Equalization of EDFA Gain Spectrum and Increase of OSNR through Introducing a Hybrid Raman-EDFA Solution

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Abstract— The main goal of this paper is to demonstrate the advantages of a hybrid Raman-EDFA optical signal amplification solution over the use of conventional EDFA amplifiers. The most promising solution of hybrid amplification is supplementing the existing discrete amplifier with a distributed Raman amplifier, as it not only can broaden and equalize the gain spectrum, but it also can increase the optical signal-to-noise ratio of the signal at the output of the amplifier and can provide higher level of amplification. The obtained results have shown, that the implementation of the hybrid solution has allowed to increase the optical single-to-noise ratio by at least 1.7 dB in all of the channels.

1. INTRODUCTION

Due to the rapid growth of the number of internet and other service users, as well as with the increasing availability of these services, a rapid increase of the amount of transferred information has been observed over the last two decades. To satisfy this constantly increasing demand for higher network capacity, fibre optical transmission systems with wavelength division multiplexing (WDM) have been intensively studied and applied [1–3]. It is possible to increase the WDM system throughput capacity either by increasing the data transmission speed in channels or the number of channels. By raising the data transmission speed, it becomes necessary to reduce the optical noise produced by optical components (light sources, modulators, amplifiers, receivers, etc.), as higher transmission speed signals have lower noise immunity. In cases where the throughput capacity of existing networks is raised by increasing the number of channels of a WDM system, the attenuation caused by the optical signal division also is being raised, especially in systems, where power splitters are used [4]. Therefore, solutions are needed for compensating the ever increasing accumulated signal attenuation in an ever broader wavelength range.

Currently, erbium doped fibre amplifiers (EDFA) are most commonly used around the globe for compensation of optical signal attenuation. The amplification bandwidth of EDFAs is strictly limited (for conventional EDFA solutions, it is only 35 nm), which restricts the wavelength range used for the transmission in existing systems [5, 6]. It is thus necessary to seek new solutions for amplifying optical signals and opportunities of expanding the amplified wavelengths range and increase the attainable amplification level for the already existing optical signal amplification solutions.

The goal of this article is to investigate the possibility of expanding and equalising the gain spectrum of a conventional EDFA and increasing the optical signal-to-noise ratio (OSNR) at the output of the amplifier by supplementing the system with a distributed Raman amplifier (DRA) and, therefore, forming a hybrid Raman-EDFA solution.

2. SIMULATION MODEL

To investigate the possibility of expanding and equalising the gain spectrum of a conventional EDFA and increasing OSNR by implementing a hybrid Raman-EDFA solution, a simulation model of a 16 channel 10 Gbps DWDM transmission system with NRZ-OOK modulation format was introduced (see Figure 1). Each of the 16 channel transmitters operates at its own frequency in range from 193.05 to 193.8 THz with 50 GHz spacing between channels, the power of each transmitter was 1 dBm. All of the 16 generated optical pulse sequences are combined using an optical power combiner and, afterwards, the obtained optical flow is sent through a 150 km long standard single-mode fibre (SMF).

At the output of this SMF fibre the attenuated signal was sent through an in-line EDFA. Two scenarios were realised to amplify the signal: 1st — when the signal was amplified only by an in-line EDFA with 25 dBm (316 mW) 980 nm co-propagating pumping radiation and 10 meters long erbium doped fibre; 2nd — when the EDFA was reconfigured and the system was supplemented with a distributed Raman amplifier, in such a way forming a hybrid amplifier. After processing through the amplifier the signal was sent through a second SMF that was 50 km long, and afterwards divided among all 16 receivers using an optical power splitter with 13.5 dB insertion loss [3]. At

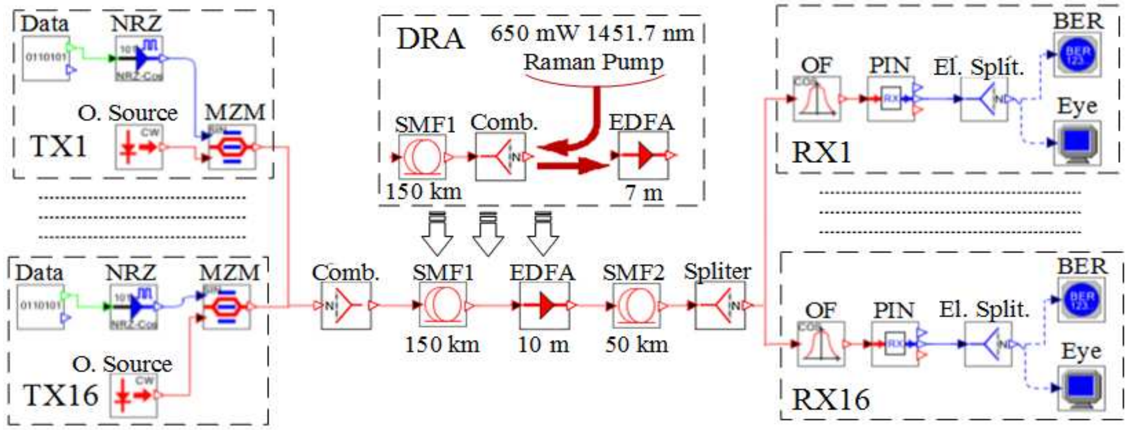

Figure 1: Simulation model of the 16 channel 10 Gbps DWDM transmission system with an EDFA inline amplifier or with a hybrid Raman-EDFA amplifier.

each receiver the signal was processed through an optical band-pass filter, leaving only the optical radiation that corresponds to the specific channel, and afterwards converted into electrical current using a PIN photodetector.

3. RESULTS AND DISCUSSIONS

When only the EDFA was used for amplification, the peak power level of each channel at the input of the amplifier has reached -37.1 ± 0.1 dBm. The in-line EDFA with 25 dBm 980 nm co-propagating pumping radiation and 10 meters long erbium doped fibre has ensured on-off gain from 38 to 39.5 dB for the 16 channels, therefore, 1.5 dB gain difference was obtained. Such gain was the minimal the minimal gain that could ensure BER values below the 10^{-12} mark in all channels. Such difference in amplification will not produce severe degradation on amplified signal quality in case in there is only one amplification span in the transmission system. The obtained Gain spectrum is shown in Figure 2(a). Our previous studies show that in systems with multiple transmission spans such amplification difference will increase with every following amplification span and as result higher pumping level will be required to ensure the required level of amplification for all channels. In such case the channels with higher level of amplification will initiate occurrence of explicit channel-channel four-wave mixing (CC-FWM) interactions, which would produce great amount of inter-channel crosstalk, thus severely degrading the quality of the signal. One more thing that degrades signal quality in such systems is the amplified spontaneous emission (ASE) noise produced by EDFAs, as each amplifier not only produced its own ASE, but also amplifies the noise that was produced by the previous amplifier. This also reduces the gain of the EDFA as significant part of the obtained population inversion is wasted on ASE amplification.

Taking into account the facts mentioned above, the Raman-EDFA hybrid solution was configured

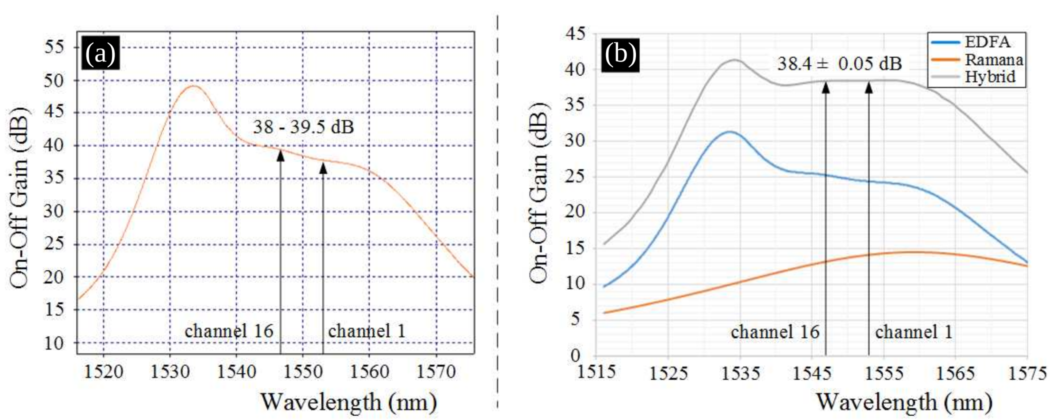

Figure 2: Gain spectra (a) of the EDFA inline amplifier and (b) of the hybrid Raman-EDFA amplifier.

with the aim to not only to equalise the gain spectrum in the wavelength band used for transmission and to ensure the required level of amplification, but also to reduce the amount of EDFA produced signal impairments. The SMF1 fibre was used as the gain medium for the DRA, where the 650 mW 1460 nm pumping radiation was launched in the counter propagating direction in respect to the signal to be amplified. Based on the obtained results it was decided to shorten the erbium doped fibre in order to reduce the amount of ASE produced by the in-line EDFA. To ensure the required level of population inversion a 23 dBm (200 mW) 980 nm co-propagating pumping radiation was used. The gain spectra that are ensured by the re-configured EDFA, by the DRA and the total gain spectrum of the hybrid solution are shown in Figure 2(b).

The results shown in Figure 2 clearly indicate that by implementing the hybrid Raman-EDFA solution much more uniform gain was obtained in the wavelength region used for transmission. The maximal difference in amplification between all 16 channels in the system with the hybrid Raman-EDFA amplifier has reached just 0.1 dB. Furthermore, the hybrid solution ensured gain difference below 1 dB over a 23 nm wavelength range (from 1538 to 1561 nm, by 17 nm more than was used for transmission of all 16 channels), which allows to significantly increase the number of channels in WDM transmission systems.

To compare the performance of the stand alone in-line EDFA and the hybrid Raman-EDFA amplifier OSNR values for all channels were obtained and compared at the output of the discrete amplifier. The obtained results are shown in Figure 3.

As can be seen in Figure 3, implementation of the hybrid solution has ensured OSNR improvement in all 16 channels from 1.7 up to 2.6 dB that in average is increase by ∼2 dB. Such OSNR improvement can be explained with the following facts:

- the usage of the distributed Raman amplifier has raised signal power at the input of the EDFA by 13.1–14.1 dB, therefore, the EDFA was functioning closer to the saturation point;
- the EDF fibre length was decreased by 3 meters, which allowed reducing the required input signal power for saturation of the EDFA;
- the coherent nature of stimulated Raman scattering (SRS) ensures that in SMF1 optical fibre, the signal was amplified more effectively than the low power optical noise, which allowed obtaining negative noise figure values (from −0.4 to −0.6 dB in the wavelength region used for transmission), and accordingly improved OSNR.

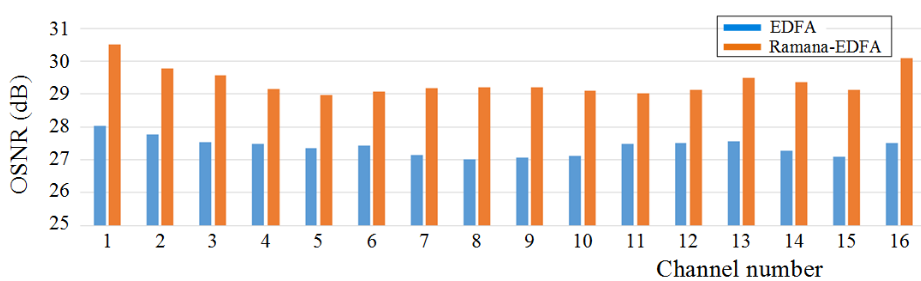

Figure 3: OSNR comparison among all 16 channels in the system with the EDFA inline amplifier and the hybrid Raman-EDFA amplifier.

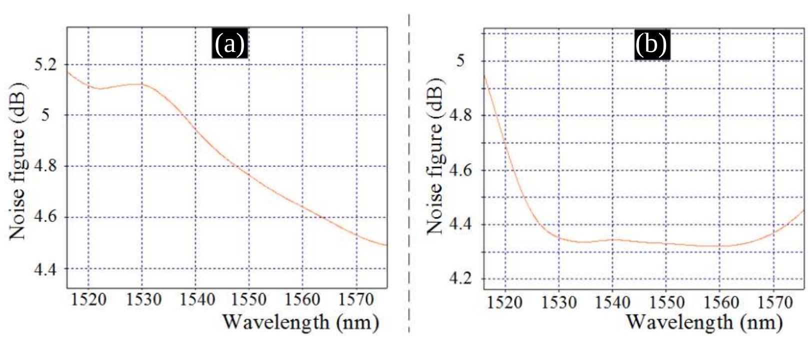

Figure 4: The EDFA Noise Figure wavelength dependence (a) in the system with the stand-alone in-line EDFA and (b) in the system with the Raman-EDFA hybrid amplifier.

To assess the influence of implementation of the hybrid solution on the amount of ASE produced by the EDFA, noise figure (NF) wavelength dependencies were obtained for the system with the stand alone in-line EDFA, and for the system with the hybrid Raman-EDFA amplifier. The obtained results are shown in Figure 4.

From Figure 4 it can be seen that in raising the signal power at the input of the EDFA and reducing the length of the erbium doped fibre allowed to obtain by 0.3–0.4 dB lower noise figure values for the EDFA.

4. CONCLUSIONS

In this article the authors have investigated the possibility of expanding and equalising the gain spectrum of a conventional EDFA and increasing the optical signal-to-noise ratio (OSNR) at the output of the amplifier by supplementing the system with a distributed Raman amplifier (DRA) and, therefore, forming a hybrid Raman-EDFA solution.

After comparing the aforementioned EDFA and Raman-EDFA solutions, it was concluded that the hybrid amplifier can ensure more even amplification over a broader wavelength region and higher OSNR values. However, more powerful lasers are necessary for implementing such solutions, which increases the costs of developing this solution. For the EDFA inline amplifier 316 mW of pumping power was required to amplify the −37.1 dBm input signal by more than 38 dB. In the case of the hybrid solution, the Raman amplifier required 650 mW of pumping power to ensure that gain is high enough and that its slope can compensate the slope of the EDFA with 200 mW pump gain spectrum, but the total pumping power of the hybrid amplifier has reached 850 mW. However, the hybrid solution ensured gain difference below 1 dB over a 23 nm wavelength range (from 1538 to 1561 nm, by 17 nm more than was used for transmission of all 16 channels), which in future will allow to significantly increase the number of channels in the WDM transmission system under attention.

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