

BER IMPROVEMENT USING A 2-R REGENERATOR BASED ON AN ASYMMETRIC NONLINEAR OPTICAL LOOP MIRROR

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Abstract: BER improvement of 15 decades is observed using an asymmetric NOLM at a bitrate of 40Gbit/s and an input OSNR of 28.7dB. The BER improvement can be converted into 3.9dB of OSNR gain. Both were achieved by optimizing NOLM input power and splitting ratio. This allows for longer spans and thus reduces the over all amount of amplifiers or allows for an increased system reach.

1. INTRODUCTION

Signal regeneration is a key element for future data transmission at high bit rates. 3-R and 2-R regenerators are currently under investigation using all optical techniques. If no retiming is required NOLM based 2-R regenerator are an interesting alternative to 3-R regenerators, as they are less complex but have high potential for increasing the system reach [1, 2]. Their set-up uses only a few components and integration in an existing optical transmission system is simple [1, 2]. We use a 2-R regenerator based on an asymmetric NOLM suggested by Smith and Doran [3]. With the nonlinear power transfer characteristic of the device (see Fig. 2) it is possible to suppress noise and thus to prohibit the formation of new bit errors. The feasibility of such a setup concerning noise reduction and BER improvement was experimentally shown [4, 5].

We present for the first time to our knowledge a detailed analysis of the NOLM's impact on the BER. The BER improvement in dependence of the NOLM in-

put power and splitting ratio is investigated, and the OSNR performance with optimized NOLM parameters is measured.

2. SIGNAL REGENERATION WITH AN ASYMMETRIC NOLM

Due to the nonlinear transmission characteristic of the NOLM (e.g. Fig.2) it is possible to reduce amplitude noise imposed on the "1" bits of the signal. In addition the noise on the "0" bits is reduced to some degree. By this noise reduction the probability density functions (pdf) of "1" and "0" bits are compressed, compensating for the broadening in the preceding EDFA. Therefore the formation of new bit errors due to an overlap of both pdfs is reduced. The NOLM itself is a passive device and thus cannot reverse any already existing overlap between the two pdfs, being responsible for the BER. Thus the usage of NOLMs as in-line regenerators has best impact on the signals evolution at the beginning of a transmission-link as done in our experimental setup. Implementation of the NOLM at the end of the link has only little impact on the BER. Furthermore the NOLM should be used at good OSNR around 30dB, as maximum noise reduction is achieved under these conditions [6].

3. EXPERIMENTAL SETUP

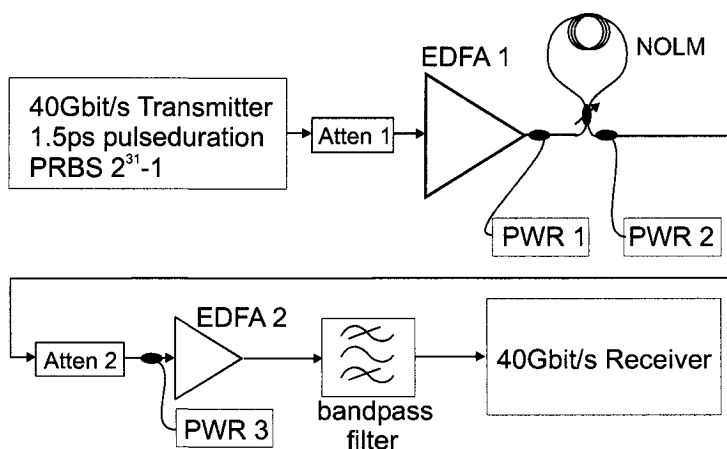


Figure 1. Experimental Setup. The setup emulates a 2 span transmission system in which fiber is emulated by attenuators.

The experimental setup is depicted in Fig.1. A 1.5ps laser with 10GHz repetition rate is multiplexed to a 40GB/s pulse train which is modulated with PRBS $2^{31} - 1$ data. With attenuator1 and the following high power EDFA1 the NOLM input OSNR and the NOLM input power are adjusted. The NOLM

consists of a variable fiber coupler and 1840m of NZDSF fiber. After the NOLM the signal is attenuated and amplified again by EDFA2. This emulates a fiber span following the NOLM. The input power of EDFA2 is kept constant to -24dBm with attenuator2, thus adding always a constant noise to the NOLM output signal. Then the data signal is band pass filtered and detected.

4. EXPERIMENTAL RESULTS

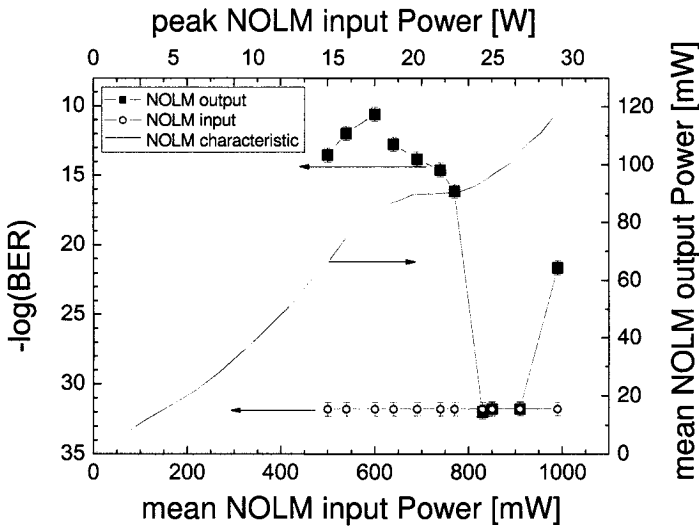


Figure 2. NOLM transfer characteristic and BER measured directly behind the NOLM. BER measured behind EDFA1 is shown, too. The splitting ratio was adjusted to 12:88, the OSNR at the output of EDFA1 was 28.7dB.

We measured the BER versus the decision threshold (V-curves) at different NOLM input powers with the NOLM directly in front of the receiver, excluding attenuator 2 and EDFA 2. From these V-curves the minimum BER was extrapolated. The NOLM input OSNR was set to 28.7dB, the splitting ratio was 12:88. As shown in Fig.2, the BER taken at the NOLM output, varies with the NOLM input power. For comparison the BER without the NOLM is also shown. It is clearly visible that the NOLM can only degrade the BER in this application, but never improve it. Only at the upper end of the plateau the NOLM induces no BER degradation, and the same level as without the NOLM is reached. Thus, implementing a NOLM at the end of a transmission link, directly in front of the receiver, is shown to be ineffective. Broad-

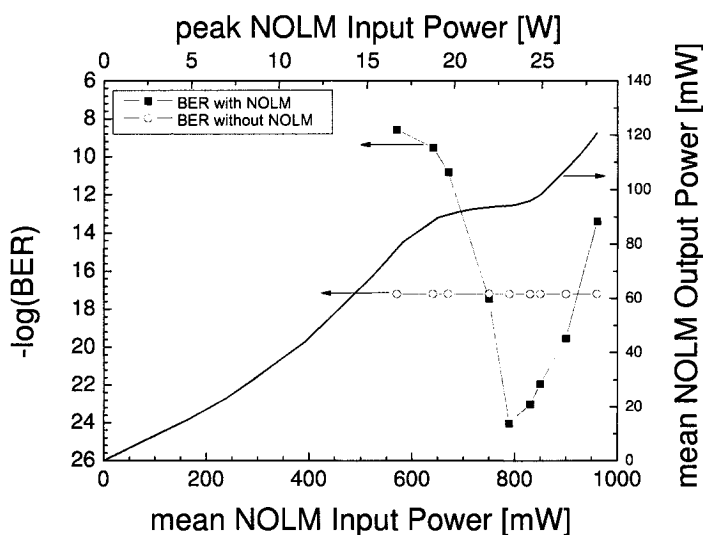


Figure 3. NOLM transfer characteristic, BER with and without NOLM measured at the output port of bandpass filter. The splitting ratio of the NOLM was set to 14:86, the OSNR at the output of EDFA1 was set to 28.7dB

ing the probability density functions of "1" and "0"bits with the subsequent EDFA2, by adding noise to the signal after the NOLM, BER improvement can be demonstrated as shown in Fig. 3. The receiver input OSNR was set to 25.7dB. As expected from the measurement without adding noise, the optimum operation point is the upper end of the plateau region. In these measurements, too, the BER is extrapolated from V-curves. The BER is reduced from 10^{-17} to 10^{-25} . Changing the NOLM input power the BER improvement reduces, and for powers below and above the plateau region even BER degradation may be observed. Varying the splitting ratio the BER can be optimized further, as shown in Fig.4. Best results are achieved for a splitting ratio of 16:84. For more symmetric splitting ratios the BER improvement reduces and for splitting ratios more symmetric than 28:72 the NOLM only degrades the signal. Measuring the OSNR performance of the NOLM leads to Fig. 5. This figure shows the BER with and without NOLM as a function of the output OSNR of EDFA1. Additionally this figure shows the OSNR gain achieved with the NOLM on its right hand side. As expected from noise measurements [6] and Fig.4 adaption of the NOLM splitting ratio on the NOLM input OSNR was necessary to optimize the results. The BER with NOLM was taken at the upper end of the plateau, as shown in Fig.3 for splitting ratios of 12:88 and

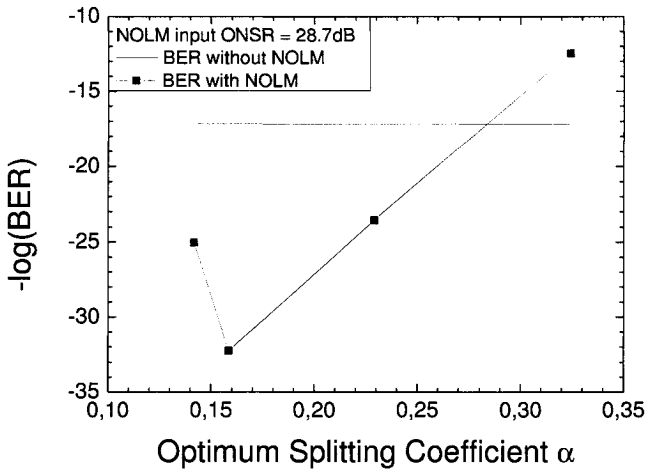


Figure 4. BER taken at the output port of the bandpass filter for different splitting ratios. The BER without NOLM is given for reference. The BER was taken at the upper end of the plateau.

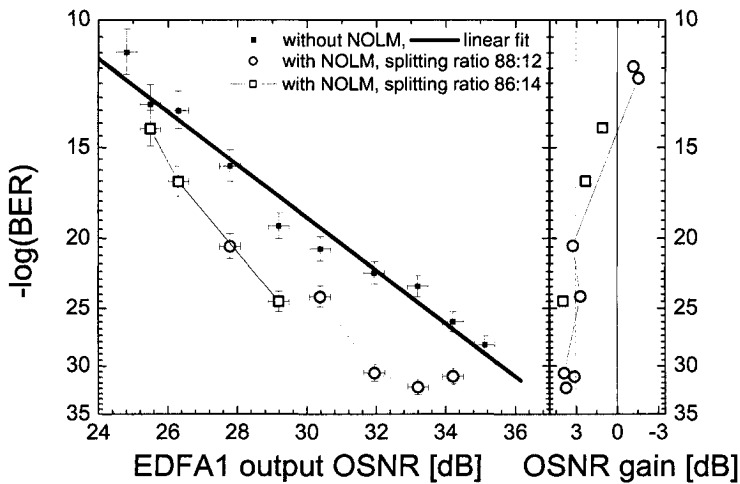


Figure 5. OSNR performance without and with NOLM for different OSNR, taken at the output of EDFA1, and different splitting ratios.

14:86. For NOLM input ONSRs between 27dB and 32dB, corresponding to BERs between 10^{-21} and 10^{-32} , more than 3dB of OSNR gain are achieved. Best OSNR gain of 3.9dB is achieved for a BER of 10^{-24} . Measurement of data for lower OSNR and higher BER could not be performed due to a lack of power, provided by EDFA1. At low OSNR a large part of EDFA1's pump power generates ASE noise, thus reducing the power available for signal amplification. Currently the power needed to operate the NOLM is very high. But with the development of modern photonic crystal fibers, fibers will be available which have a high nonlinearity and thus can reduce the power requirement to a few mW.

5. CONCLUSIONS

BER improvement by a 2-R regenerator based on an asymmetric NOLM has been studied. 15 decades of BER improvement at a NOLM input OSNR of 28.7dB were demonstrated after optimizing the splitting ratio to 16:84. For optimum operation the NOLM input power has to reach the upper end of the plateau. More than 3dB gain of OSNR were observed for NOLM input OSNR between 27dB and 32dB by implementing the NOLM into a transmission link. A maximum OSNR gain of 3.9dB was observed for NOLM splitting ratio of 86:14 and a BER of 10^{-24} . Thus by using the NOLM as an in-line regenerator the system reach can be more than doubled. Alternatively the length of a span can be elongated by up to 19km, as up to 3.9dB of extra attenuation can be tolerated. This in turn can be used to reduce the amount of amplifiers needed for a transmission system. The amount of amplifiers used for example in the FLAG-Atlantic-1 cable can be reduced by 31% when using NOLMs.

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