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GAIN FLATTENING OF DWDM CHANNELS FOR THE ENTIRE C & L BANDS

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A hybrid amplifier consisting of one stage of Erbium Doped Fiber Amplifier and two stages of Raman amplifiers is constructed. Two Raman fibers are cascaded in series to suppress the intensity noise due to double Rayleigh scattering. Backward pumping is applied at all stages in order to increase the gain of Erbium Doped Fiber Amplifier and to decrease the polarization dependent gain of Raman fiber amplifier. In our previous experiment a 16 channel Wavelength Division Multiplexed system with channel spacing of 5 nanometers was considered. In this experiment a Density Wavelength Division Multiplexed system having 80 channels and a channel spacing of 0.8 nm was taken in to account. Gain Flattening is achieved for the entire C-band and L-bands. Experimental results showed that the hybrid amplifier has the average Gain of more than 19 dB in the wavelength range between 1530–1600 nanometers, with the Noise Figure of less than 6 decibels. The Gain of the Erbium Doped Fiber Amplifier and Raman was optimized to minimize the ripple value as low as 0.045 decibels with an output power of 15.265 decibel-milli.

Keywords: *Raman fiber amplifier, hybrid amplifier, Erbium Doped Fiber Amplifier, Noise Figure, Wavelength Division multiplexing, Density Wavelength Division multiplexing, Gain Flattening Filter.*

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ВЫРАВНИВАНИЕ УСИЛЕНИЯ В КАНАЛАХ DWDM В ПОЛНЫХ ПОЛОСАХ C И L

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Разработан гибридный усилитель, состоящий из одного каскада эрбиевого волоконного усиления и двух рамановских усилительных каскадов. Два рамановских волоконных усилителя размещены последовательно для подавления шумов вследствие двойного рэлеевского рассеяния. Во всех усилителях направление волн накачки противоположно направлению распространения сигнала с целью увеличения усиления эрбиевым усилителем и снижения поляризационной зависимости усиления в рамановских каскадах. В наших предшествовавших экспериментах рассматривалась 16-канальная система с мультиплексированием по длине волны, со спектральным разносом каналов 5 нм. В настоящем эксперименте описана DWDM-система, содержащая 80 каналов с разносом каналов 0,8 нм. Выравнивание усиления достигнуто для полных C и L полос. Экспериментальные результаты показали, что гибридный усилитель обладает усилением более 19 дБ в полосе длин волн 1530–1600 нм, с шумовым показателем менее 6 Дб. Усиление в эрбиевом и рамановских усилителях было оптимизировано таким образом, чтобы уменьшить его неравномерность до 0,045 дБ при выходной мощности 15,265 дБм.

Ключевые слова: *рамановский волоконный усилитель, гибридный усилитель, эрбиевый волоконный усилитель, коэффициент шума, система с мультиплексированием по длине волны, плотные WDM, фильтр, выравнивающий усиление.*

1. Introduction

Different techniques exist to enhance the flattened gain bandwidth of fiber amplifiers such as using gain equalizers (GEQ's), new host materials and connecting Erbium Doped Fiber Amplifier (EDFA) and thulium – doped fiber amplifiers in parallel configuration [1–4]. The techniques also include an EDFA, a GEQ and an Raman Fiber Amplifier (RFA) in serial configuration [5].

One possible way to increase the Gain Bandwidth is to combine numerous amplifiers with different Bandwidth Gain's and construct a hybrid amplifier [6]. These amplifiers could either be connected in series or parallel configuration. In parallel configuration Wavelength Division Multiplexed (WDM) signals that serve as an input to the amplifiers are demultiplexed by the WDM coupler into numerous wavelength band groups. After amplification, these signals are again multiplexed through a WDM coupler [7]. On the contrary a very wide seamless Gain Band is observed for the amplifiers joined together in series configuration, because they do not need any WDM couplers. So connecting an EDFA amplifier in series with an RFA is an effectual approach because RFA can give any gain band by appropriately choosing the pump wavelengths and powers.

Thus, in order to add spectral shaping flexibility in broadband applications a high output power EDFA can be used with RFA [8]. The main bottleneck in such configuration lies in correctly setting up pump wavelengths and pump powers for RFA's. Optimization of the pump wavelength and pump power can make the gain spectrum extremely flat [9]. However Raman amplifiers are modeled by non-linear coupled equations with pump-pump and pump-signal interactions and there is no simple relation between wavelength, gain and power of the multiple pump lasers that can be found without seriously compromising the accuracy of the results [10].

In our previous work [11] the gain of EDFA and Raman amplifiers was optimized for long haul WDM systems. In this work the simulation setup is same as in [11] but the results were obtained for an 80 channel Density Wavelenght division multiplexed (DWDM) system. Fig. 1 shows the setup, used for the purpose of simulation which is the same as used in [11]. The difference is that, instead of a WDM transmitter and receiver a DWDM transmitter and receiver is used. Pump powers and pump wavelengths for laser diodes are same as used in [11]. But in order to compensate 80 channels and to obtain a flat gain, the parameters of the transmission filter also known as the Gain Flattening Filter (GFF) are changed, optimized and adjusted.

The fundamentals of hybrid amplifiers and several important results are given in [12–24].

2. Simulation Setup and Results

The simulation setup, shown in fig. 1, consists of an 80 channel DWDM transmitter with each channel carrying a 10 Gbps signal with a power of –20 dBm per channel in the wavelength range of 1530–1600 nm with 0.8 nm spacing. DWDM channels served as an input to the 5 m EDFA pumped by a laser diode. A laser array of 8 laser diodes act as an input to the first stage of 25 km Raman fiber where second stage of Raman fiber is pumped by a single laser diode [11]. By using the technique of accurate numerical methods, optimized values of pump power and pump wavelengths for the laser diodes were found [11]. These values are the same as used in [11] and are given in fig. 2–5, and table.

Simulation results for the gain of each stage and noise figure were obtained by using the mathematical equations of Gain and Noise Figure given in [11] (fig. 6–8).

A thin film 2 port Gain Equalization Filter or Gain Flattening Filter (GFF) with the operating wavelength range in the C/L band is used for the purpose of Gain Equalization [11]. The filter used in this experiment is the same Dynamic

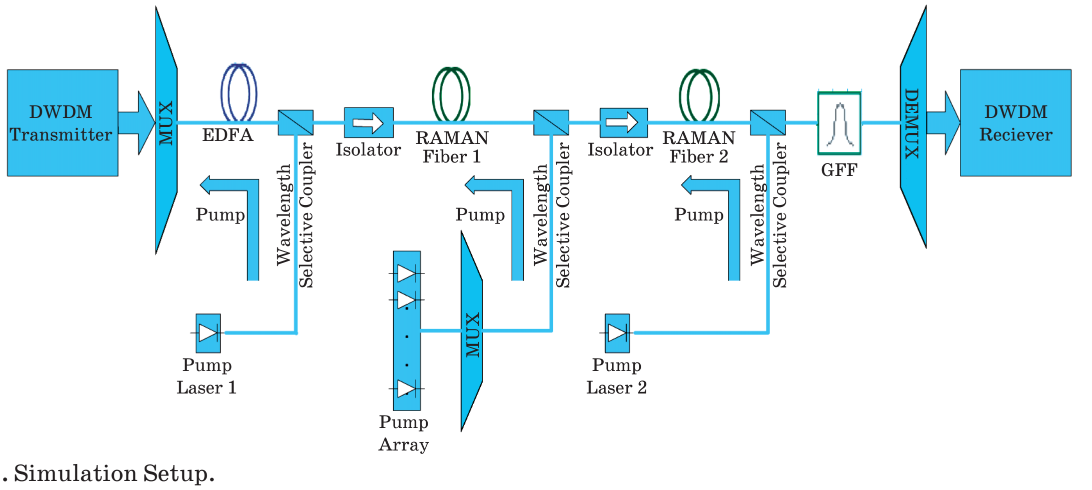

Fig. 1. Simulation Setup.

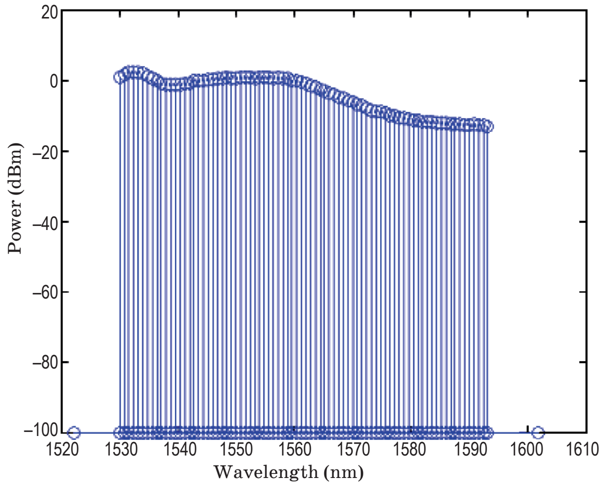

Fig. 2. Power in dBm after passing through EDFA.

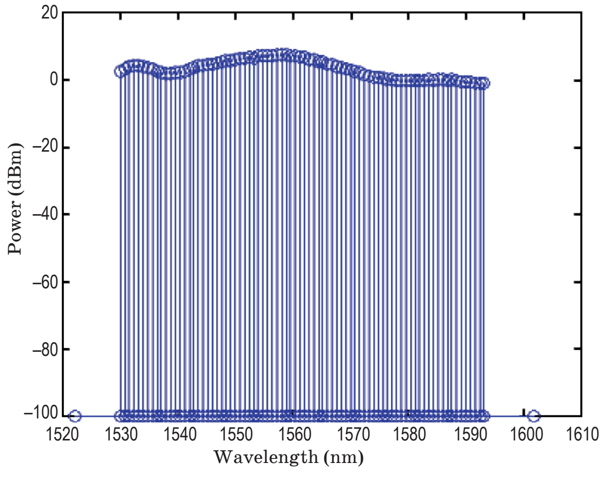

Fig. 3. Power in dBm after passing through first Raman fiber.

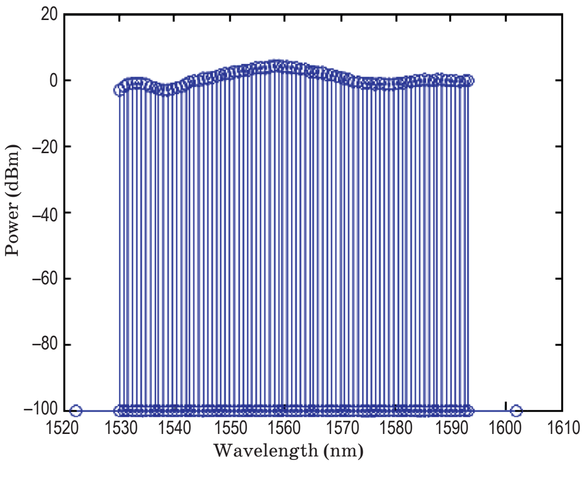

Fig. 4. Power in dBm after passing through 2nd Raman fiber.

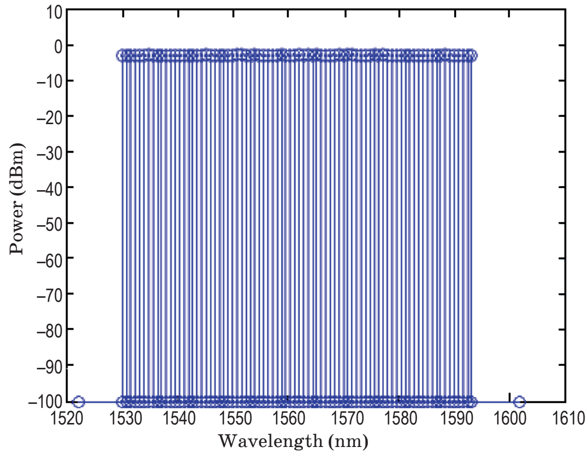

Fig. 5. Power in dBm after passing through Gain Flattening Filter.

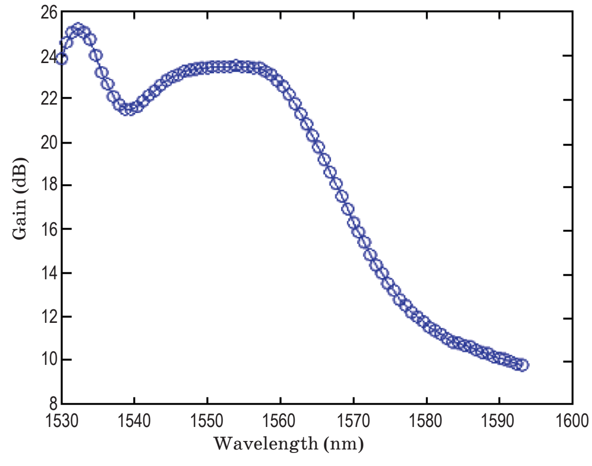

Fig. 6. Gain Profile after passing through EDFA.

Pump powers and wavelengths for the laser diodes after applying the optimization

Pump Sources	Wavelength, nm	Power, mW
Pump Laser 1	1458.91	91.2012
Pump Array (8 pumps)	1430.599; 1437.846; 1444.967; 1454.552; 1465.354; 1482.255; 1493.366; 1510	46.78; 48.52; 43.04; 66.85; 154.76; 191.90; 173.04; 187.67
Pump Laser 2	1503.24	209.887

Gain Flattening Filter (DGFF) continuous envelope equalizer [11] but instead of using 16 independent notches [11], 24 notches were used. By using this filter, although overall gain of the system has reduced to 19 dB but astonishing results were obtained for the ripple factor. The ripple factor was reduced to as low as 0.045 dB in comparison with 0.7 dB obtained in [11].

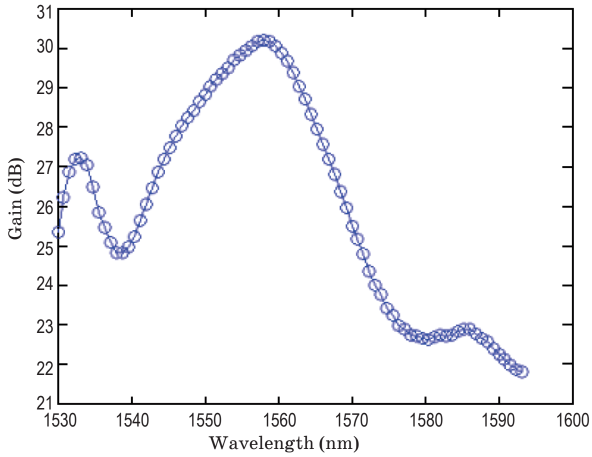

Fig. 7. Gain Profile after passing through first Raman fiber.

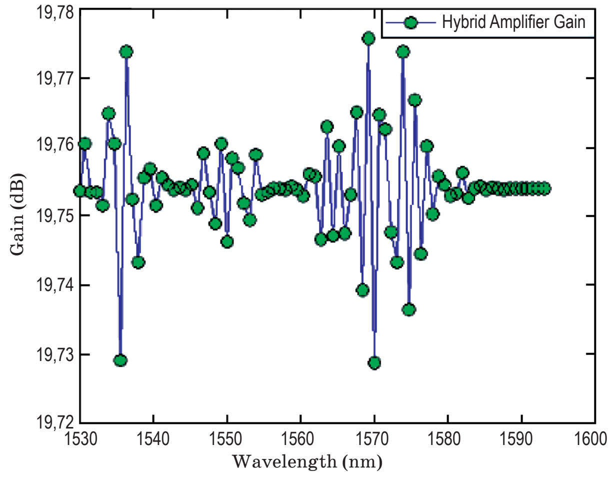

Fig. 9. Gain Profile after passing through Gain Flattening Filter.

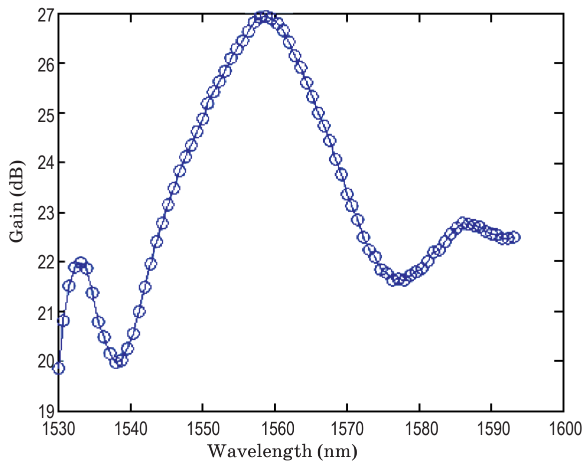

Fig. 8. Gain Profile after passing through 2nd Raman fiber.

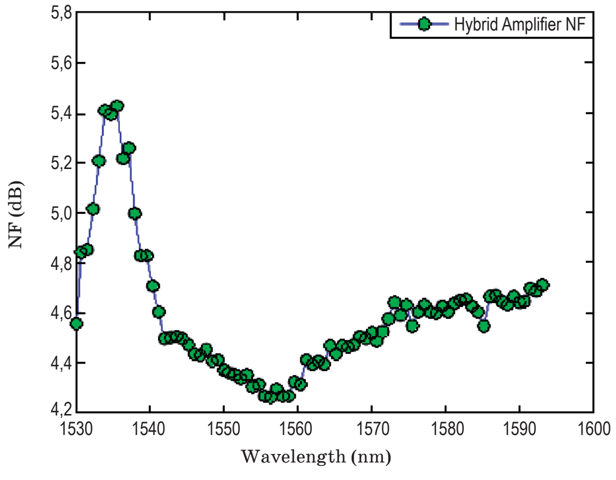

Fig. 10. Noise Figure.

Gain profile shown in Fig. 9, indicates a maximum Gain of 19.775 dB and a minimum Gain of 19.73 dB. So the ripple value which is calculated as $G_{max} - G_{min}$ comes out to be 0.045 dB. The maximum value of Noise Figure (NF) was observed to be 5.4 dB, as can be seen in Fig. 10: Noise Figure and total Power was found to be 15.265 dBm.

3. Conclusion

We have constructed a hybrid amplifier comprising of one stage of Erbium Doped Fiber Amplifier (EDFA) and two stages of Raman amplifiers. Two Raman fibers are cascaded in series to suppress the intensity noise due to double Rayleigh scattering. In our previous experiment, optimized results were obtained for a 16 channel WDM system. In this experiment an 80 channel DWDM system is considered. The optimized pump powers and pump wavelengths for the laser diodes are the same as in the previous experiment but in order to obtain a flat gain for 80 channel system, parameters of GFF were changed and optimized. Gain Flattening is achieved for the entire C band and L band. We obtain a high gain in the wavelength range from 1530–1600 nm by using hybrid amplifiers. Simulation results show that the ripple values can be minimized to as low as 0.045 dB. Optimized values for the wavelengths and powers of pump sources were obtained by accurate numerical methods. Gain Equalization is achieved with the help of a Gain Flattening Filter (GFF). Thus a hybrid amplifier with an average Gain of 19 dB, an output power of 15.265 dBm, a ripple value less than 0.05 dB, and a NF less than 6 dB in the 70-nm gain band was achieved.

* * * * *

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