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All-Optical 2R Regenerator Non-Linear Optic Based on the Mamyshev Model

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ABSTRACT: This paper aims to present a fiber optic telecommunications network design capable of suppressing noise and improving the quality of the transmitted signal through the self-phase modulation effect in a highly nonlinear fiber (HNLF), thus allowing the regeneration 2R (Reamplification and Reshaping) in a totally optical way. For a distance of up to 300 km of SMF, the values of factor Q = 6, BER = 10^{-9} and OSNR = 13.5 dB were found. The project was developed and simulated in Optisystem software. The results confirm that the proposed 2R regenerator was efficient.

KEYWORDS: 2R Regenerator; Optical networks; Degraded signal; Regenerated signal.

I. Introduction

Signal regeneration techniques in fiber-optic telecommunication systems, whether 1R (Reamplification), 2R (Reamplification and Reshaping) or 3R (Reamplification, Reshaping and Retiming) have been of interest to researchers all over the world. These techniques are implemented in today's telecommunications networks in order to increase performance and gain in optical signal transmissions and receptions.

Some regenerators were developed with the insertion of optical fibers: Highly Nonlinear Fibers (HNLFs), Dispersion Shifted Fibers (DSFs), Dispersion Compensated Fibers (DCFs) and Photonic Crystal Fibers (PCFs) [1]. These fibers are used to highlight the non-linear effects of self-phase modulation (SPM), cross-phase modulation (XPM) and four-wave mixing (FWM) [2]. The nonlinear effects associated with signal regeneration techniques have resulted in several devices for the processing of optical signals, such as [2]: Nonlinear Optical Loop Mirror (NOLM), Mach-Zenhder Interferometer Semiconductor Optical Amplifiers (SOA- MZI) or with Michelson Interferometer (SOA-MI) and also Electro- Absorption Modulators (EAM) [3], among others.

The regeneration of a signal can be electrical, all-optical or opto-electronic [4], but in this work we choose the second option. Since, fully optical regeneration is a technique that is constantly under investigation [2], it consists of treating degraded optical signals during fiber optic transmission and amplifiers and transmitting them without distortion, crosstalk and noise. Optical regenerators can offer numerous advantages in terms of compaction to electrical regenerators such as: component reduction and cost, transparency and scalability. In addition to avoiding the conversion of O-E-O (Optical-Electrical-Optical), which is considered a bottleneck for optical networks. For these and other reasons is that totally optical regeneration is replacing the electric regeneration.

In this paper, we present a 2R regeneration scheme of all-optical signals based on an HNLF, which will act with the aid of the self-phase modulation effect. In Section II, the schematic of the 2R regenerator based on SPM and their respective characteristics and functioning are presented. In Section III, the different results regarding the performance of the system are described, which were analyzed through the quality factor (Q-factor), bit error rate (BER) and Optical Signal-to-Noise Ratio (OSNR).

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II. THEORETICAL BASIS AND OPERATING PRINCIPLE OF PROPOSED 2R REGENERATOR

The 2R regeneration is characterized by having a setting with fewer parameters of control, so it is considered simpler, runs only two functions to reamplification and reshaping, because the optical clock recovery circuit. Along the length of an optical link can occur numerous defects which are caused by random noise accumulated, so the use of regeneration is essential to extend the transmission distance of the digital signal in addition to the limitations [8]. Therefore, the removal or remodeling those noises in the optical domain require the use of non-linear optical materials, optical fiber is excellent.

A pulse to propagate in an optical fiber can suffer numerous influences due to multiple non-linear effects, which can be as to the content or as to the scattering. These are natural responses of any dielectric medium, when subjected to a power in your intensity electromagnetic field. According to [4], non-linear effects are no more deleterious for fiber-optic telecommunication systems and can be used in signals regeneration techniques.

The Highly non-linear fibers based on standard silica with a nonlinear coefficient of $\gamma \sim 20\ W^1/km^{-1}$or other types of materials and also with photonic crystals, both of which have required lengths in the order of tens or hundreds of meters [8], have been used in 2R regenerators or 3R. Another interesting type of fiber is the fiber with dispersion compensation, which has as main characteristic, a negative dispersion, whose function is to compensate for the effects of phase displacement, caused by the color dispersion of the SMF link used in the same network. The use of a DCF in a light wave system is very important because it has nonlinear parameters and optical intensities greater than SMFs, in addition to highlighting non-linear effects. A small segment of 6 to 8 km DCF with optical amplifiers spaced 60 to 80 km can compensate for GVD and also losses [2].

Mamyshev is attributed as one of the pioneers in the publication of research papers in which 2R regeneration with HNLFs is applied [4]. The schematic shown in figure 1 is an example of a Mamyshev regenerator based on SPM, which was published in 1998[10] and has served as a reference for new 2R and 3R regenerator designs to the present day.

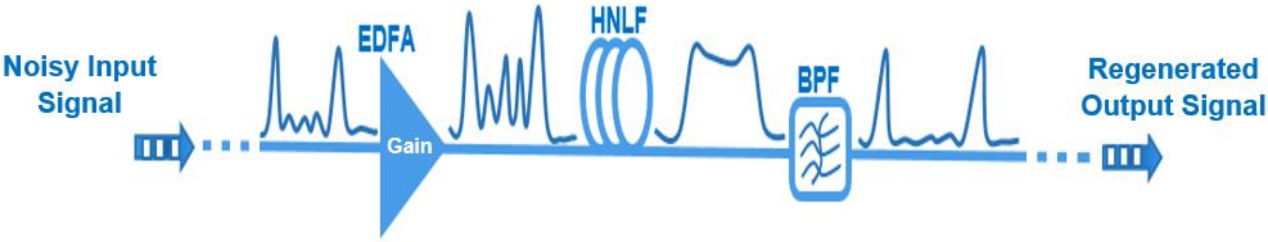

Fig. 1. Schematic of a Classic Mamyshev Regenerator.

This classic Mamyshev 2R regenerator is a simple suppression of "zeros" and "one" amplitudes fluctuations [4], based on Self Phase Modulation (SPM), in which the noisy signal is initially sufficiently amplified by an Erbium Doped Fiber Amplifier (EDFA),then the pulse goes through a process of enlargement induced by SPM effect to propagate by Highly Non-Linear Fiber (HNLF) and at the end this signal is filtered and reformatted by a Band-Pass Filter (BPF),which also reduces unwanted noise in the output of the regenerator, improving therefore the extinction ratio.

A. *Simulation Setup:*

In our project we present a regenerator based on the ideas of Mamyshev, as shown in figure 3. The scheme has three types of fibers and is also divided into three parts: Transmission, Degradation and Regeneration. Figure 2 shows the main part of the system, which follows the same Mamyshev model.

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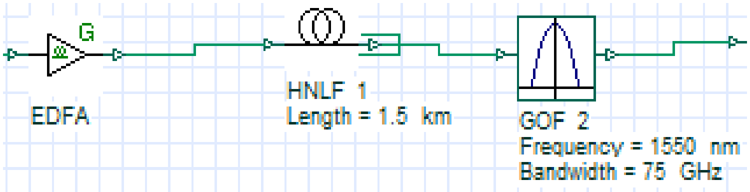

Fig. 2. Main Part of the 2R Regeneration System.

The transmission part consists of a 10 Gb/s pseudorandom bit sequence generator (PRBS) connected to a Optical Gaussian Pulse generator (OGP), which in the simulations will have a power ranging from 0 to 10 dBm and wavelength of 1550 nm.

The second part is responsible for degradation, which is composed of a 100 km long single mode fiber (SMF), with an anomalous dispersion of 17 ps/nm.km, a dispersion slope of 0.08 ps/nm^2.km, attenuation of 0.2 dB/km, effective area of 80 µm^2, refractive index of 2.6x10^{-20}. The signal will be degraded in up to 3 loops of the same fiber, that is, 300 km. A dispersion compensating fiber (DCF) of 21 km in length was also used in order to compensate the SMF dispersion, which has as parameters: attenuation of 0.6 dB/km, normal dispersion of -80 ps/nm.km, dispersion slope of 0.21 ps/nm^2.km, effective area 30 µm^2 and refraction index of 2.6x10^{-20} m^{2}W.

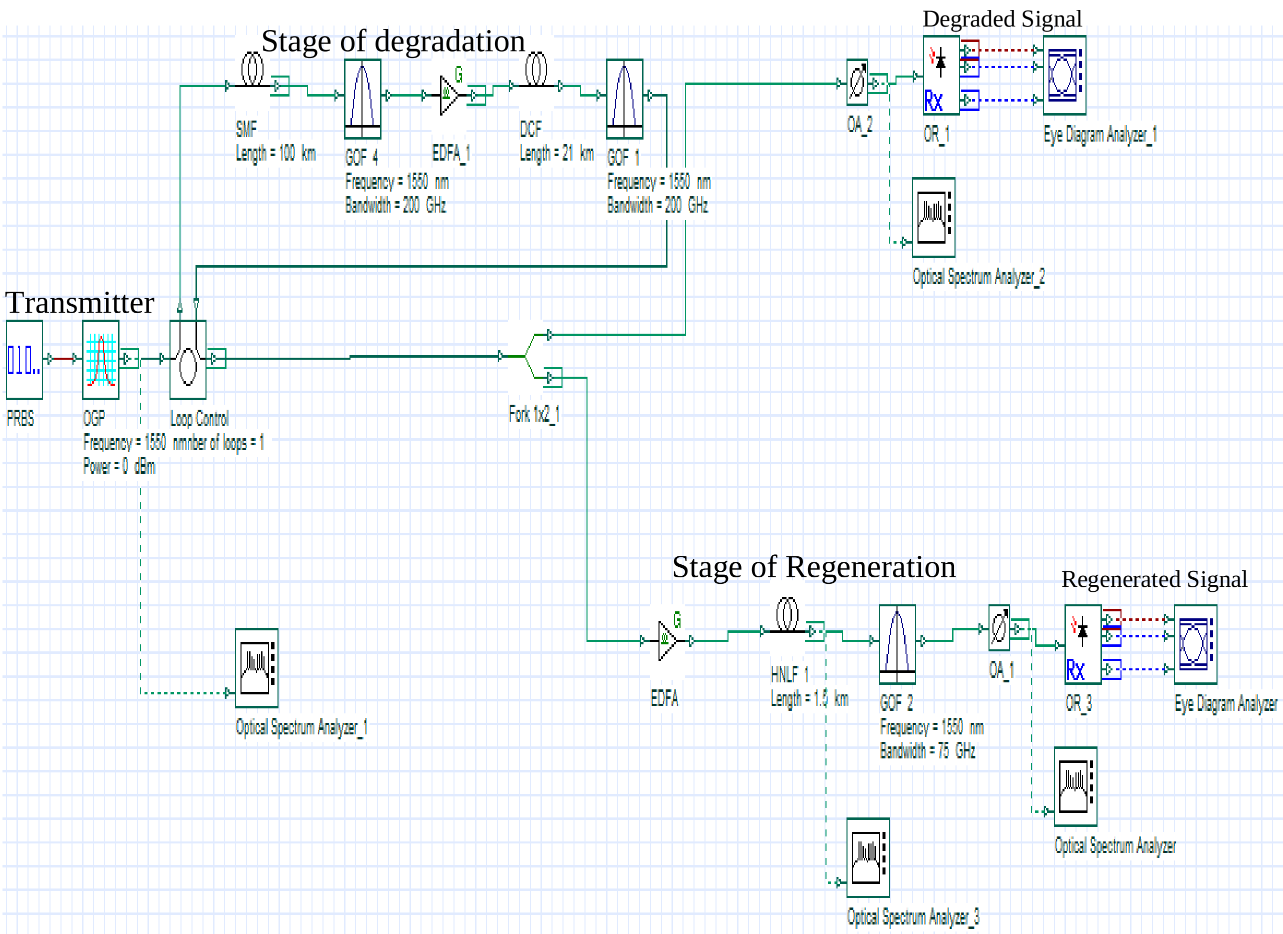

Fig. 3. 2R Regenerator Schematic of Highly Non-linear Fiber based on SPM.

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After the SMF and DCF, EDFAs were used, gaining 20 dB and 32.8 dB and with a noise figure of 4 dB, these amplifiers are used to recover losses. In the degradation part there are also two Gaussian filters, both with a bandwidth of 200 GHz, which will be responsible for the reduction of the noise caused by the amplified spontaneous emission (ASE) of the amplifiers.

In the third part, signal regeneration was performed, using a 1.5 km long HNLF with dispersion of -72 ps/nm.km, dispersion slope of -0.0075 ps/nm^2.km, attenuation of 0.47 dB/km, Effective area of 1.81 μm^2, refractive index of 2.6x10^{-20}m^{2}Wand soon after a Gaussian filter with 75 GHz bandwidth and with central frequency located at the same wavelength of the transmitter.

The components used to collect the results in the two parts of the proposed 2R regenerator were: Eye Diagram Analyzer and Optical Spectrum Analyzer. These instruments were used to determine bit error rate (BER), quality factor (Q), eye height, optical signal noise ratio (OSNR) and pulse shape.

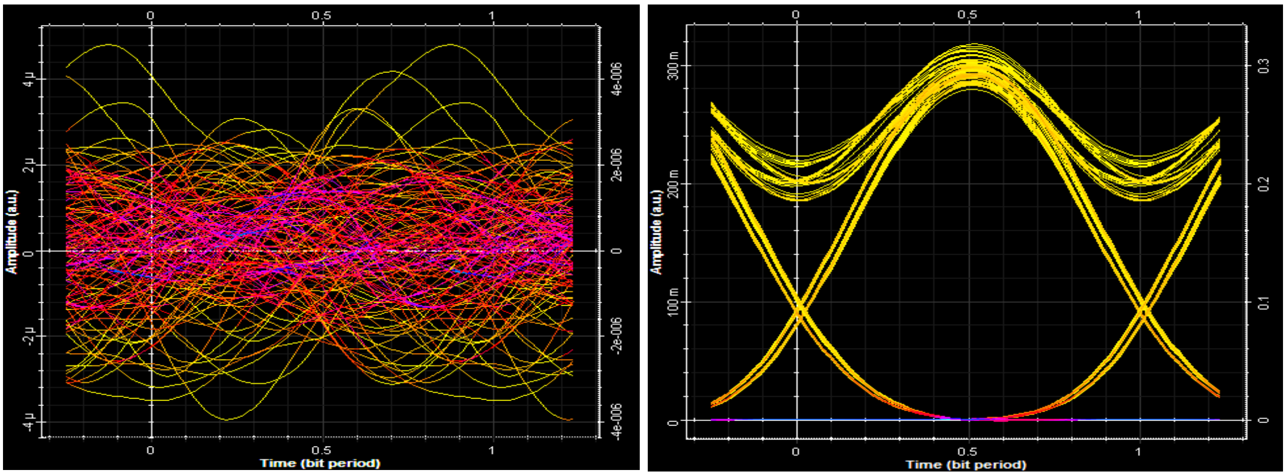
III. Analysis and Discussion of Simulated Results

The results will be shown according to the stages of signal degradation and regeneration. For the analysis of the eye diagram, a power sweep at the output of the transmitter was performed at 0 dBm, 5 dBm and 10 dBm, for the chosen modulation format. The values of BER, Q-factor and OSNR were also obtained for each SMF length and injected power levels in the signal degradation and regeneration process.

A. *Comparison between Signal Degradation and Regeneration Stages:*

Initially we made a comparison of the signal in the degradation stages and in the regeneration stages, in order to analyze the performance of the system. Figure 4 shows what occurred with the optical pulse when propagating in the fibers and other components used in the design of the proposed optical communication system, through the eye diagrams for degradation stages 4 (a) and regeneration 4 (b), For a transmission rate of 10 Gb/s, with 100 km of SMF.

After the degradation process, the value of Q-factor = 0 and BER = 1 was obtained and after the regeneration process the value of Q-factor = 35 and BER = 2.5x10^{-213}, with input power of 0 dBm. Note that in the degradation step, the signal is noisy and with loss of power, this occurred due to the dispersion and attenuation induced by the SMF link. This degraded signal causes serious damage to the system, as shown by the stressed eye of Figure 4 (a).



(a) **(b)**

Fig. 4. Eye diagrams: (a) after the stage of degradation and (b) after the regeneration stage.

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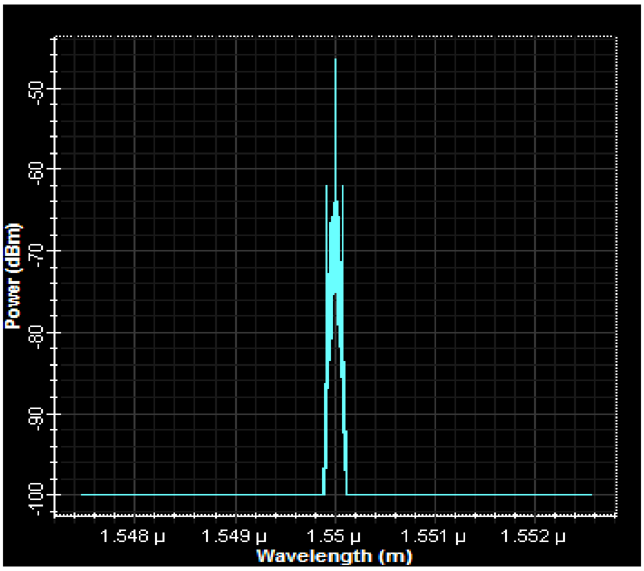
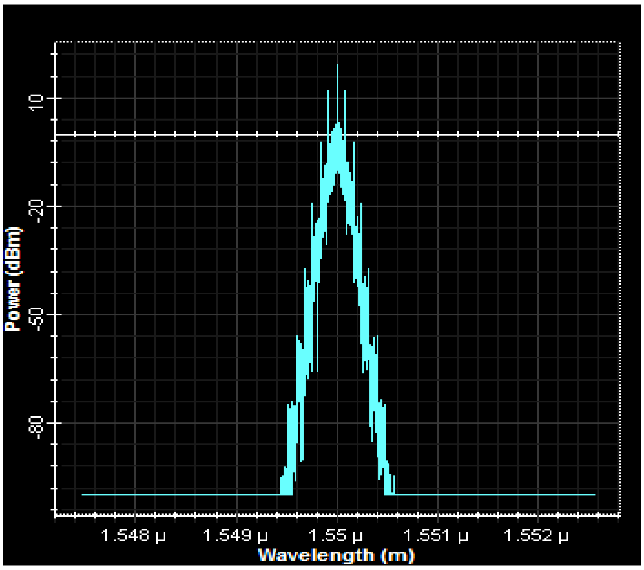
In this project HNLF is the main part of the 2R regenerator, which was used to eliminate noise through the effect of SPM [3]. It was also responsible for reformatting the signal, despite its short length, but sufficient to obtain the desired nonlinear effect and also improve the degree of integration of the system. Therefore, the signal eye diagram at the output of the stage of regeneration (figure 4 (b)) appears lighter (healthy eye) than the signal eye diagram of the stage of degradation (figure 4 (a)).

The results show that both the quality factor and the bit error rate showed significant improvements in the pulse amplitude and consequently there was a power gain. Therefore, through the effect of SPM induced by the short length of the HNLF, the signal quality and also the sensitivity of the receiver were restored because of the pulse compression and noise suppression level "0", which resulted in the stability of the Mechanical vibrations, thus avoiding possible polarization fluctuations.

Below are shown the optical spectra of degraded signal before the HNLF Figure 5 (a) and after the HNLF Figure 5 (b). You can see that in Figure 5 (b), the spectrum is wider, it is justified by the action of the SPM effect inside the highly non-linear fiber and also due to the pulse amplification EDFA in the early stage of regeneration.



(a)



(b)

Fig. 5. (a) The Spectrum of the Degraded Signal and (b) Spectrum of the Regenerated Signal.

B. *2R Regenerator Performance in Relation to Distance and Transmission Power:*

The optical signal-to-noise ratio (OSNR) is the optical power generated when the optical signal is converted into electric current and is also considered the main source that determines the noise level. It is also a very important metric to determine the performance of an optical network.

Thus the OSNR is the ratio of the average power at the output of the EDFA to the ASE optical noise power, which is determined at a certain reference bandwidth and is defined in dB by [2]:

$$OSNR = 10log\frac{\text{average signal power EDFA}}{\text{ASE optical noise power}} \quad \text{eq. (1)}$$

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The value of the OSNR can also be determined through the Optical Signal Analyzer (OSA) or its relation to the Q-factor and to the BER, because as the BER increases the factor Q and the OSNR decrease [9], this is Harmful to the proper functioning of the telecommunications system. This relation is expressed by [5]:

$$OSNR = \frac{1}{2}Q(Q + \sqrt{2}) \quad \text{eq. (2)}$$

Generally, in optical network projects a safety margin of 3 to 6 dB system efficiency is given [5], this ensures that the BER threshold does not exceed the variation in the time of parameters such as: transmitter output and attenuation or background noise. In this sense, the quality factor should be the highest possible value for an optimal input power value, because at low power levels the Q-factor can be limited by noise or by non-linear effects in case of high levels of input power [4].

The 2R regenerator performance proposed here will be determined by the BER, Q-factor, eye diagram, eye height and the regenerated signals OSNR depending on the variation of the power and also the distance. The aim is to obtain detailed results aa step of regeneration, where the signals were analyzed in three levels of powers of entry, i.e., to 0 dBm, 5 dBm and dBm 10 and also with three different SMF distances: 100 km, 200 km and 300 km, as shown in table 1 below:

Table 1. Regenerator 2R Performance in the Regeneration Stages.

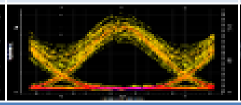
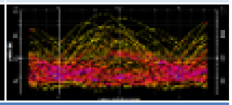
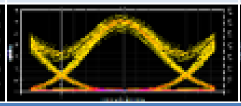
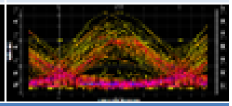
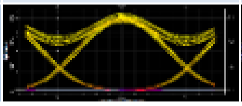
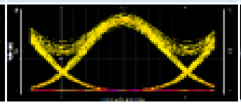
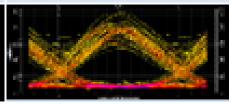
TRANSMITTER POWER		SMF DISTANCE (Km)		
		100	200	300
0 dBm	BER	2.5×10^{-271}	1.4×10^{-19}	1
	Q-Factor	35	9	0
	OSNR	28 dB	16.7 dB	0 dB
	Eye Height	0.0306162	0.00124744	0
	Eye Diagram			
5 dBm	BER	0	1.3×10^{-60}	1.2×10^{-3}
	Q-Factor	39.4	16.4	3
	OSNR	29 dB	21.6 dB	8.2 dB
	Eye Height	0.094863	0.00476962	-2.2×10^{-6}
	Eye Diagram			
10 dBm	BER	7.5×10^{-230}	3×10^{-116}	1×10^{-9}
	Q-Factor	32.3	23	6
	OSNR	27.4 dB	24.5 dB	13.5 dB
	Eye Height	0.268056	0.015319	0.000295093
	Eye Diagram			

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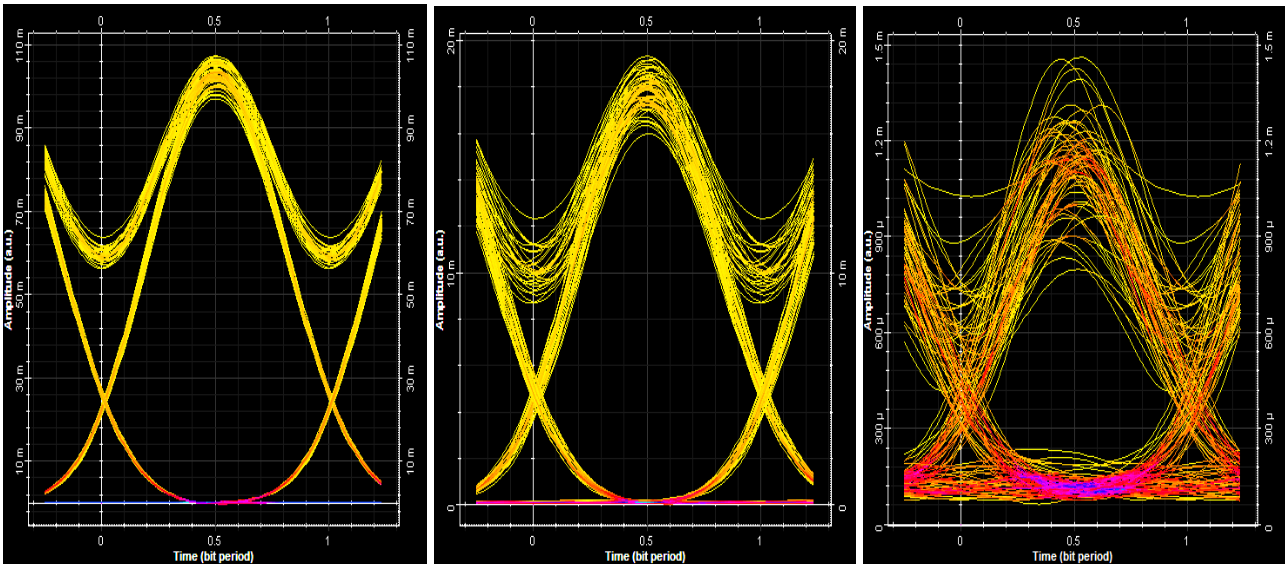
Table 1 shows that, with an increase in the distance from 100 to 300 km, the bit error rate increased and consequently the Q-factor and the OSNR decreased, that is, the signal became weak, distorted and noisy. Is detrimental to system performance.

The highest values of OSNR found in the simulations were for a 2R regeneration system with 100 and 200 km of SMF for the transmission powers of 0, 5 and 10 dBm as shown in table 1. We emphasize that for the distance of 300 km was only possible There was an improvement of the signal with the input power level of 10 dBm, where a Q-factor = 6, BER = 10^{-9} and OSNR = 13.5 dB was obtained, so [2, 4, 5] these values are Considered ideal for error-free detection in optical systems. Therefore, the regenerator proposed here proved to be also efficient for the 300 km of SMF.

Figure 6 shows the best eye diagrams for the three SMF lengths used in the 2R regenerator simulations, being 6 (a) after100 km, 6 (b) after200 km and 6 (c) after300 km.



(a) **(b)** **(c)**

Fig. 6. Eye diagrams: (a) after 100 km of SMF, (b) after 200 km of SMF and (c) after 300 km of SMF.

It was observed that for 100 km of SMF in the regeneration stage the best OSNR is for the input power of 5 dBm, and for the 200 and 300 km of SMF the best OSNR for both happens with the input power of 10 dBm. In the case of 0 dBm power, it is advisable not to use distance values of SMF near 300 km, because it was found bad values of factor Q, BER and OSNR.

Therefore, with the convenient input power to the required length of SMF with a DCF and a HNLF and also with other components such as amplifiers and filters it is possible to create a system capable of regenerating the signal in a totally optical way, and this was achieved through of the project presented in this article.

IV. CONCLUSION

This work studied the phase auto-modulation through a highly non-linear fiber for 2R regeneration of noisy signals in a totally optical way based on the Mamyshev model in an optical link of up to 300 km of SMF at a transmission rate of 10 Gb/s If input power of 10 dBm. Through this simple method it was possible to carry out the re-amplification and reformatting of the signal, besides reducing the complexity, the energy consumption and the cost of the project, all this guaranteed the reliability of the system. It is also possible to state that this system can be used in long-distance and high-speed transmissions in the future, since the simulations proved that as the input power increased, the regenerator performance improved with increasing distance.

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REFERENCES

1. S. N. S. Mat Yaacob, N. S. Mohd Shah, N.N. Shamsuddin and B. Das, “10GB/S NRZ based on self-phase modulation in all optical 2R regeneration”, ARPN Journal of Engineering and Applied Sciences, vol. 10, nº 19, october, 2015.
2. G. P. Agrawal, “Fiber-Optic Communication Systems”, 3rd ed., John Wiley Sons, Inc., New York, NY, 2002.
3. S. X. Xu, Zhou, L., & Xiao, J., “40 Gb/s Optical 3R-Regeneration Based on XPM and SPM in PCF”, In Advanced Materials Research, vol. 571, p.180-184. Trans Tech Publications, 2012.
4. P. A. Andersen, P. Jeppesen, C.B. Peucheretand A. Clausen, “All-Optical signal processing using highly nonlinear photonic crystal fiber”. Technical University of Denmark Danmarks Tekniske Universitet, Department of Electromagnetic Systems Institut for Elektromagnetiske Systemer. 2007.
5. K. Gerd, “Optical Fiber Comunications”. Mcgraw Hill. Fourth Edition, 2008.
6. S. S. Hnaung, “Design and Implementation of 10 Gbps All Optical 2R”. International Journal of Scientific and Research Publications, vol. 4, 6 de june, ISSN:2250-3153, 2014.
7. R. H. Solanki1, H. A. Gupta, A. Lavingia, K. Lavingia, “Simulation & Performance Evaluation of Optical Access Network Based on WDM–PON”, International Journal of Innovative Research in Computer and Communication Engineering. Vol. 4, Issue 1, january, D.O.I: 10.15680/IJIRCCE.2016.0401107, 2016.
8. M. Matsumoto. “Fiber-based all-optical signal regeneration”, IEEE Journal of Selected Topics in Quantum Electronics, v. 18, n. 2, p. 738-752, 2012.
9. F. B. de Sousa, J. E. de Oliveira, M. B. C. Costa, E. R. Sabino. “Mach-Zehnder Interferometer of Highly Non-Linear Photonic Crystal Fiber for All Optical 3R Regeneration”, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol.6, Issue. 06, June, 2017.
10. P. V. Mamyshev, “All-optical data regeneration based on self-phase modulation effect”, Proceedings European Conference on Optical Communication, ECOC’98, Madrid, Spain, p. 475, september. 1998.
11. F. B. de Sousa, J. E. de Oliveira, E. R. Sabino, F. M. de Sousa and M. B. C. Costa, “Simulations of SPM, XPM and FWM in Single-Mode Fiber Optic Networks”, In Seminatec 2017 – XII Workshop on Semiconductors and Micro & Nano Technology, ISBN: 978-85-86686-2. April, 2017.

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Fabio Barros de Sousa holds a degree in Mathematics from the Federal University of Pará (2014). Improvement in Mathematics in Secondary Education by the National Institute of Pure and Applied Mathematics (2012). Computer Technician from the Federal Institute of Pará (2017) and holds a Master's Degree in Electrical Engineering from the Post-Graduate Program in Electrical Engineering at the Federal University of Pará (2017).

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Marcos Benedito Caldas Costa holds a bachelor's degree in Physics from the Federal University of Pará (2001), a Ph.D. in Geophysics from the Federal University of Pará (2005) and a PhD in Teleinformatics Engineering from the Federal University of Ceará (2013). He is currently Adjunct Professor II of the Federal University of Pará, working in Electrical Engineering, mainly in the following subjects: Optical fiber devices, optical devices in photonic crystal fibers and PBG antennas.