

# Performance enhancement of recycling residual pumped hybrid Raman-EDFA in bi-directional wavelength division multiplexed- passive optical network

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We propose and exemplify a novel concept of remotely pumped hybrid Raman and erbium doped fiber amplifier (EDFA) in the scenario of bi-directional wavelength division multiplexed-passive optical network (WDM-PON). In proposed system, single fibre bragg grating (FBG) is used to reflect Residual pump power for multiband band amplification. The gain flattening filter is also used to increase the gain flatness over effective gain bandwidth and as a result the gain variation is reduced to  $-0.26$  dB and  $-0.47$  dB for upper and lower arm, respectively.

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**Keywords:** Wavelength division multiplexing (WDM), Raman fibre amplifier (RFA), Erbium doped fibre amplifier (EDFA)

## 1. Introduction

In topical years, WDM has potentially augmented system capacity to many folds making optical fibre communication future of telecommunication [1-3]. The bi-directional WDM-PON has become most imperative research interest in optical communication due to its high speed, high capacity, cost effectiveness, simplicity etc. Since no active component is used in PON, it offers enormous benefit to both user and operator. On the other hand, the hybrid optical amplifier (HOA), composed of a Raman and an EDFA, has emerged as a promising solution for extending the span and transmission capacity of WDM systems [4]. It is attractive because of its ability to tailor the gain profile, compensate for fiber dispersion loss, and suppress spontaneous [5-6]. This particular hybrid Raman and EDFA architecture has also a positive impact over the global gain profile when recycling the residual Raman pump in a cascaded EDF section as secondary signal amplification block. In recent years, remotely pumped fiber amplifiers being explored as their maintenance becomes simple as compared to normal pumping. In addition, due to high speed channels the dispersion dominates the performance of the network so the Raman amplification in dispersion compensation fibre (DCF) and dispersion flattened fibre (DFF) is the best solution to amplify and compensate the dispersion simultaneously [6,7].

WDM-PON suffers power penalty, i.e. transmission and component losses which are the most important issues that need to be addressed [8]. According to current requirement, there is a need of optical access network with cost effective solutions. To achieve this objective a bi-directional WDM-PON with recycle residual pumped HOA is proposed. In the upper arm of proposed bi-

directional WDM-PON the RFA is used as a gain medium and in lower arm hybrid Raman-EDFA is situated [9,10]. In addition our aim is to achieve large gain flatness (using gain flattening filter) with acceptable performance (in the terms of bit error rate (BER), Q-factor etc.) at both upper and lower end.

## 2. System set up

Fig. 1 depicts a basic setup of bi-directional WDM-PON, where the upper arm (having 55 channels over 1512-1555.2 nm bandwidth with 0.8 nm of channel spacing are tenuously pumped by array of laser diode with 300 mw pump power) signals are passes through 10 km of dispersion flattening fiber which provides a flat dispersion of 0.85 ps-km/nm and then is further passed through RFA of 25 km. RFA provides a large gain of approximately 10 dB over the entire bandwidth. But we tend to encounter large gain ripples over the gain bandwidth. So, gain flattening filter is used to decrease gain ripple to approximately 0.26 dB in upper arm. Signal then passes through pump reflector which forms the base for residual pumping. The four pumps (tuned at 1424 nm, 1434 nm, 1444 nm, 1454 nm, each pump wavelength is used with 300 mW power) are used to directly pump the RFA and residually pump the HOA for efficient amplification of S+C+L bands. FBG reflects pump power and transmits the pumped signal to lower arm for further pump a hybrid amplifier. In lower arm 55 channels over 1556 nm – 1599.2 nm with 0.8 nm channel spacing is passes through the proposed hybrid amplifier after traveling via GFF1. The hybrid amplifier provides a good gain with approximately 7 dB of gain ripple which is flattened by gain flattening filter. The gain flattening filter provides

gain flatness of 0.71 dB. The BER analysers are used at both upper and lower end to analyse the performance of the proposed network in the term of BER, Q-factor, eye diagrams etc. In upper arm only Raman fiber amplifier is used which is enough to amplify 55 channels with better gain and gain flatness, as the original pump is co-propagated in parallel to data channels. But after FBG reflector the pump power is reduced after travelling through Raman amplifier, so to achieve better gain and gain flatness we have used EDF with Raman amplifier called hybrid amplifier. This hybrid amplifier is residual pumped by same pump signal. The various parameters of RFA, EDFA, uplink and downlink used in this analysis is described in Table 1-4, respectively.

Table 1. RFA parameters

| Parameters                         | Values                    |
|------------------------------------|---------------------------|
| Raman fibre length                 | 25 km                     |
| Raman loss                         | 0.2 dB/km                 |
| Residual Pump wavelengths          | 1424, 1434, 1444, 1454 nm |
| Pump power                         | 300 mw each               |
| Pump attenuation                   | 0.2 dB/km                 |
| Dispersion at reference frequency  | 16.75 ps/nm/km            |
| Reference frequency for dispersion | 1550 nm                   |
| Operating temperature              | 300 k                     |

Table 2. EDFA parameters

| Parameters                  | Values                             |
|-----------------------------|------------------------------------|
| EDFA length                 | 10 m                               |
| Erbium metastable life time | 10 ms                              |
| Core radius                 | 2.2 $\mu\text{m}$                  |
| Erbium ion density          | $10 \times 10^{24} \text{ m}^{-3}$ |
| Numerical Aperture          | 0.24                               |

Table 3. Uplink fiber parameters

| Parameters                         | Values                       |
|------------------------------------|------------------------------|
| Dispersion flattened fibre length  | 10 km                        |
| Pump attenuation                   | 0.2 dB/km                    |
| Dispersion at reference frequency  | 0.85 ps/nm/km                |
| Reference frequency for dispersion | 1550 nm                      |
| Dispersion slope                   | 0.075 ps/nm <sup>2</sup> /km |

Table 4. Downlink fiber parameters

| Parameters                                 | Values                      |
|--|-----------------------------|
| Downlink dispersion flattened fibre length | 10 km                       |
| Pump attenuation                           | 0.2 dB/km                   |
| Dispersion at reference frequency          | 0.15 ps/nm/km               |
| Reference frequency for dispersion         | 1550 nm                     |
| Dispersion slope                           | 0.01 ps/nm <sup>2</sup> /km |

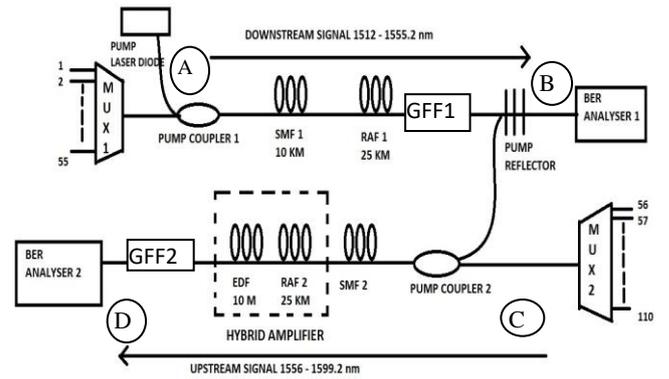


Fig. 1. Schematic of bi-directional WDM-PON with remotely pumped Raman/EDFA hybrid amplifier

### 3. Result and discussion

In this Section, the results from the proposed setup is discussed at the different observation points i.e. A, B, C and D (see Fig. 1). Fig. 2 shows the optical spectrum of downstream signals at both Stage A and B, respectively. It can be observed that the power levels of pump and data signals are same (as shown in Fig. 2 (a)) but after 35 km the variation in power power is observed over the effective channels due to induced non-linearities and noises, noise can be seen in the green lines (as shown in Fig. 2 (b)). On the other hand, same pattern can be observed in Fig. 3, the pump signals are not flat, because it is reflected by FBG to lower arm for further pumping. But the power spectrum of data signals are flat because they are newly introduced from multiplexer 2 (see Fig. 3 (a), at Stage C). At stage D (shown in Fig. 3 (b)) due to the noise introduced by fiber and amplifiers, the gain variation over effective bandwidth is observed which is reduced to its minimum value by using GFF. The green lines shows the noise generated over the bandwidth which alter the power/gain levels of the data signals.

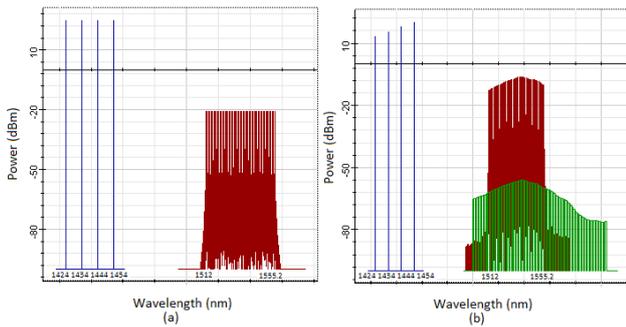


Fig. 2. Optical spectrum having data and pump signals at (a) Stage A and (b) Stage B

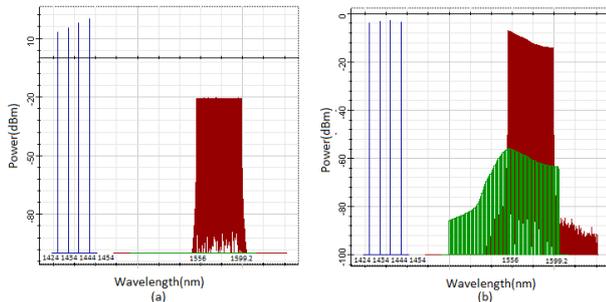


Fig. 3. Optical spectrum having data and pump signals at (a) Stage C and (b) Stage D

Fig. 4 shows the pump power variation at different Stages. It can be seen that the power level is going to reduce after pumping the multiple amplifiers and after traveling through fibers.

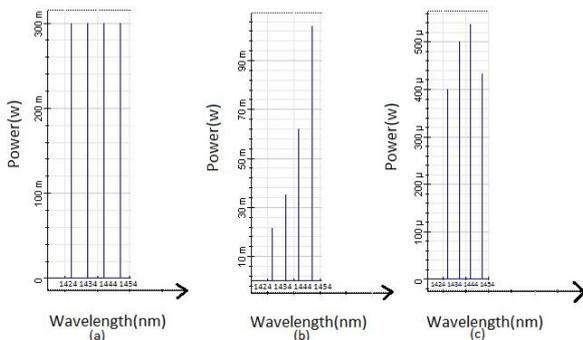


Fig. 4. Pump power at (a) Stage A (b) Stage B and (c) Stage D

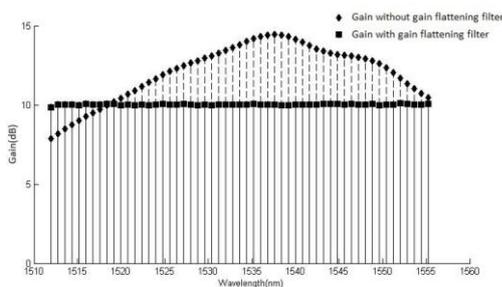


Fig. 5. Gain spectrum of for S+C band (covering 1512 – 1555.2 nm bandwidth) with and without gain flattening filter

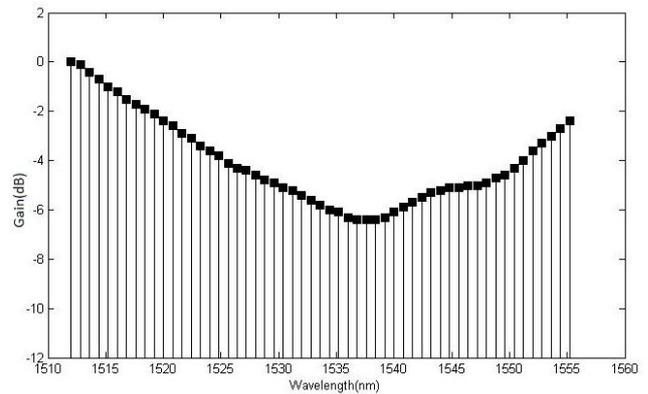


Fig. 6. Gain profile of GFF1 for downstream channels covering 1512 – 1555.2 nm with 0.8 nm of interval

Fig. 5 shows gain profile of downstream channels (covering 1512 nm – 1555.2 nm) with and without gain flattening filter. It can be seen that the gain spectrum is not flat, so there is need of gain flattening filter to increase the gain flatness. To reduce the gain variation of downstream signals the GFF1 is used with selective gain profile as shown in Fig. 6. These gain values are direct replica of the gain values of downstream signals. From Fig. 5, it can be seen that, using GFF1, the gain variation of downstream signals are reduced from ~7.1 dB to ~0.26 dB.

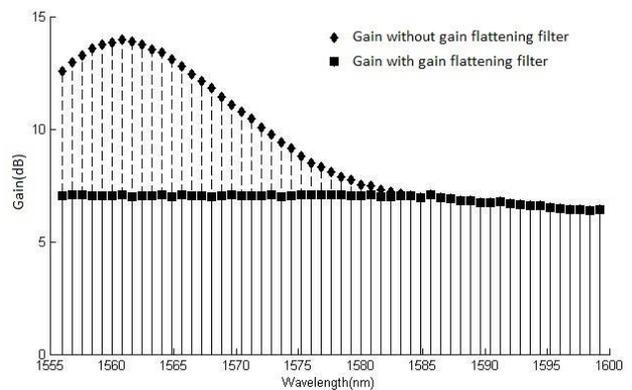


Fig. 7. Gain spectrum of for C+L band (covering 1556 – 1599.2 nm bandwidth) with and without gain flattening filter

Fig. 7 shows gain profile of upstream channels (covering 1556 nm – 1599.2 nm with 0.8 nm of interval) with and without gain flattening filter. It can be seen that the gain spectrum is not flat having gain variation of more than 7 dB. To reduce the gain variation of upstream channels, the GFF2 is used with selective gain profile as shown in Fig. 8. These gain values are direct replica of the gain values of upstream signals. From Fig. 7, it can be seen that, using GFF2, the gain variation of upstream signals are reduced from ~7.6 dB to ~0.47 dB.

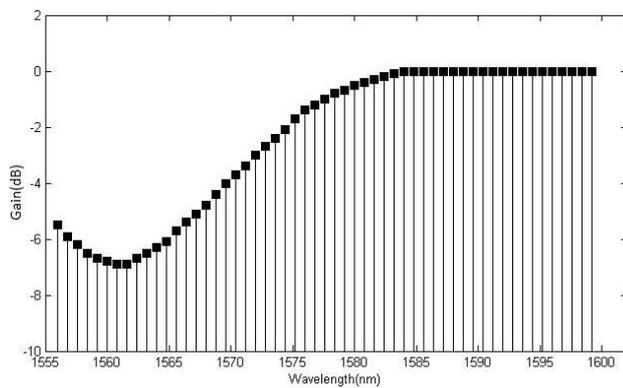


Fig. 8. Gain profile of GFF2 for upstream channels covering 1556 – 1599.2 nm with 0.8 nm of interval

From previous results it can be seen that the proposed system provide good level of gain values with improved gain variation ( $< 0.46$  dB). To further check the acceptability of the proposed system, the BER performance is also analysed. Fig. 8 and 9 shows the BER performance of downstream and upstream channels, respectively. It can be seen that, all channels are detected with acceptable BER (i.e. near  $1 \times 10^{-12}$  and  $1 \times 10^{-13}$  for downstream and upstream channels, respectively). For validity the eye diagrams at 1512 nm and 1556 nm (shown in Fig. 11) have been detected with good level of eye opening.

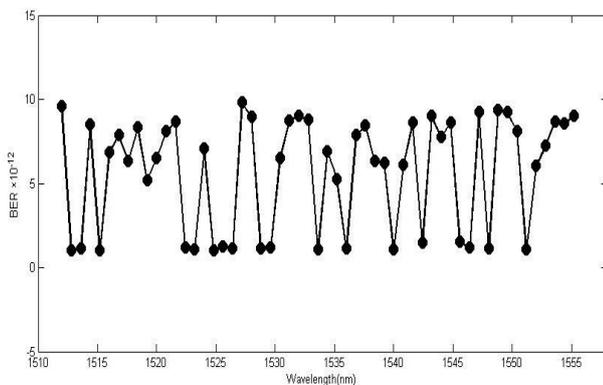


Fig. 9. BER values versus downstream channels

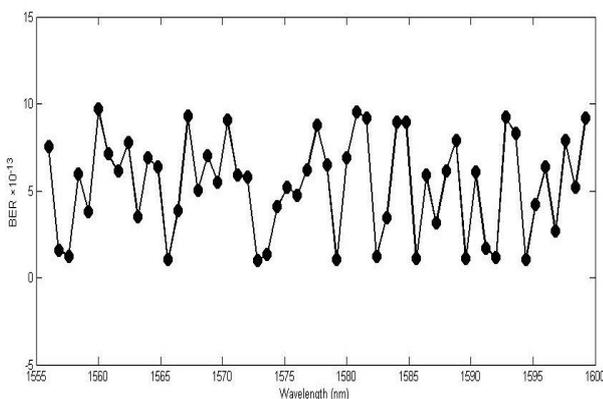


Fig. 10. BER values versus upstream channels

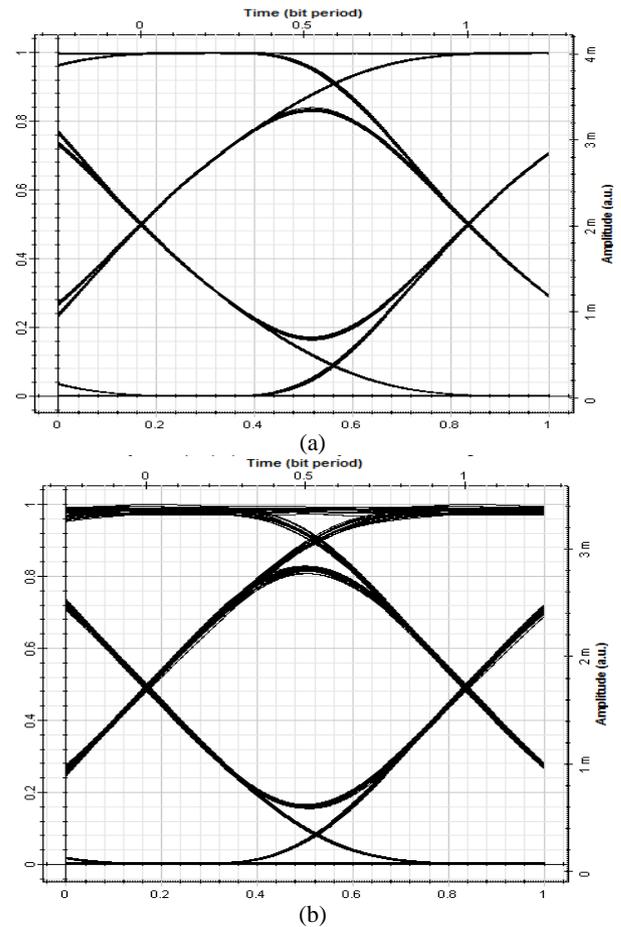


Fig. 11. Eye diagram detected at (a) 1512 nm and (b) 1556 nm

#### 4. Conclusion

We illustrated 110 DWDM channel bi-directional WDM-PON with RFA and HOA being remotely pumped by multi pump laser diodes. It is observed that using Gain flattening filters (GFF1 and GFF 2) the proposed setup provides gain flatness of 0.26 dB and 0.47 dB in upper and lower arm, respectively. After having the acceptable values of BER even in the scenario of remotely pumped broadband amplifiers the proposed system is recommend for future high capacity optical technologies with cost effective solution.

#### References

- [1] Govind P. Agrawal, 3rd edition, Academic Press 1 (2011).
- [2] S. Singh, R. S. Kaler, Int. J. Fiber Integr. Opt. **31**(3), 208 (2012).
- [3] S. Singh, R. S. Kaler, IEEE Photon. Technol. Let. **26**, 173 (2014).
- [4] S. Singh, S. Saini, G. Kaur, R. S. Kaler, Journal of the Optical Society of Korea **18**(2), 118 (2014).
- [5] A. Banerjee, Y. Park, F. Clarke, H. Song, S. Yang, J. Opt. Netw. **4**, 737 (2005).

- [6] S. Singh, R. S. Kaler, *Optik* **123**, 2199 (2012).
- [7] P. Palai, K. Thyagarajan, B. P. Pal, *Opt. Fiber Technol.* **3**, 149 (1997).
- [8] W. Lee, M. Y. Park, S. H. Cho, *IEEE Photon. Technol. Lett.* **17**, 2460 (2005).
- [9] S. Singh, S. Saini, G. Kaur, R. S. Kaler, *Opt. Eng.* **53**, 765 (2014).
- [10] J. M. Oh, S. G. Koo, D. Lee, S. J. Park, *J. Lightwave Technol.* **26**, 144 (2008).
- [11] J. H. Lee, Y. G. Han, S. B. Lee, *Opt. Express* **14**, 9036 (2006).

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