Performance Configuration of Raman-EDFA Hybrid Optical Amplifier for WDM Applications

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Abstract. A hybrid configuration of Raman amplifier and erbium-doped fiber amplifier (EDFA) is proposed to obtain a better performance in term of gain, noise figure and flat gain. It is based on the optimum parameter configuration of a singly-based Raman amplifier and EDFA. The best parameter for both amplification has been analyze in terms of its input signal power, pump power and their fiber length whereas the best erbium ion density has also been analyze in EDFA setup. All the parameters are varied to some values to get the optimum result. The simulation is done by using Optisystem 14.0 software. The hybrid amplifier consists of Raman amplifier with multi-pump power set up and bidirectional pump power of EDFA with the pump wavelength of 980 nm is designed and simulated in order to obtain higher gain and lower noise figure. From the simulation of the hybrid configuration, the optimum output has been achieved. The hybrid configurations exhibit the average gain of 46 dB and average noise figure of 3 dB. The flat gain obtained is between 1530 nm to 1600 nm which include C-Band and L-Band frequency with the gain bandwidth of 70 nm.

1. Introduction

Due to the increasing demand of high transmission capacity and best performance system of optical fiber communication system, hybrid amplifiers become the best option to solve the problem. As singly based optical amplifier such as semiconductor optical amplifier (SOA), erbium-doped fiber amplifier (EDFA) or Raman amplifier has few limitations to provide high gain amplification as well as broadband operation. These amplifier exhibit its own advantages, for instance SOA uses less electrical power, more compact and fewer components [1], whereas erbium-doped fiber amplifiers (EDFAs) can be develop by using various host and codopant materials, such as silica, alumina, telluride, phosphate, bismuth, and others, to improve the gain performance. Raman amplifier exhibit an ability to provide distributed amplification within the transmission fibre, thereby increasing the length of spans between amplifier and regeneration sites. In contrast with EDFA, the SOA have some drawbacks which makes EDFA has better performance than SOA. SOA has nonlinearities in gain, higher coupling losses, high noise figure, and generation of crosstalk in multichannel systems [2]. EDFA are able to pump the device at different wavelengths, low gain dependence on light polarization and low coupling loss. However, from the previous work reported, most of singly-based amplifier exhibits lower gain compared to hybrid configuration. Combination of Raman amplifier and EDFA performs the best of hybrid amplifier reported previously.

It is necessary to optimize the design parameters such as length of amplifiers, pump power wavelength and input pump power of both amplifiers separately before both are combined. These parameters optimization can be done through simulation using simulation software. In our work, Optisystem software is used to obtain the best performance of optical fiber amplifier for WDM application. As reported by Singh et. al [3], a hybrid two stage Raman-EDFA amplifier can give a flat gain of L-Band. The increasing of input power increase the gain variation over the bandwidth. Flat
gain of greater than 10 dB is achieved using the input power of 3 mW for the frequency between 187 to 190.975 THz. Without using gain-flattening technique, the gain variation obtained is less than 4.5 dB. Based on the study by Martini et. al [4], the use of recycled multipump lasers for WDM systems in two configurations which are Raman-EDFA and EDFA-Raman is reported. The EDFA-Raman configuration gives the best performances with the global gain of 40 dB, noise figure of 4 dB and gain ripple of 0.8 dB.

Sharma et. al [5] proposed the configuration of hybrid amplifier using 20x50 Gbps WDM system with the range from 1560 nm to 1577 nm wavelength. The input power use is 15 dBm and bit rate of 10 Gbps. The result shows that gain and noise figure variation will increase as the input power, number of pump and pump wavelength increases. The configuration successfully obtained a maximum gain of 22.81 dB and low noise figure of 7 dB. The gain variation is 2.79 dB. Three stage hybrid amplifier has been proposed in a work reported by Kaushik et. al [6] with multiple pump recycling. Using this configuration, the gain bandwidth of 80 nm and gain ripple of 2.5 dB is obtained, while the maximum gain reported is 25 dB. The advantage of this technique is to reduce the cost of equipment in the communication network.

In our proposed design, the EDFA-Raman configuration has been used to perform hybrid amplifier.

2. Design and Simulation
Optisystem software has been used in order to design and simulate the configuration of EDFA, Raman amplifier and hybrid EDFA-Raman amplifier. The simulation started with the configuration and optimization of EDFA and followed by Raman amplifier. Then, using the optimum parameter of both amplifiers, a hybrid optimum Raman-EDFA is configured and simulated.

2.1. Configuration of Erbium Doped Fiber Amplifiers (EDFA)
Figure 1 shows the proposed configuration of EDFA. The parameter involves to be tested in this configuration are pump wavelength, erbium ion density, EDFA length, pump power and input signal power. These parameters will be varied in order to check for the best amplifier performance for the design configuration. The frequency for the WDM channel is from 1530 nm to 1620 nm with 19 channels of 5 nm spacing. The frequency is the range for C-Band and L-Band. The pump wavelength of the EDFA can be 980 nm or 1480 nm with three different configurations which are forward, backward or bidirectional [1, 7]. Firstly, the simulation is tested for forward and bidirectional pumping with 980 nm and 1480 nm and the other parameters are set as shown in figure 1. Secondly, for the optimum erbium ion density, the density is varied between 100 ppm-wt to 2500 ppm-wt while the pump configuration is set to optimum which is 980 nm bidirectional pumping. In optimizing the EDFA length, the length is varied between 1 m to 40 m with the previous optimized parameter is set to the configuration. Then, for input signal power optimization, the power is varied between -200 dBm to 0 dBm to obtain the best input signal power.
2.2. Configuration of Raman Amplifier

Figure 2 shows the proposed configuration of Raman amplifier. The WDM transmitter uses the frequency range between 1520 nm to 1620 nm with 10 nm spacing. The input signal power of -40 dBm is set to constant throughout this simulation. In this simulation, the optimum Raman length and pump power have been observed. There are 11 pump laser arrays of various frequencies ranging from 1420 nm to 1520 nm with increment of 10 nm. The difference between pump wavelength and signal wavelength should be 100 nm to obtain high Raman gain coefficient [8]. The optimization of Raman length is done by varying the length from 10 km to 100 km. Besides, in optimizing the pump power, the amplifier length is set to the optimum length obtained previously which is 45 km with variation of pump power from 50 mW to 250 mW. As the optimum length and pump power has been achieved, the value has been used in the configuration and the result obtained is shown in figure 5.
2.3. Configuration of Hybrid EDFA-Raman amplifier

Figure 3 shows the proposed configurations of Hybrid EDFA-Raman Amplifier with the optimum parameter of EDFA and Raman amplifier tested previously. The WDM transmitter is set to 11 channels with 1530 nm to 1620 nm wavelength and 10 nm spacing. The input signal power is set to -40 dBm. The EDFA parameter used in this simulation is 300 mW bidirectional pump power with 980 nm pump wavelength, 1000 ppm-wt of erbium ion density and EDFA length of 5 m. The Raman parameter used in this configuration is the Raman length of 45 km and 150 mW pump power of each pump laser. Then, the configuration is changed with the combination of Raman amplifier followed by EDFA.

![Figure 3. Configuration of Hybrid Amplifier.](image)

3. Result and discussion

3.1. Optimization of EDFA

Figure 4 shows the gain and noise figure performances for EDFA. It is shown that the flat gain can be obtained from 1540 nm to 1560 nm with the average gain around 41 dB and average noise figure of 4 dB. The achievable flat gain bandwidth is 20 nm. This optimum EDFA is obtained based on the 300 mW bidirectional pump power with 980 nm pump wavelength. Pumping EDFA with 980 nm can give less noise and larger population inversion compared to 1480 nm pump wavelength [1]. In terms of pumping configurations, the best configuration is by using bidirectional pumping as it will provide higher gain and lower noise figure. The optimum erbium ion density used to obtain this result is 1000 ppm-wt. For this configuration, 5 m EDFA length is chosen as the optimum length as it gives highest gain, lowest noise figure and flat gain compared to other length. When longer length is used, the gain will decrease as the pump power does not have sufficient energy to produce complete population inversion. The optimum input signal power used is -40 dBm which is the threshold input signal. If the input signal is higher than the threshold, the gain will decrease.
3.2. Optimization of Raman Amplifier

Figure 5 shows the performance of optimum Raman amplifier. As in the figure, the flat gain is obtained from 1604 nm to 1620 nm with the bandwidth of 16 nm. The average gain obtained from the flat gain is 38 dB while the average noise figure is -38 dB. This shows that Raman amplifier will gives better noise figure compared to EDFA. In this configuration, the optimum Raman length used is 45 km as it obtained the highest gain for the signal wavelength of 1600 nm. Gain increases with the increasing Raman length and decreases when the length is longer than 45 km. The optimum pump power for each of the pump laser is 150 mW as it gives less gain variation when compared with 200 mW pump power. This Raman configuration gives better noise figure compared to EDFA.

Figure 4. Gain and Noise Figure of Optimum EDFA.

Figure 5. Gain and Noise Figure of Raman Amplifier.
3.3. Optimization of Hybrid Raman Amplifier

Figure 6 shows the performance of Hybrid Raman amplifier. The flat gain can be obtained from 1530 nm to 1600 nm which is 70 nm bandwidth. The best performances of Hybrid Raman amplifier is the configuration of hybrid EDFA-Raman as is gives the highest average gain of 46 dB and lowest noise figure of 3 dB as compared to optimum singly-based EDFA and Raman as well as hybrid Raman-EDFA. Research in [4] also proves that the best performance of hybrid amplifier is the combination of EDFA-Raman amplifier. This hybrid EDFA-Raman amplifier give the higher gain compared to [3] and [4]. In comparing with the latest work in year 2016 which is [5] and [6], the performances of configuration in figure 3 is much better in terms of gain and noise figure even though the bandwidth is reduced in 10 nm compared to [6].

![Figure 6. Optimum performances of Hybrid Raman amplifier.](image)

4. Conclusion

In conclusion, the optimization of hybrid EDFA-Raman amplifier performance improved significantly in terms of flat gain bandwidth as well as higher gain of transmission system. The design of optimum hybrid amplifiers is very important in obtaining a broad flat gain and better noise performances. The parameters which can be optimize the EDFA’s performance in term of noise figure and gain are erbium ion density, EDFA length, input signal power, pump power and pump wavelength while the parameters to optimize the Raman amplifier are Raman length and pump power. As these parameters are used in the hybrid amplifiers, it gives a higher gain, low noise figure and a better flat gain bandwidth.

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