Optically gain clamped Erbium-doped fibre amplifiers for next generation optical networks

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ABSTRACT:

The performance of optically gain clamped Erbium-doped fibre amplifiers is analysed in a realistic next generation network scenario. For this purpose, key design parameters and causes of transmission degradation are identified.

It is demonstrated that the gain clamping technique deployed effectively reduces gain fluctuations of the amplifier due to simultaneous add/drop of bursts. Quality degradation due to gain fluctuations is shown to be time-dependent along the duration of the burst.

All-optical gain clamping poses a trade-off in the amplified link performance due to the presence of a feedback channel. Feedback attenuation and wavelength must be chosen in such a way that quality of transmission remains within acceptable range with the minimum possible gain dedicated to the feedback channel.

Key words: Optical fibre amplifiers, gain transients, optical feedback, wavelength division multiplexing (WDM), optical networking.

1.- Introduction

Erbium-doped fibre amplifiers (EDFAs) are widely used in optical communication networks because of their transparent behaviour and broad gain spectrum, which allows the amplification of several channels present in WDM networks.

Lately, traffic evolution both in demand and nature has pushed the development of dynamically reconfigurable optical networks [1]. In this kind of networks, channels or wavelengths are dynamically added or dropped in response to changes in traffic demand. Thus, new requirements are needed in network components, which should be able to adapt to changes in optical power.

In the case of EDFAs, as they usually operate in saturation regime, changes of input power results in gain fluctuations of the amplifier, which lead to performance degradation [2-4].

Several techniques have been proposed for avoiding transmission penalties due to EDFA gain dynamics [5-8].

In this work the performance of all-optically gain-clamped EDFAs [5] (GC-EDFAs) is analyzed. In this technique, a portion of ASE from EDFA output is coupled back into its input to absorb gain transients.

2.- Experimental setup

Figure 1 shows the experimental setup used in the analysis. We consider an amplified WDM link, two tunable laser sources (*laser A* and *laser B* in the figure) represent the data channels. In order to emulate a scenario were several channels are added or dropped simultaneously, *laser A* is operated in burst mode while *laser B* represents the probe channel operating in continuous mode. Additionally, variable optical attenuators *VOA A* and *VOA B* are used to set the relative optical power

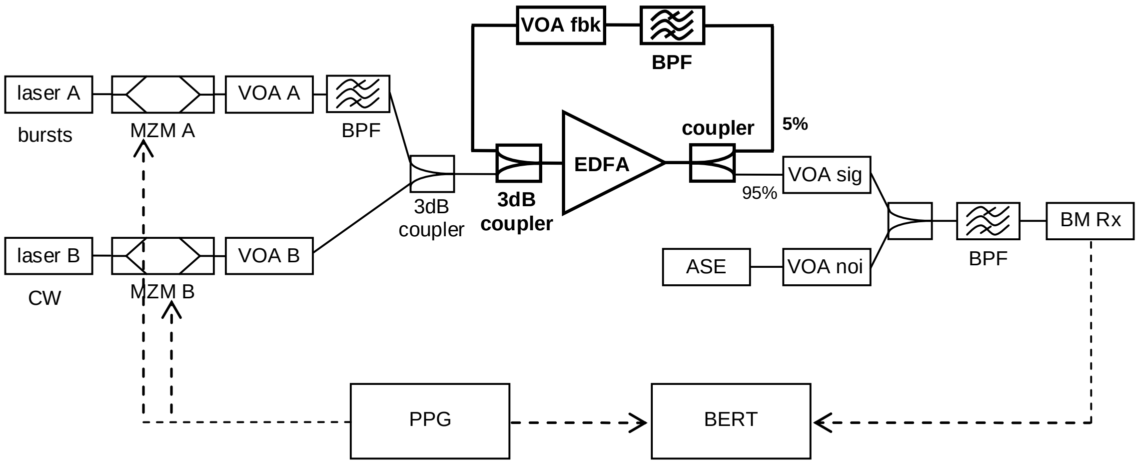

Fig. 1: Experimental setup for the measurements. The part in bold shows the all-optical GC-EDFA.

between burst and probe channels and thus the number of added/dropped channels in a realistic network. Data rate is 10 Gb/s, burst duration is fixed and set to 200 µs, which is in the range used in next generation networks [1].

As shown in the figure, the technique consists of an optical feedback loop which injects back a portion of output power at a given wavelength into the amplifier input. Therefore, at the input of the GC-EDFA there are three channels: feedback, signal and burst channel. The feedback loop is composed of bandpass filter and attenuator. Both components determine the application range of the clamping properties of the technique.

After amplification, in order to be able to analyse different situations of OSNR, noise from an ASE source is added to the channels. At the reception end, a burst mode receiver with adaptive threshold is used.

As already mentioned, the goal of the investigation is to determine the optimum configuration for the optical feedback loop. For this purpose, the set of feedback wavelengths and attenuations shown in Table 1 is considered.

Channel	Wavelength (nm)	Optical power (dBm)
feedback	1528, 1538, 1551	0 – 20 dB att.
CW probe	1542.5	-17
Burst	1535.9	-17, -11, -5

Table 1: Channel wavelengths and optical powers used in the experiments.

3.- Results

The presence of a feedback channel in the link, poses a trade-off in the performance of the GC-EDFA. Higher power in the feedback channel allows absorption of stronger fluctuations, but on the other hand, the amplifier gain available for signal channels is reduced. Figure 2 shows this effect, which should be taken into account for a proper design of a GC-EDFA.

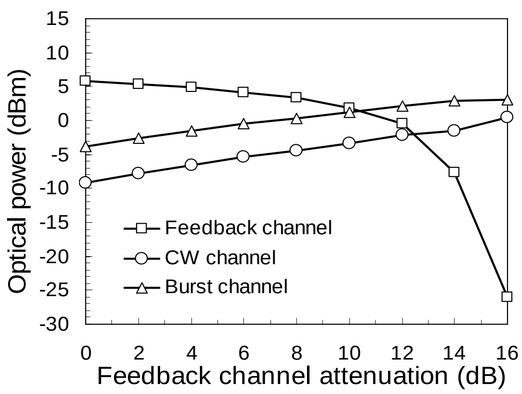

Fig. 2: Optical power of the channels present in the link as a function of the attenuation in the feedback loop.

The reduction of optical power of the signal channel degrades the performance of the amplified link and will result in transmission penalties.

The choice of the feedback wavelength affects the GC-EDFA performance because of the non-uniformity of the amplifier gain spectrum over wavelength. Wavelengths near

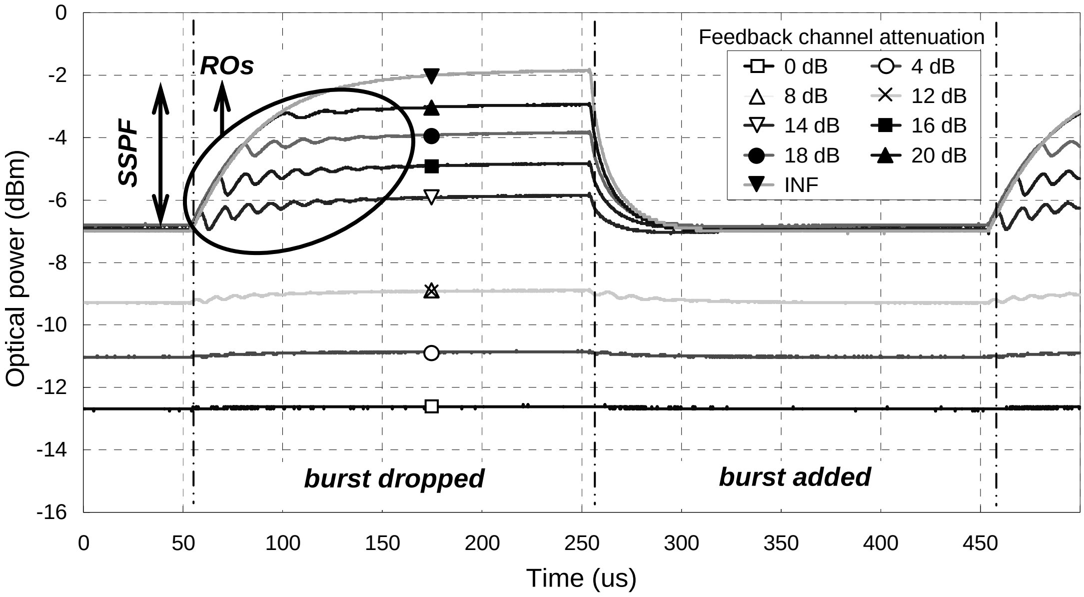

Fig. 3: Magnitude of the CW probe channel power transients when bursts are added and dropped for different values of feedback channel attenuation.

the gain peak (about 1528 nm) require more attenuation in the loop for the same scenario and thus the gain available for data channels is increased.

The optical power of the CW channel suffering from gain fluctuations due to the burst channel is plotted in Figure 3. Feedback channel attenuation of 0 dB represents the case of maximal gain clamping in the EDFA. As the feedback channel attenuation increases, gain clamping becomes weaker; infinite attenuation represents the case of amplifier without feedback loop. As it is observed, there are two separate contributions: relaxation oscillations (ROs) and steady state power fluctuations (SSPF) [9].

3.1.- Relaxation oscillations

ROs appear as a result of lasing phenomenon in the feedback cavity; their frequency and magnitude vary with the value of the feedback channel attenuation. This effect is worst for intermediate attenuation values (in the range 14 – 18 dB in Figure 3).

Figure 4 shows the evolution of RO magnitude and frequency as the feedback attenuation increases for different relative powers between burst and probe channel. Since the power of the CW probe channel remains constant (see Table 1), this represents

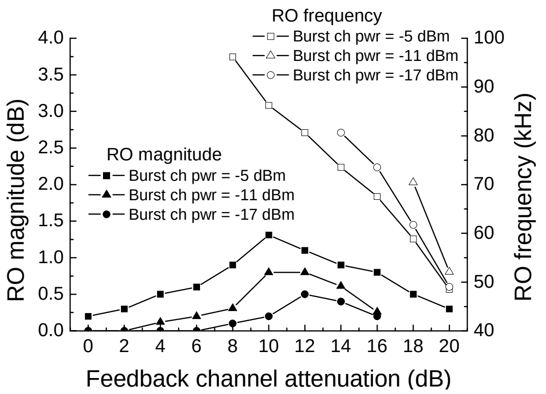

Fig. 4: RO magnitude and frequency as a function of feedback channel attenuation for different powers of the burst channel.

network scenarios with different number of bursts being added or dropped.

As for the previous figure, it is shown that the effect of ROs is greater for attenuation values in the middle of the range considered. The attenuation value for which the maximum of the RO magnitude is reached depends on the burst channel power and shifts to the left for increasing number of added/dropped bursts.

3.2.- Steady state power fluctuations

SSPF appear as a result of inhomogeneity in the Erbium gain spectrum. As shown in Figure 3, this effect is more noticeable when the amplifier is not gain clamped. The reduction of SSPF is achieved by decrease of feedback channel attenuation. This also leads to overall reduction of power in the probe channel.

Figure 5 shows SSPF variation with feedback attenuation for different values of burst channel power. For all the cases considered, there is a flat region for low feedback attenuation values. In this range of values, the feedback channel has enough power to absorb the gain transients. As the feedback attenuation increases, the gain clamping technique

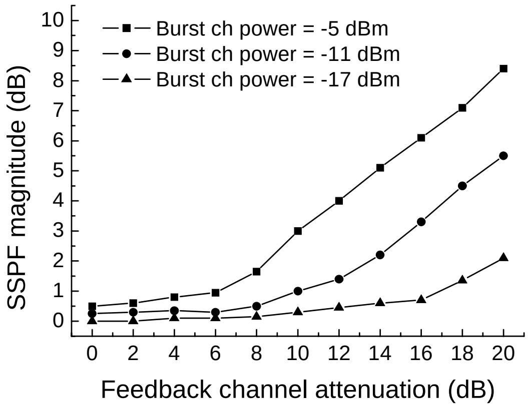

Fig. 5: SSPF magnitude as a function of feedback channel attenuation for different powers of the burst channel.

becomes inefficient and SSPF increase. As it can be observed from the figure, the attenuation value for which gain fluctuations are not suppressed depends on the burst channel power. When the number of added/dropped bursts increases, the feedback channel power must be higher in order to suppress SSPF.

4.- Conclusion

An experimental setup has been designed to analyze quality degradations due to add/drop of bursts in a WDM amplified link operating at speeds realistic to next generation networks.

All optical gain clamping has been demonstrated to decrease gain transients by using a relative simple technique with two configuration parameters: feedback attenuation and feedback wavelength.

There is a trade-off in the choice of the feedback attenuation: lower values reduce gain fluctuations, but more amplifier gain is dedicated to the feedback channel; higher values increase the gain available to data channels, but are not able to absorb strong gain fluctuations. On the other hand, feedback wavelength should be chosen near the amplifier gain peak in order to have the maximum available gain for the data channels.

The two factors that contribute to the performance degradation of the amplified link have been assessed.

Results show that knowledge of network environment (number of channels sharing the same link) is a key issue in the design of GC-EDFAs.

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