuah, et al., J. Russ. Laser Res., 29, 57 (2008).

[3] S. Singh and R. S. Kaler, Opt. Eng., 53, 036102 (2014).

[4] R. S. Kaler, T. S. Kamal, and A. K. Sharma, Int. J. Fiber Integr. Opt., 21, 361 (2002).

[5] M. L. Nielsen, K. Tsuruoka, T. Kato, et al., J. Lightwave Technol., 28, 837 (2010). 217

Journal of Russian Laser Research Volume 35, Number 2, March, 2014

[6] J. H. Lee, Y. M. Chang, Y. G. Han, et al., J. Lightwave Technol., 23, 3483 (2005).

[7] S. Singh and R. S. Kaler, IEEE Photon. Technol. Lett., 26, 173 (2014).

[8] Mohammed N. Islam, Raman Amplifiers for Telecommunications 2: Physical Principles, Springer, New York (2004), p. 422.

[9] S. Singh and R. S. Kaler, Opt. Commun., 266, 100 (2006).

[10] Uh-C. Ryu, K. Oh, W. Shin, and U. C. Paek, IEEE J. Quantum Electron., 38, 149 (2002).

[11] H. S. Chung, J. Han, S. H. Chang, and K. Kim, Opt. Commun., 244, 141 (2005).

[12] J. D. Downie, J. Hurley, S. Ten, et al., Electron. Lett., 46, 60 (2010).

[13] S. Singh and R. S. Kaler, IEEE Photon. Technol. Lett., 25, 250 (2013).

[14] C. R. Giles and E. Desurvire, J. Lightwave Technol., 9, 271 (1991).

[15] C. Headley and G. P. Agrawal, Raman Amplification in Fiber Optical Communication Systems, Elsevier/Academic Press, New York (2005).

[16] A. A. M. Saleh, Electron. Lett., 24, 835 (1988).

[17] A. Carena, V. Curri, and P. Poggiolini, IEEE Photon. Technol. Lett., 13, 1170 (2001).

[18] C. R. S. Fludger, V. Handerek, and R. J. Mears, Electron. Lett., 37, 15 (2001).

[19] K. S. Bhatia, T. S. Kamal, and R. S. Kaler, J. Russ. Laser Res., 33, 483 (2012).

[20] S. Singh, and R. S. Kaler, Int. J. Fiber Integr. Opt., 31, 208 (2012).

[21] G. Zhang, J. T. Stango, X. Zhang, and C. Xie, IEEE Photon. Technol. Lett., 17, 501 (2005). 22. S. Singh and R. S. Kaler, Opt. Fiber Technol., 19, 428 (2013).

[22] U. Tiwari, K. Rajan, and K. Thyagarajan, Opt. Commun., 281, 1593 (2008).

[23] S. Singh and R. S. Kaler, Opt. Eng., 52, 096102 (2013).