A high flatness gain subsisting of cascaded EDFA-TDFA hybrid optical amplifier for super dense wavelength division multiplexing system

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Abstract Flat gain with least noise figure (NF) is the backbone feature of super dense wavelength division multiplexing (SD-WDM) system. It indicates the good amplification in terms of high-quality factor, lowest bit error rate, and good rating output power. So, in this paper, we have mainly focused on the characteristics of proposed EDFA-TDFA hybrid optical amplifier (HOA) in terms of flat gain and noise figure for C-Band. Evaluation has done for 400 × 2.455 Gb/s SD-WDM system with channel spacing of 0.8 nm. Moreover, effect of proposed HOA has also observed with displacement of channel wavelength for evaluating the impact of different set of HOAs for analysis the same characteristics.

Keywords EDFA · TDFA · RAMAN · SD-WDM · Gain · Noise figure

1 Introduction

Flat gain is the highly acceptable characteristics for super dense wavelength division multiplexing (SD-WDM) system which try to achieve with the combination of different optical amplifiers in terms of hybrid optical amplifiers (HOAs) (Kani et al. 1999; Masuda and Kawai 1999). Number of examples has given in the present literature such as combination of hybrid optical amplifiers and erbium-doped fiber amplifiers (EDFAs) in C plus L band (Aisawa et al. May 1998; Sun et al. 1998), combinations of thulium-doped fiber amplifiers (TDFAs) and (EDFAs) in S plus C plus L band (Fukuchi et al. 2001; Kani et al. 1999) and combination of (EDFAs) and Raman amplifiers (FRAs) in C plus L plus U band respectively (Matsuda et al. 2004). But, combination of EDFA and T DFA is most significance arrangement for delivering the flattered gain and also mitigate the effect of fiber nonlinearity (Sakamoto et al. 2003, 2004; Segi et al. 2001). Optical and at some place electrical pumping are the main feature for the existing optical amplifier. Internal defects such as
Crosstalk and optical amplifier nonlinearity can also be controlled by adjusting the level of pumping power. Multiple pumping has also been recommended in the literature (Singh et al. 2012; Lee et al. 2002; Emami and Harun 2009) for TDFA to enhance the performance of super multiplexing system in terms of bit error rate, output power, higher gain bandwidth, and noise figure. Performance of TDFA has also been observed for different cascaded amplification for different set of wavelength region (Sakamoto et al. 2003, 2004; Segi et al. 2001).

In this paper to the best of authors knowledge, first time combination of EDFA and TDFA hybrid optical amplifier is recommended for getting flat gain with insignificant effect of noise figure (NF) for super dense wavelength division multiplexing (SD-WDM) system.

However, paper is represented in IV sections. Section I, explained the introduction of the paper, section II, explained the simulation setup of the proposed hybrid amplifier with dual pumping technique, section III, explained the final outcome from proposed system and section IV, explained the final conclusion.

2 Simulation setup

The simulation setup for EDFA and TDFA hybrid amplifier is shown in Fig. 1. Simulation is carried out with dual pumping technique for both optical amplifiers. EDFA is pushed with dual pumping of 990 nm with 675 mW and 1490 nm with 540 mW respectively. In the similar manner, TDFA is pushed with dual pump of 1440 nm with 680 mW and 1460 nm with 690 mW respectively.

In fact, carrier concentration in terms of population inversion can only be possible to set the level of pump laser diode (LD). Subsequently, outcome of the optical amplifier would be in good rating flattered gain with least noise figure (Sakamoto et al. 2006).

Further, optical signal is injected to EDFA amplifier then to cascaded TDFA amplifier. This is called EDFA-TDFA hybrid optical amplifier. Gain of EDFA is set to 25 dB with noise figure of 4 dB. Optical signals are received at the receiver side by PIN photodiode, which is operated at 0.875 A/W of responsivity and 0.1 nA of dark current. Channel spacing of 0.8 nm is maintained for C-band.

Fig. 1 Simulation setup for EDFA and TDFA hybrid optical amplifier
In this proposed system, 400 optical signals are generated from 400 CW laser sources. Power of each input probe is set to $-10$ mW to maintain the quality of received signal (Bhatia et al. 2012). Data rate is set to 2.455 Gb/s NRZ binary sequence which further injected to sine-squared amplitude modulator to enhance the power level of low optical signal to higher optical signal. Resultantly, output is come out in terms of modulated signal.

3 Results and discussion

Final outcome in terms of gain and noise figure with respect to C-band is shown in Fig. 2. Observed values for different set of hybrid optical amplifiers in terms of flat gain are given as 20.1 dB to 18.55 dB for EDFA-TDFA HOA, 15.1 dB–13.55 dB for RAMAN-EDFA HOA, 10.1–8.55 dB for EDFA-EDFA HOA and 8.1–6.55 dB for RAMAN-RAMAN HOA respectively for the range of 1530–1565 nm.

Recorded values of NFs (Noise figures) are given as 8.5 dB for RAMAN-RAMAN HOA, 7.5 dB for EDFA-EDFA HOA, 7.2 dB for RAMAN-EDFA HOA and 2.5 dB for EDFA-TDFA respectively. It shows that our proposed HOA delivers the maximum gain of 25.55 dB with variation of 1.22 dB than the reference (Sakamoto et al. 2006) which is good sign for optical communication.

However, performance of proposed hybrid amplifier is also evaluated with displacement in the channel wavelength in Fig. 3. It is clearly observed that impact of proposed HOA still maintained in terms of flat gain with least variation of 1.5 dB. But we can also noticed that gain is linearly increasing till 1555 nm and decrease continuously till 1570 nm due to nonlinearity effect induced by hybrid optical amplifier. It is basically occurred due to retardation of optical signal but it can also be improved by adjusting the power level of CW laser and power range of optical pump. Further, eye diagrams from different set of HOAs are also shown from figs.4, 5, 6, 7 respectively to explore the impression of individual HOA. Nonlinear effect has highly dominating nature over optical communication which can only maintained with suitable rating of power amplification which has also done with
the arrangement of EDFA-TDFA HOA. In fact, power strength of optical signals must be retained throughout the optical communication which further lead to good quality optical signals with least effect of dominating signals. Impression of proposed HOA is also observed in terms of power amplification in optical medium and at the receiver end which is also shown in Figs. 8 and 9 respectively. Eye opening of sudden checking quality of the transmission signals is also shown with the support of proposed HOA in Fig. 10. Here, it is also observed that overall impression of EDFA-TDFA HOA is acceptable to maintain the flat gain with acceptable rating noise figure.
A high flatness gain subsisting of cascaded EDFA-TDFA hybrid…

4 Conclusion

Performance of proposed EDFA-TDFA hybrid optical amplifier for $400 \times 2.455$ Gb/s super dense wavelength division multiplexing (SD-WDM) system has been done in terms of flat gain and noise figure. Maximum gain of 25.55 dB with least variation of 1.22 dB is recorded. Impact of HOA is really helped out to maintain the flat gain for the range of 1530–1570 nm. On the other hand, influence of proposed hybrid optical
Fig. 7 Eye diagram of RAMAN-RAMAN hybrid optical amplifier

Fig. 8 Power amplification in the optical medium from EDFA-TDFA hybrid optical amplifier
Fig. 9 Observation of power amplification near the receiver section from EDFA-TDFA hybrid optical amplifier

Fig. 10 Observation of eye diagram from EDFA-TDFA hybrid optical amplifier in the middle of transmission medium
amplifier (HOA) still retains with displacement of channel wavelength in terms of flat gain with variation of 1.5 dB.

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Data availability Data used for the results are available in the manuscript.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Consent to participate We here give our consent to participate and communicate paper in this journal.

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