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Performance evaluation of dynamically flattened gain *L*-band RAMAN-EDFA-RAMAN hybrid optical amplifier for super dense wavelength division multiplexing system

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In this paper, we have evaluated the performances of super dense Wavelength Division Multiplexing (SD-WDM) system with respect to flat gain. RAMAN-EDFA-RAMAN hybrid optical amplifier (HOA) is the backbone of the system. Further, this model has investigated the effects in terms of L-band flattened gain, output power, crosstalk, and bit error rate with 50 GHz channel spacing. Flat gain greater than 14 dB has obtained at 5 mW and reported the poor performances by 7 mW and 17 mW with the range of 188-192 THz. Gain variation < 2.1 dB has obtained. Highest output power has also obtained at 5 mW, 7Mw and 17 mW accordingly. Final conclusion has recommended that better gain flatness has attained without using any costly components such as gain equalizer and multi-pumping for SD-WDM system.

Keywords: SD-WDM system, Gain flatness, Hybrid optical amplifier

1 Introdction

Hybrid optical amplifier shows the remarkable improvement in the long haul super dense multiplex system. Gain flatness is an important parameter to boost up the level of the SD-WDM system and more flattened gain are reflected the best performance of the system with least bit error rate and cross talk. Now a day, it is the hot topic for the researcher. Simranjit *et al*.[1] have explored a model for flat gain and proven to attain (> 10 dB) flat gain with minor variation (< 4.5 dB). The best performances of the system can be enchanced by RAMAN-EDFA-RAMAN. So, many modifications have made to enhance the performances with this amplifier in terms of flat gain. Kaler *et al*.[2] have explored the performances of 130x10 Gbps WDM system with 0.02 nm channel spacing. Further, it has observed with the declaration that Er-doped waveguide amplifier and Er-Yb co-doped waveguide amplifier has been reduced the variation in terms of power and gain from 7.2-3.1 dB. Least variation and distortion are the current requirement of for high speed network. So, cascaded optical amplifier has been shown the best choice for the researcher to enhance the performance of the SD-WDM system. Karasek *et al*.[3] have explored the model to enhance the performance of HOA gain and best rating of OSNR has been reported in literature[10-12]. Takushima *et al*.[4] have investigated the gain spectrum of EDFA with the observation that the gain has clamped in the band of 1555 nm.and depends up on the power level for the band of 1535 nm with suggestion that the improvements can be made by the MZ gain equalizer. Yeh *et al*.[5] have demonstrated a model based on EDFA and EDWA with the help of two experiments. In the first experiment, maximum gain variation of 2.05 dB can be accomplished in the range of 1528-1562 nm. Evaluation with respect to gain has been made by the optical feedback method in the second experiment. It has also been suggested that GF and GC were the main parameters to adjust the gain variation. Piskarska *et al*.[6] & Kaler *et al*.[7] have reported that RAMAN and EDFA amplifier were the essential backbone for the SD-WDM system.

Kidorf *et al*.[8] have reported that EDFA amplifier provides the best response to the system in terms of flat gain than RAMAN amplifier due to multi layer transmission, but it could be further improved by providing suitable pumping. Furthermore, hybrid

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optical amplifier also provides the incredible performances for SD-WM system and it is dismissed the effect of nonlinearity and crosstalk in the medium and provided the best output in terms of flat gain. Lee *et al*.[9] have proclaimed that hybrid RAMAN-EDFA-RAMAN is the vital technology for the future DWDM system, respectively.

Rakesh *et al.*[10] have explored a new concept of the polarization hybrid passive optical network for the different optical amplifier. Rakesh *et al*.[11,12] have investigated the WDM/TDM PON for 256 ONUs. In this paper, we have proposed a new model for the SD-WDM system with RAMAN-EDFA-RAMAN HOA. And declare that it provides the better gain flatness without using costly components such as gain equalizer and multi pumping etc.

Kumar *et al*.[17-20] have shown the impact of different set of hybrid opical amplifier (HOA) in various aspects in terms of chaneel spacing, fiber nonlinearities,crosstalk, power lekage and HOA nonlinearity for super dense wavelength division long distance optical communication with recived the quality factor of 45.5 dB, gain of 36 dB, ouput power of 28.55 dBm and bit error rate of 10^{-6}. Further, apporach from these publications have shown massive support in this research work for attaining dynamically flattened gain.

2 Simulation Setup

The simulation setup for 180x10 Gbps SD-WDM system for L-band with 188 to 192 THz is shown in Fig. 1. Each input signal is modulated with the help of amplitude modulator. 180 channels are transmitter with 50 GHz channel spacing. Data source, electric drive, NRZ modulator and CW laser are the main components of the transmitter. The performances of the proposed system are evaluated by applying different per channel input laser power 5 mW, 7mW, and 17mW, respectively. The parameters of the different optical amplifier are given in Tables 1 and 2, respectively. The received signals are demultiplexed on the receiver side. PIN photodetector with responsively of 0.875 A/W and dark current of 0.08 mA are also used to optical to electric conversion for analysis the signal characteristics.

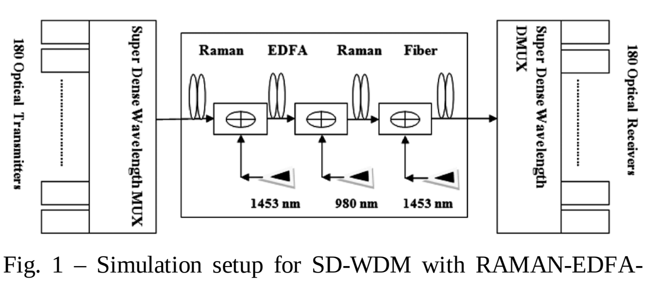

Fig. 1 – Simulation setup for SD-WDM with RAMAN-EDFA-RAMAN amplifier.

3 Results and Discussion

The effect of gain versus channel spacing for the proposed model is shown in Fig. 2. The maximum values of gain are attained from 14.5 dB to 15.55 dB with input power of 5 mW, 7 mW and 17 mW, respectively. Gain flatness of 6.1 dB is recorded at 5 mW input power,which shows the better performance than literature[1,2]. Retardation is observed from 14.33 dB to 2.8 dB with the range of 190.5 THz to 192.0 THz. Least variation of 2.1 dB is recorded for 5 mW input power. Gain variations of 4.4 dB and 10.55 dB are also illustrated for 5 mW and 17 mW, respectively. This is due to the effect of non-linearity

Table 1 – Parameters of RAMAN amplifier in SD-WDM system

Parameters	Value
RAMAN fiber length	14 km
RAMAN loss	0.2 dB/km
Pump Wavelength	1450-1485 nm
Pump power	480 mW
Pump attenuation	0.2 dB/km
Dispersion	2.15 ps/nm/km
Operating Temperature	300 K
Reference frequency for dispersion	1555 nm

Table 2 – Parameters of EDFA amplifier in SD-WDM system

Parameters	Value
Noise figure	4.5 dB
Maximum small signal gain	35.6
Gain shape	Flat
Out Power	32 mW

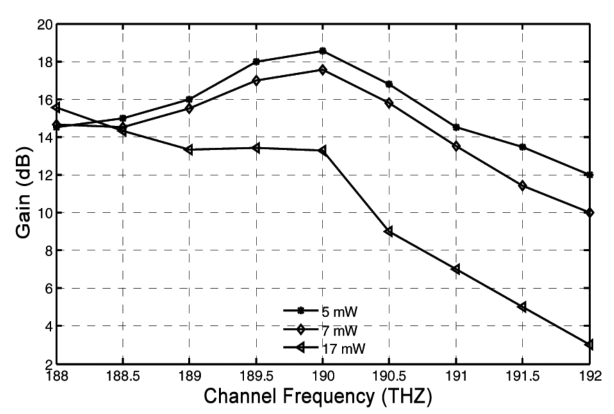

Fig. 2 – Gain spectra for RAMAN-EDFA-RAMAN hybrid optical amplifier for L-band SD-WDM system.

induced by each amplifier and ASE, further, it can be improved by selecting the suitable pumping wavelength and power. Here, it is also concluded that at the input power of 17 mW, nonlinearity, ASE, and losses are maximized. Resultantly, not many good results are reported for flattened gain.

To illustrate the effect of crosstalk by RAMAN-EDFA-RAMAN hybrid optical amplifier is shown in Fig. 3. Mainly, there are two types of approach available in the research articles for calculating the cross talk. According to the first approach, two input signals are taken, where only one of them is modulated. On the other hand, both the input signals are modulated in the second approach. We recommend the second approach in our proposed model for calculating the cross talk. The crosstalk here by calculated[13] as:

$$\text{Cross talk} = \frac{P1out(P2in=off) - P1\ out(p2in=on)}{P1,out(P2,in=off)}$$

Where, two input signal wavelength is given by index 1 and 2, and P_{1in} and P_{2out} are the amplified input and out power. The crosstalk induces by RAMAN-EDFA-RAMAN, HOA is calculated with respect to different input power 5 mW, 7 mW and 17 mW, respectively. It is also observed that effect of crosstalk increases due to gain saturation from (-22 dB to -11 dB) for 5 mW, (-24 dB to -13 dB) for 7 mW and (-26 dB to -15.55 dB) for 17 mW, respectively. On the basis of above analysis, it is recommended that 5 mW input power reported better performances than the other proposed input power.

The effect of output power with respect to different pumping wavelength is shown if Fig. 4. The observed values of output power at 1485 nm wavelength are given as 20 dBm, 24 dBm, and 16 dBm, respectively. The output powers at 1465 nm are given as 12 dBm, 12 dBm and 8 dBm, respectively. Least transient time in terms of output power such as 4 dBm, 3 dBm and 2 dBm are observed at 1450 nm pumping wavelength. It means, as we increase the pumping wavelength, increment are noticed in terms of output power and it is also declared that a flat gain profile can be archived by the good choice of number of injected pumps, their wavelength, and power levels[14,15].

The proposed model is further illustrated with respect to quality factor and observation is taken out from Fig. 5. Conversion of optical to electrical signal is made with the help of PIN photodetector on the receiver side to illustrate the effect of the quality factor. Variations in quality factor due to nonlinear effect and inter-channel crosstalk by HOA are given as (41.86 dB to 41.5 dB) for 5 mW power, (44.86 dB to 38.30 dB) for 7 mW power and (42.86 dB to 35.30 dB) for 17 mW power, respectively. Highest quality factor is also recorded than literature[1,2] which is given as 51 dB, 46 dB and 44 dB for 5 mW,7 mW and 17 mW, respectively. It is ceased that best rating of quality factor is recorded with 5 mW input power than the other rating of input power for the proposed model.

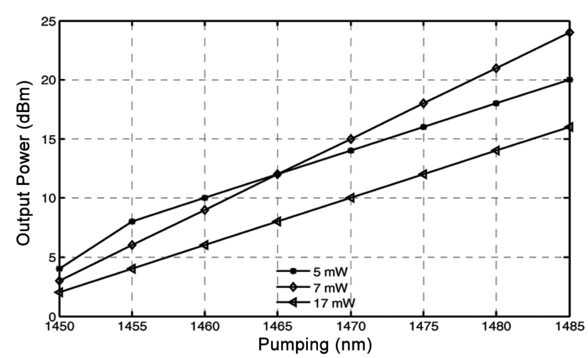

Fig. 4 – Output power with respect to different pumping wavelength.

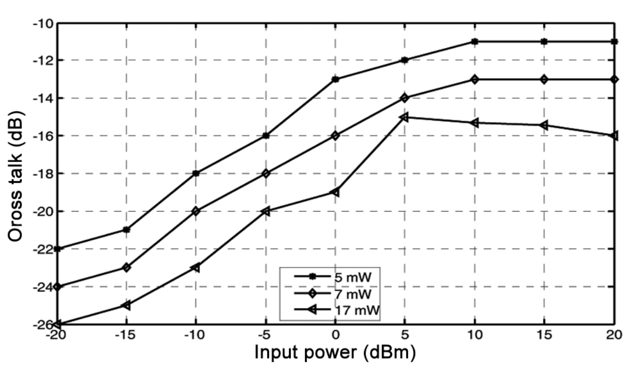

Fig. 3 – Crosstalk with respect to different input power.

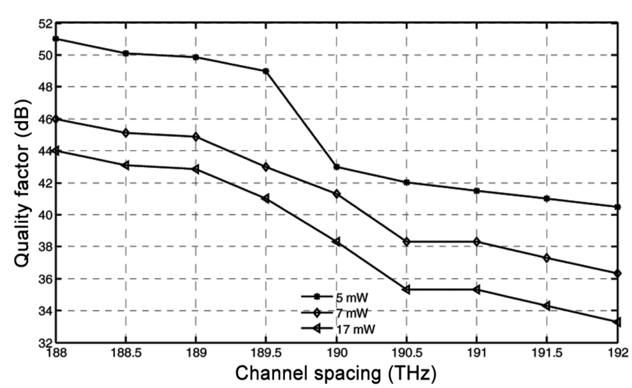

Fig. 5 – Quality factor with respect to channel spacing.

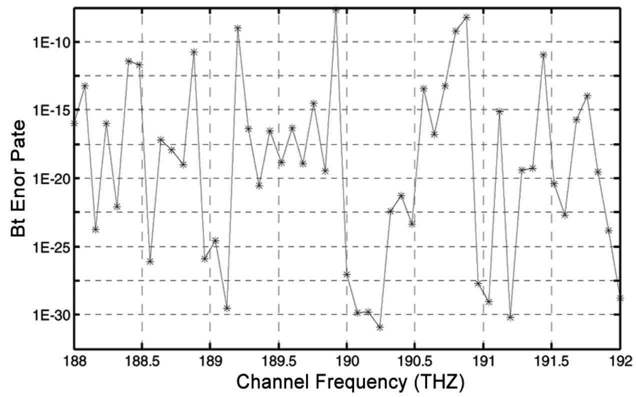

Fig. 6 – Bit error rate with respect to channel spacing.

Best rating of flattened gain is recorded for SD-WDM system with less variation. It is further justified with the help of bit error rate. Evaluation in terms of bit error rate and channel spacing are shown in Fig. 6. Crosstalk induced by RAMAN-EDFA-RAMAN is directly affected the gain of the system and this crosstalk due to nonlinearity such as stimulated four wave mixing, RAMAN scattering, self and cross-phase modulation, etc.[16] Influence of crosstalk is further analyzed from Fig. 6 and best rating of bit error rate (< 1e-10) is coming out from the proposed

4 Conclusions

The performances of the proposed SD-WDM system with RAMAN-EDFA-RAMAN is illustrated with 50 GHz channel spacing. Input power of 5 mW provides the best rating in terms of flattened gain (>14 dB) with the least variation of 2.1 dB without using any gain flattening techniques, which is the cost effective solution. Best outcome is reported by 5mW power in terms of crosstalk. Also, it is recommended that best output power is reported in terms of flattened gain at 1485 nm pumping wavelength. This paper ceased with the declaration that 5 mW input power delivers the best rating outcome in terms of quality factor and least the bit error rate of (< 1e-10).

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