A Comparative Study of EDFAs and DRAs in Dispersion Compensation Modules for Long-Haul Optical Communication Systems

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Abstract

The need of dispersion compensation modules is mandatory on high-speed ultra-long communication systems. However, these dispersion modules impose a system penalty in terms of optical signal to noise ratio and nonlinear signal distortion that have to be minimized and quantified. The aim of this work is to compare the performance of Erbium Doped Fiber Amplifiers (EDFAs) and Distributed Raman Amplifiers (DRAs) as losses compensation elements for dispersion compensation modules.

I. INTRODUCTION

Longer distances and higher bit rates, caused by the increasing need of transporting traffic over optical fibers, expose the optical signal to deteriorating effects such as nonlinearities and chromatic dispersion. Chromatic dispersion in optical fibers leads to pulse broadening of the transmitted signal. When increasing the bit rate, the impact on signal quality rises significantly. The use of dispersion compensating fibers (DCFs) is an efficient way to avoid such effect [1]. DCFs consist simply of a single-mode fiber with a dispersion that is of opposite sign relative to the transmission fiber. There are two methods of compensation with DCFs: periodic and all-at-the-end compensation [2]. Periodic compensation's best performance can be achieved introducing a small pre-chirp at the beginning of the link. The all-at-the-end compensation scheme is based on the transmission of very short return-to-zero (RZ) pulses that are rapidly dispersed and allowed to reduce the nonlinear effects.

In this work we focused our attention in the dispersion compensating scheme coined all-at-the-end. A disadvantage of this design arises from the strong nonlinear distortions that occur in the DCF modules, mainly due the small effective area of this fiber. This effect could be minimized limiting the input signal average power in the DCF modules, but these causes strong penalty in the optical signal-to-noise ratio (OSNR).

Our goal is to obtain an optimum amplification scheme that provides, simultaneously, low nonlinear distortion and high OSNR. We analyze the effect of lumped and distributed amplification in conjugation with the DCFs.

II. SIMULATION AND RESULTS

A. *DESCRIPTION OF THE SYSTEMS*

In this section, we report a scheme of the transmission system used for the simulation.

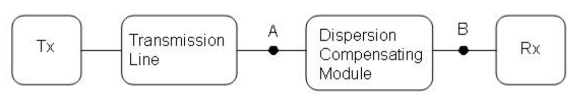

Fig. 1 Schematic used in the simulations

Figure 1 shows the schematic of the system used in the simulations. Tx generates the optical signal to be transmitted, in this case a pulse with a Gaussian shape, temporal full width half maximum equal to 5ps, and peak power between 0 and 10 dBm. The transmission line is composed by five 100km spans of single mode fiber. Rx is the receiver. The dispersion compensating module (DCM) is based on DCFs.

Figure 2 shows two possible configurations of a DCM with EDFAs. In the first scheme, figure 2 (a), the EDFA appears after the DCF, this scheme is known as post-amplification. In the second one, figure 2 (b), the amplifier appears before the DCF and is known as pre-amplification. The number (n) of dispersion compensation spans used in the DCM could be adjustable.

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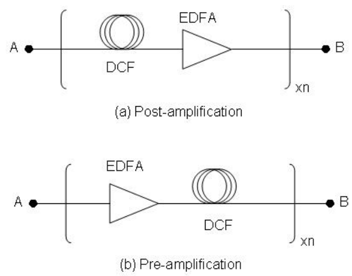

Fig. 2 - Schematic of the dispersion compensating module with EDFAs.

Figure 3, shows the distributed Raman amplification scheme with backward, forward, and bi-directional pumping.

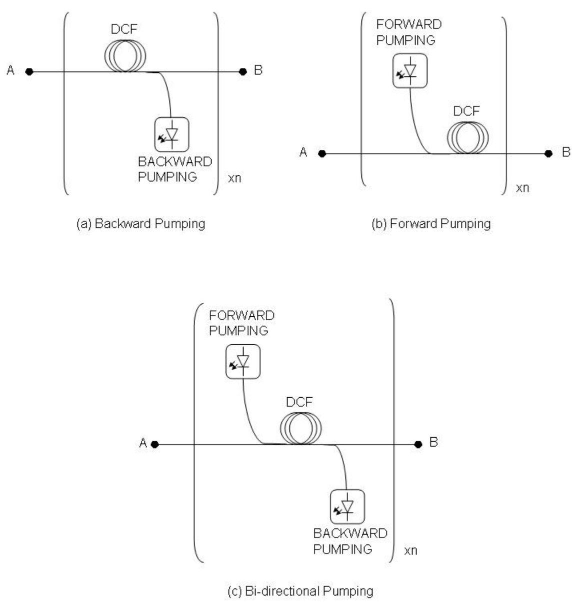

Fig. 3 - Schematic of the dispersion compensating module with DRAs

B. *OSNR*

During optical amplification, noise is introduced and amplified. In high-speed optical transmission system it is necessary a large signal-to-noise ratio (SNR) at the receiver input to obtain a low bit-error-rate (BER) [7]. This is the reason why we studied the effect of the noise on both schemes varying the number of dispersion compensating spans.

With two, four and ten EDFAs we have a similar behavior as the one shown in figure 4 for five EDFAs. As we can see, when input power increases, the value of EOP decreases. The EOP becomes smaller with a high input power because the effects of noise will diminish compared with it. So, we have a better system performance with high levels of input powers.

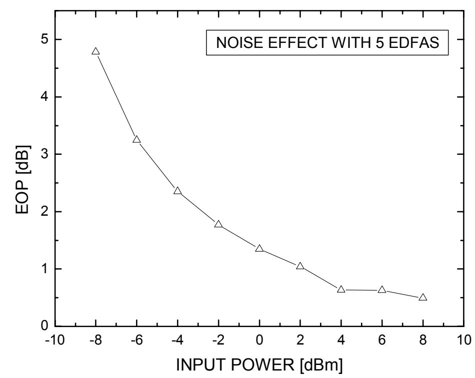

Fig. 4 - EOP in a system with five EDFAs considering noise effect.

With a Backward Distributed Raman Amplifier (BDRA) scheme the behavior is similar to the one observed in figure 4, as is shown in figure 5

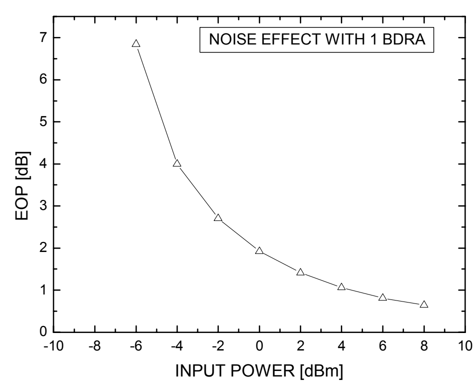

Fig. 5 - EOP in a system with one BDRA considering noise effect.

Studying Bi-directional Distributed Raman amplifiers (BiDRAs) and Forward Distributed Raman Amplifiers (FDRAs), we found that they have EOPs higher than

BDRAs, as we can see on figure 6 for BiDRAs. For FDRAs the behavior is similar.

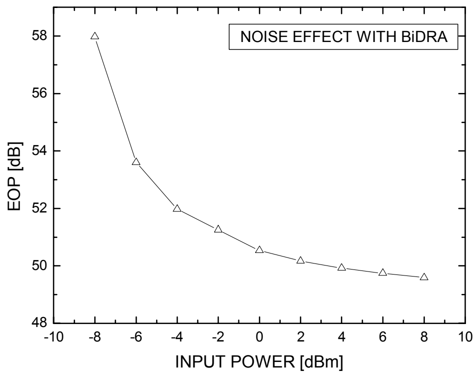

Fig. 6 - EOP in a system with one BiDRA considering noise effect.

C. *Nonlinear Degradation*

With the development of lightwave communication systems carry large amounts of information, higher optical power is required. However, this is limited by nonlinear effects [8]. Basically three nonlinear effects take place in a single channel system: Self Phase Modulation (SPM), Intrachannel Cross phase Modulation (IXPM), and Intrachannel Four-Wave Mixing (IFWM) [2]. For few hundred kilometers, pulse distortion induced by SPM has not a strong effect. However, timing jitter and energy fluctuations induced by IXPM and IFWM can play a major role in the system performance [2].

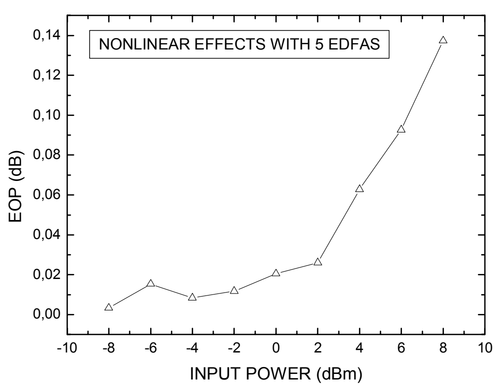

Fig. 7 - EOP in a system with five EDFAs considering nonlinear effect.

In figure 7 and 8, it is shown the degradation due to nonlinear effects in the DCFs for, respectively, the scheme with EDFAs and the scheme with BDRAs.

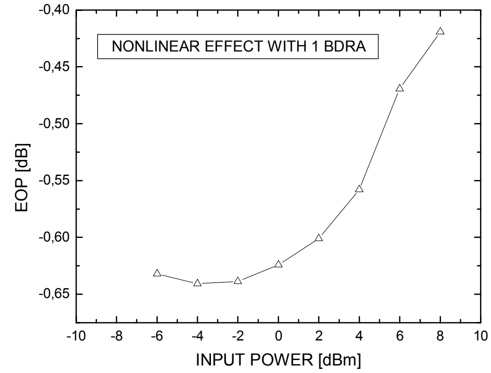

Fig. 8 - EOP in a system with one BDRA considering nonlinear effect.

With the increase of the input power, EOP increases, as expected. Nonlinear effects start to take a major role.

For the case of FDRA, it has higher values of EOP and BiDRAs has values in the same range of BDRAs.

D. *Both Effects*

From figures 9 and 10 we can see both effects on the systems.

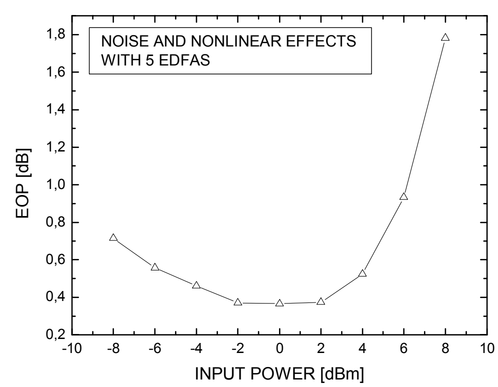

Fig. 9 - EOP in a system with five EDFAs considering noise and nonlinear effects.

It can be seen that the behavior of the systems are similar. Before 0 dBm their characteristics are predominantly the result of noise and, for higher input powers the nonlinear effects are the main degradation effect.

With both effects, BiDRA presents values of EOP in the same range of BDRA, and the FDRA presents higher values.

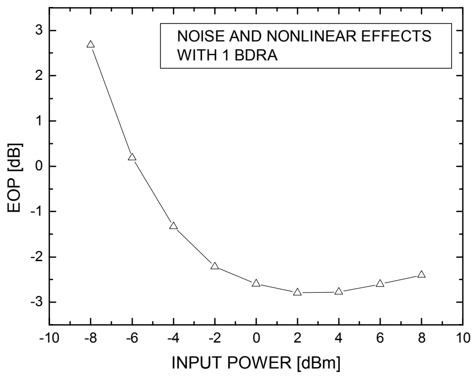

Fig. 10 - EOP in a system with one BDRA considering noise and nonlinear effects

III. Conclusions

We could see that OSNR is more important when input power decreases for both configurations, lumped and distributed amplification. With nonlinear effects it is the opposite, the EOP arise with the increase of the pump power. When we put both effects, until 0 dBm we had the characteristics behavior dependent basically of the noise and for higher levels of power the nonlinear effects are dominants.

Comparing the behavior of BiDRA, FDRA and BDRA we could see that BDRA are better because they have less EOP than the other two.

IV. References

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