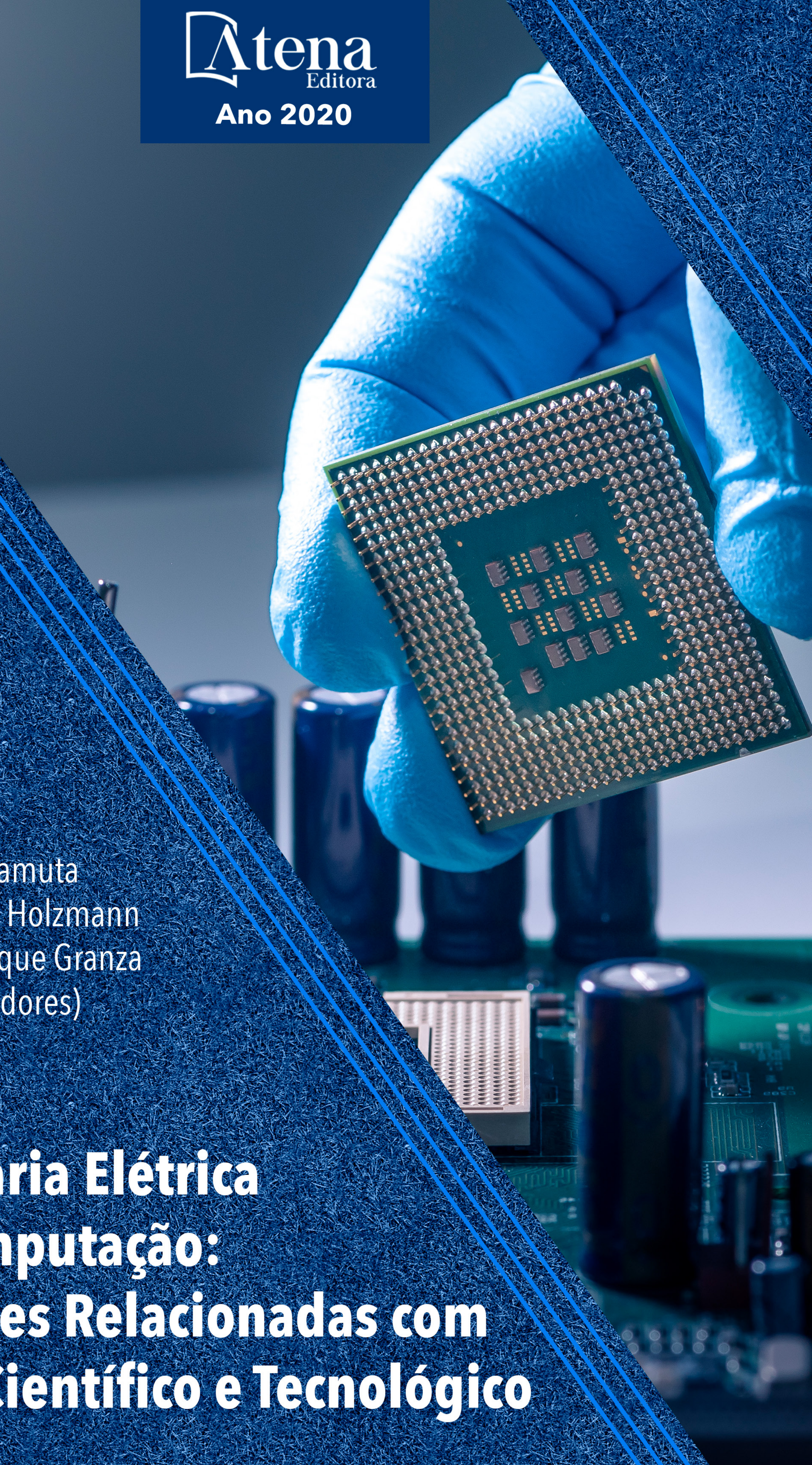
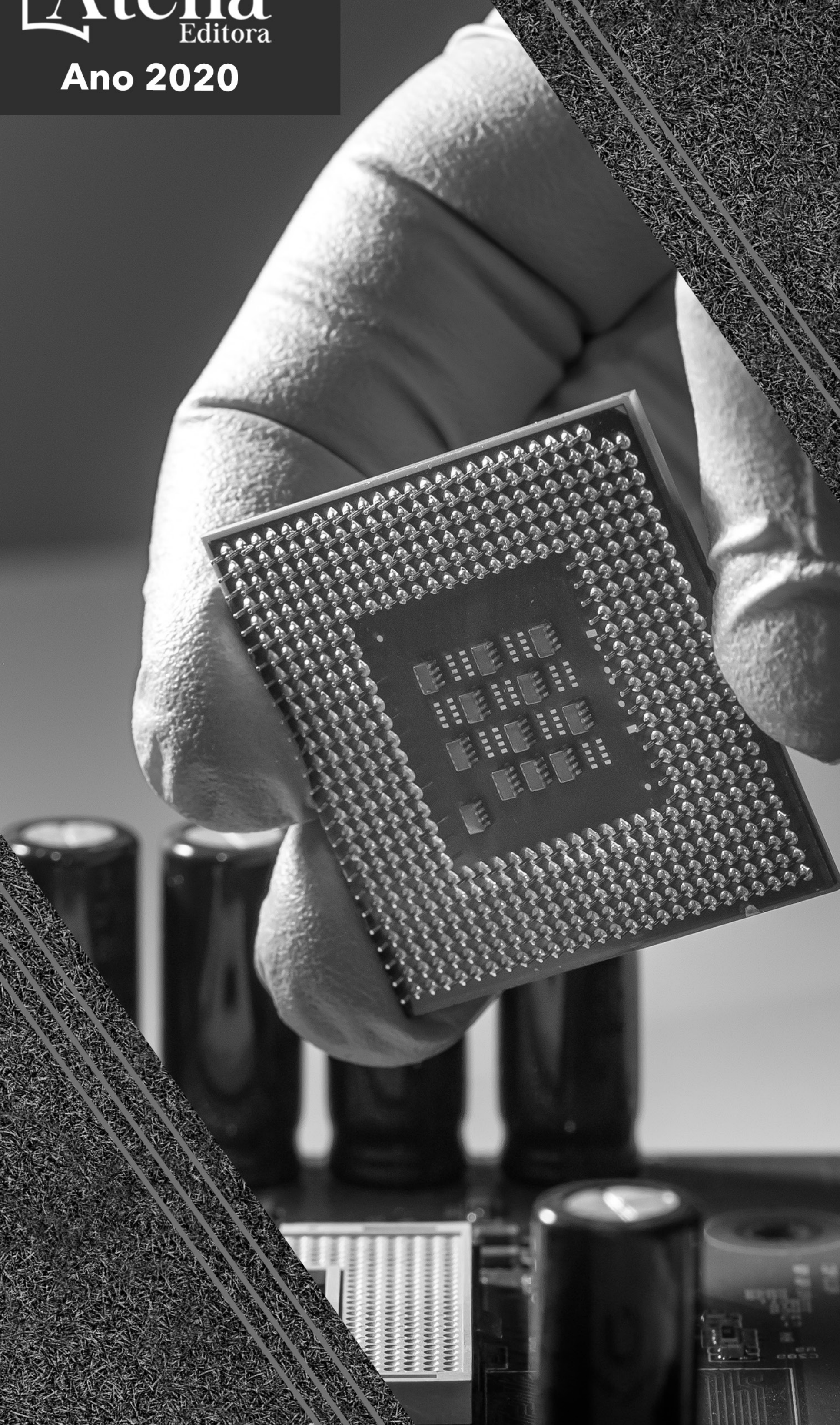
Atena Editora
Ano 2020



João Dallamuta
Henrique Ajuz Holzmann
Marcelo Henrique Granza
(Organizadores)

Engenharia Elétrica e de Computação: Atividades Relacionadas com o Setor Científico e Tecnológico

Atena Editora
Ano 2020



João Dallamuta
Henrique Ajuz Holzmann
Marcelo Henrique Granza
(Organizadores)

Engenharia Elétrica e de Computação: Atividades Relacionadas com o Setor Científico e Tecnológico

Editora Chefe: Profª Drª Antonella Carvalho de Oliveira
Diagramação: Camila Alves de Cremo
Edição de Arte: Lorena Prestes
Revisão: Os Autores

Atena Editora
Ano 2020

Atena
Editora
Ano 2020

Dados Internacionais de Catalogação na Publicação (CIP)
(eDOC BRASIL, Belo Horizonte/MG)

E57 Engenharia elétrica e de computação [recurso eletrônico] : atividades relacionadas com o setor científico e tecnológico 1 / Organizadores João Dallamuta, Henrique Ajuz Holzmann, Marcelo Henrique Granza. – Ponta Grossa, PR: Atena, 2020.

Formato: PDF
Requisitos de sistema: Adobe Acrobat Reader
Modo de acesso: World Wide Web
Inclui bibliografia
ISBN 978-65-5706-167-1
DOI 10.22533/at.ed.671200207

1. Ciência da computação – Pesquisa – Brasil. 2. Engenharia elétrica – Pesquisa – Brasil. I. Dallamuta, João. II. Holzmann, Henrique Ajuz. III. Granza, Marcelo Henrique.

CDD 623.3

Elaborado por Maurício Amormino Júnior – CRB6/2422

Atena Editora
Ponta Grossa – Paraná - Brasil
www.atenaeditora.com.br
contato@atenaeditora.com.br

Atena Editora
Ano 2020

APRESENTAÇÃO

Não há padrões de desempenho em engenharia elétrica e da computação que sejam duradouros. Desde que Gordon E. Moore fez a sua clássica profecia tecnológica, em meados dos anos 60, a qual o número de transistores em um chip dobraria a cada 18 meses - padrão este válido até hoje – muita coisa mudou. Permanece porem a certeza de que não há tecnologia na neste campo do conhecimento que não possa ser substituída a qualquer momento por uma nova, oriunda de pesquisa científica nesta área.

Produzir conhecimento em engenharia elétrica e da computação é, portanto, atuar em fronteiras de padrões e técnicas de engenharia. Algo desafiador para pesquisadores e engenheiros.

Neste livro temos uma diversidade de temas nas áreas níveis de profundidade e abordagens de pesquisa, envolvendo aspectos técnicos e científicos. Aos autores e editores, agradecemos pela confiança e espirito de parceria.

Boa leitura

João Dallamuta

Henrique Ajuz Holzmann

Marcelo Henrique Granza

SUMÁRIO

CAPÍTULO 7

DATA REGENERATION 2R IN OPTICAL COMMUNICATION NETWORK BASED ON MACH-ZEHNDER INTERFEROMETER WITH ACOUSTIC-OPTICAL FILTER AND HIGHLY NON-LINEAR PHOTONIC CRYSTAL FIBER

Data de aceite: 01/06/2020

Fabio Barros de Sousa
Universidade Federal do Pará, Programa de Pós-Graduação em Engenharia Elétrica, Rua Augusto Corrêa, 01, Belém, Pará, 66.075-110, Brasil.

Fiterlinge Martins de Sousa
Universidade Federal do Pará, Programa de Pós-Graduação em Engenharia Elétrica, Rua Augusto Corrêa, 01, Belém, Pará, 66.075-110, Brasil.

Jorge Everaldo de Oliveira
Universidade Federal do Sul e Sudeste do Pará, Faculdade de Física, Fl. 17, Quadra Especial, Lote Especial, Nova Marabá, Marabá, Pará, Brasil.

Elizabeth Rego Sabino
Universidade Federal do Sul e Sudeste do Pará, Faculdade de Matemática, Fl. 17, Quadra Especial, Lote Especial, Nova Marabá, Marabá, Pará, Brasil.

Marcos Benedito Caldas Costa
Universidade Federal do Pará, Faculdade de Engenharia de Materiais, Rodovia BR-316, km 7, Levilândia, Ananindeua, Pará, 67.000-000, Brasil.

Grupo de Pesquisa em Fotonica e Optica não Linear. http://dgp.cnpq.br/dgp/espelhogrupo/8017792785061258

ABSTRACT: In the present paper a numerical analysis of the performance of all-optical 2R regenerator (Re-amplification and Re-shaping) based on Self-Phase Modulation (SPM) was carried out through the Mach-Zehnder Interferometer (MZI) communication system with Acousto-Optic Filter (AOF) and Highly Non-Linear Photonic Crystal Fiber (HNL-PCF). The system performance analyzes were performed according to the variation of input power (from -10dBm to 10dBm) and the transmission length (from 120km to 1200km). The results showed that the regeneration scheme 2R proposed here presented values of minimum bit error rate (Min. BER) below the threshold of 10-9 and of maximum quality factor (Max. Q-Factor) above the threshold of 6, when compared to a system without regeneration.

KEYWORDS: Regeneration 2R, Self-Phase Modulation, Acousto-Optic Filter, Highly Non-Linear Photonic Crystal Fiber, Mach-Zehnder Interferometer.

REGENERAÇÃO 2R DE DADOS EM REDE DE COMUNICAÇÃO ÓPTICA BASEADA EM INTERFERÔMETRO DE MACH-ZEHNDER COM FILTRO ACÚSTICO ÓPTICO E FIBRA DE CRISTAL FOTÔNICO ALTAMENTE NÃO LINEAR

RESUMO: No presente artigo, realizou-se uma análise numérica do desempenho do regenerador 2R totalmente óptico (Reamplificação e Reformatação) baseada em auto modulação de fase (Self-Phase Modulation – SPM) através de um interferômetro de Mach-Zehnder com filtro acústico óptico (Acousto-Optic Filter – AOF) e fibra de cristal fotônico altamente não linear (Highly Non-Linear Photonic Crystal – HNL-PCF). As análises do desempenho do sistema foram realizadas de acordo com a variação da potência de entrada (de -10dBm a 10 dBm) e o comprimento da transmissão (de 120km a 1200km). Os resultados mostraram que o esquema de regeneração 2R aqui proposto apresentou valores de taxa de erro de bit mínima (Min. BER) abaixo do limiar de 10-9 e de máximo fator de qualidade (Max. Q-Factor) acima do limiar 6.

PALAVRAS-CHAVE: Regeneração 2R, Auto Modulação de Fase, Filtro Acustico Optico, Fibra de Cristal Fotônico Altamente Não Linear, Interferômetro de Mach-Zehnder.

1 I INTRODUCTION

Over the years the scientific community as well as the telecommunications industry have been engaged in designing and deploying ultrafast and high bit rate optical communication systems to meet the growing demand for network flexibility, transparency, low cost, low power consumption and high bandwidth (ALIPOOR; MIR; SHEIKHI, 2018; AZZAM; ALY, 2018; SHARAN et al. 2016). In this sense, it is also expected that these systems will be able to reduce the latency between nodes and regenerate degraded signals due to the noise accumulated during the transmission process.

Several techniques have already been investigated through the design of fiber optic communication systems based on non-linearities such as: Self-Phase Modulation (SPM), Cross-Phase Modulation (XPM), Four-Wave Mixing (FWM) and Cross-Gain Modulation XGM). Research by Azzam et al. (2018); Hui (2014); Oliveira et al. (2019) and Sousa et al. (2018) demonstrate that these non-linear effects can be induced through the use of HNL-PCF, Dispersion Compensated Fiber (DCF), HNLF and semiconductor optical amplifier (SOA). Interferometer configurations such as Mach-Zehnder, Michelson and Sagnac have been widely used for this purpose, as well as in other applications such as wavelength conversion and remote sensing temperature, strain, mechanical stress and in techniques for obtaining logic gates and signal regeneration in fiber optic communication system (ALMEIDA et al., 2019; AMEL et al., 2015; KAMENEV et al., 2014; SOUSA et al., 2019 and WANG et al., 2016).

Recently, the non-linear effects on optical fibers have been widely studied, such as the effect of FWM in a Dense Wavelength Division Multiplexing (DWDM) integration with Radio-over-Fiber (RoF) and optical double-side band modulation (ODSB), which was investigated by Alipoor, Mir and Sheikhi, 2018.

Singh et al., 2017 presented an all-optical up-and down-wavelength converter has been designed and investigated which is based on FWM effect in semiconductor optical amplifier Mach-Zehnder Interferometer (SOA-MZI) using a bit rate of 60Gbps return-to-zero on-off keying (RZ-OOK) modulated data, in which they obtained optimal Max. Q-factor values.

And Abdollahi et al. 2014 presented the simulation of a photonic data regeneration system with ultrafast and ultra-short Return to Zero (RZ) pulses generated through a link All-Photonic DRoF (AP-DRoF), which was able to perform optical quantization and wavelength conversion with power savings and improved performance.

Here, we investigated numerically the performance of all-optical 2R regenerator based on Self-Phase Modulation through a Mach-Zehnder Interferometer communication system with Acousto-Optic Filter and Highly Non-linear Photonic Crystal Fiber, which was called a 2R-MZI-AOF regenerator. The results of the proposed system are evaluated as a function of Min. BER and Max. Q-factor, optical signal to noise ratio (OSNR), eye height, timing jitter and optical spectrum. The analysis was performed for signal output in the time and frequency domain based on SPM and dispersion. In our work the structure of the 2R-MZI-AOF regenerator was described in the second part and then the analyzes and discussions of the optical pulse results in time and frequency domain were presented in the third part. And in the end the conclusion about the performance of the 2R-MZI-AOF regenerator was presented.

2 I SQUEMATIC THE PROPOSED MZI-AOF REGENERATOR 2R

The 2R regenerator proposed here is a pass-through scheme, based on a MZI configuration with one arm containing an AOF and the other arm containing a HNL-PCF. In Fig. 1 a block diagram of the proposed 2R-MZI-AOF simulation configuration is shown, it is a single channel system with externally modulated laser source on a fiber optic link up to 1200km in length 1550nm, which was developed and simulated using the OptiSystem 15.0 software in which the one-dimensional signal flow, the stimulated and spontaneous Raman scattering (SRS), the Kerr non-linearity of SPM and the dispersion were taken into account.

Our regenerator 2R-MZI-AOF was subdivided into three sections: transmission section, degradation section, regeneration section, reception section and fibers section, which will be described next.

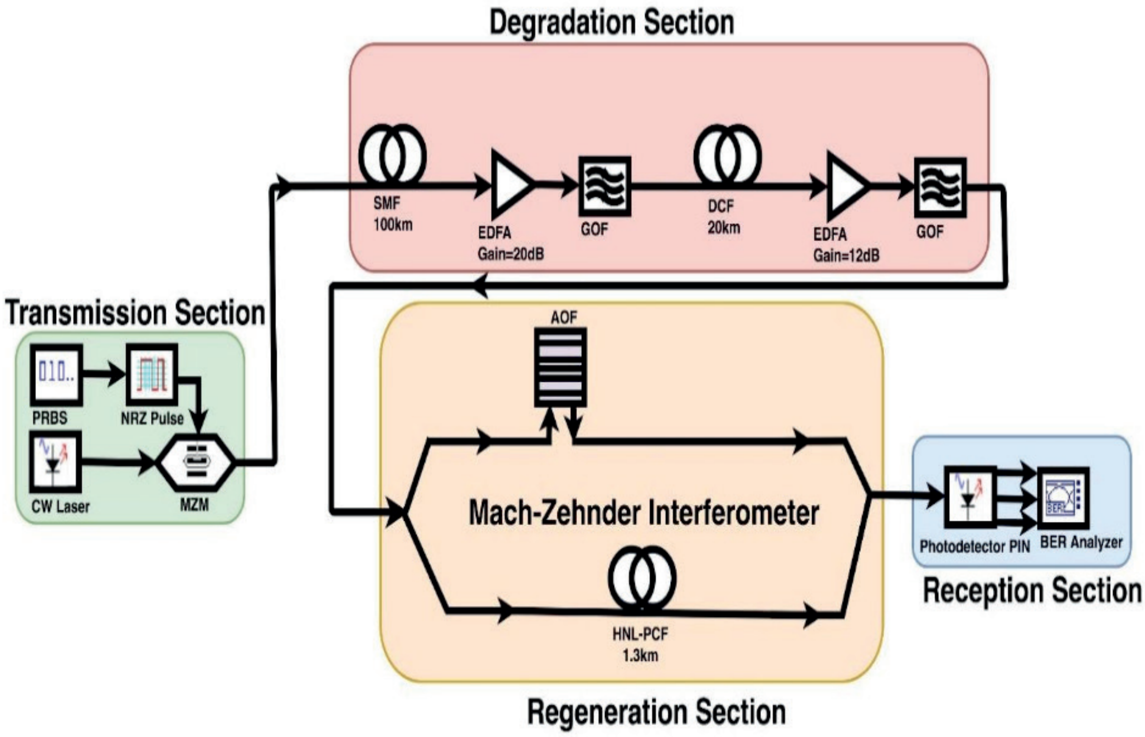


Figure 1 - Schematic of the MZI-AOF based on SPM.

2.1 Transmission Section

The numerical simulations of the proposed 2R-MZI-AOF regenerator were performed at a 10Gb/s transmission rate using a Pseudorandom Bit Sequence (PRBS) generator connected to a non-return-zero pulse generator (NRZ). The power source of the signal was a Continuous Wave (CW) laser with a central wavelength of 1550nm, with initial power of 0dBm and then varied from -10dBm to 10dBm. The amplitude of the signal was electrically controlled by an external Mach-Zehnder (MZM) modulator with extinction ratio of 30dB.

2.2 Degradation Section

The modulated signal emitted by the CW laser was sent to a Sigle-Mode Fiber (SMF) and then the losses were compensated by an EDFA with gain of 20dB and noise figure of 6dB. The distorted signal due to the ASE noise emitted by the first EDFA was filtered by a Gaussian Optical filter (GOF) with a bandwidth of 500GHz. Chromatic dispersion was compensated using a post-compensation scheme with compensated fiber dispersion (DCF). Another EDFA with gain of 12dB and noise figure of 6dB and another Gaussian filter with bandwidth of 500GHz, again with the objective of rejecting the noise of ASE. In the proposed 2R-MZI-AOF regenerator, we use a loop control to increase the transmission link distance by up to 10 times in order to degrade signal performance.

2.3 Regeneration Section

In order to perform all-optical 2R (Reshaping and Re-amplification) regeneration, we use an interferometric MZI-type wavelength converter with an AOF with 100GHz bandwidth and the same wavelength as the CW laser and a HNLF-PCF on the lower arm.

In the regeneration section the signal was divided symmetrically in two paths, using a 3dB fiber coupler. That is, half of the light was injected into the AOF that had the function of selecting the wavelength corresponding to the input signal, where in the region of interaction within the AOF the acoustic field acted on the optical fields converting the polarization signal TE to TM and vice-versa on one of the two output ports of the beam splitter. The other half of the light was injected into the HNL-PCF which produced spectral amplification induced by SPM as a function of the peak power intensity. Subsequently the light beams were recombined in the second 3dB coupler. At the output of the MZI, another additional Gaussian filter with a bandwidth of 62.4GHz was used to perform signal reshaping.

2.4 Reception Section

The signal was received in the reception session by the photodetector PIN which converted the optical bit stream into electrical bit stream and finally a low pass electric Bessel filter with a cut-off frequency of 7.5GHz was used to filter that bit stream. The responsivity of photodetector PIN is 1A/W, and the dark current is 10nA. In order to analyze the optical signal at different stages of the optical link, the optical spectrum analyzer (OSA), the optical time domain visualizer and the BER analyzer were used to evaluate the signal in the time and frequency domain.

2.5 Fibers Section

In the 2R Regenerator design, three types of optical fibers were used, both with non-linear refractive index of $2.6\times10^{-20}m^2/W$ and a reference wavelength of 1550nm. A SMF with attenuation (α) of 0.22dB/km, dispersion (D) of 17ps/km-nm2 and dispersion slope (S) of $0.08ps/nm^2/km$ at 1550nm, and core effective area of the fiber (A_{eff}) as $80\mu m^2$. The DCF segment used in each span has α of 0.5dB/km, D of -85ps/km-nm, S is $-0.45ps/nm^2/km$ and A_{eff} of $30\mu m^2$. And a HNL-PCF with α of 9dB/km, D of -0.5ps/km-nm, S of $0.01ps/nm^2/km$ and Aeff of $1.81\mu m^2$. Initially the total length of the system was segmented into 1: 5 and 1:28 ratios, ie 17km DCF and 1.3km HNL-PCF respectively, for 83km SMF.

3 I SIMULATIONS AND DISCUSSION OF NUMERICAL RESULTS

The performance analysis of the 2R-MZI-AOF regenerator was performed through an interactive search of solutions of equation (1) as a function of the variation of the power parameters of the input signal and fiber length. Thus, the initial power of the CW laser was 0dBm and then varied from -10dBm to 10dBm and the transmission length ranged from

120km to 1200km. In this sense the results were collected according to eye diagrams, optical spectra in the frequency domain and time domain waveforms at the exit of each section of the 2R-MZI-AOF regenerator. The values of Max. Q-Factor, Min. BER, eye height, timing jitter and OSNR were the metrics used to determine the performance of the system in order to investigate signal amplitude and phase distortions and the deficiencies caused by SPM and ASE noise in the transmission and reception processes.

Figure 2 shows the NRZ wave form in the time domain with 0dBm output power at the output of the transmitter, at the output of the degradation section (after 1200km transmission length) and in the regeneration section respectively. In figure 2 (b) it is possible to note that the signal has ASE noise, amplitude and phase distortions and also suffered attenuation and dispersion which resulted in loss of power in a good part of the signal.

For the signal of figure 2 (c) showing the waveform after the regeneration section, it is possible to notice a considerable difference in relation to the waveform of the degradation section shown in figure 2 (b), in this case the noises of ASE were filtered by the GOFs and also the signal was reamplified and reformatted, so the regenerated output waveform is almost the same as the input waveform.

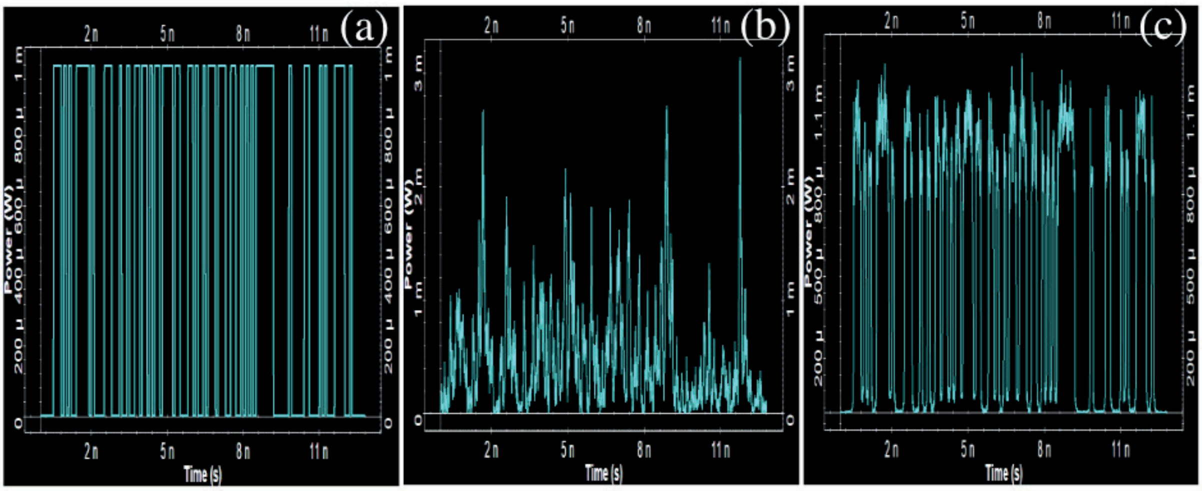


Figure 2 - (a) Initial signal NRZ at the output of the transmitter, (b) Degraded signal at the output of the degradation section and (c) Signal regenerated at the output of regeneration section 2R.

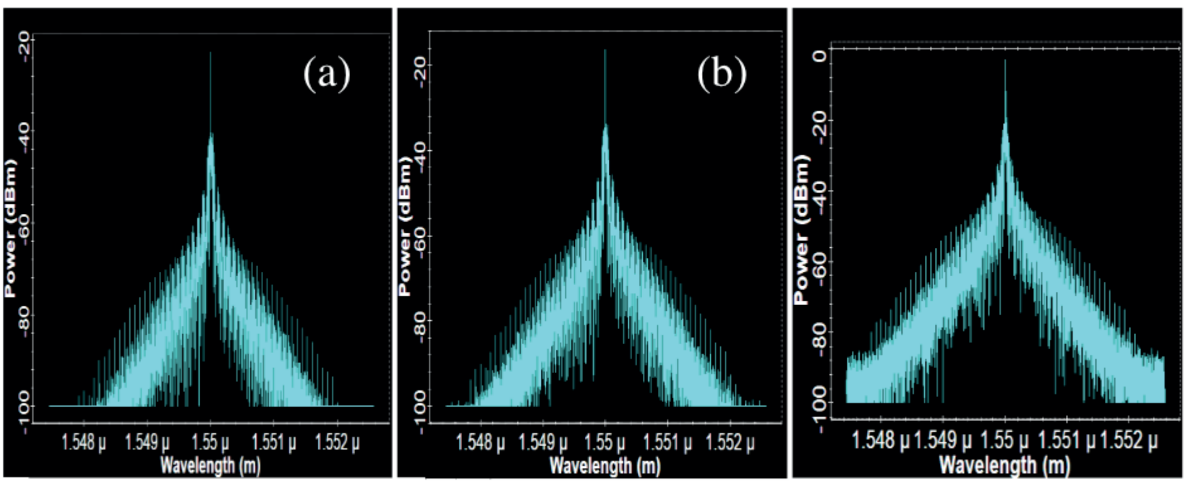


Figure 3 - Optical spectrums at (a), (b), and (c) both after HNL-PCF (signal amplified by SPM induced due to variation of input signal power).

In the spectra after the HNL-PCF shown in figures 3 (a), (b) and (c) it is possible to note that a signal widening occurred due to the increase of the SPM induced within the HNL-PCF as a function of the power increase input. It is clear that the HNL-PCF used has a normal dispersion coefficient (D<0), in this case, it served the purpose of the project, where the amplification in the signal was performed to obtain mutual compensation of Group Velocity Dispersion (GVD) and the non-linear effects of SPM induced.

The spectra after the AOF are shown in figure 4. In this case, a signal amplification occurred as a function of the signal power variation, which influenced the improvement of the Optical Signal Noise Ratio (OSNR) and the timing jitter. Signal Noise Ratio (OSNR) and the timing jitter. Also, the results in the graphs of the eye diagrams of figure 5 presented satisfactory values for the good performance of the 2R-MZI-AOF proposed for the signal after the regeneration, when compared to the values of performance for the signal before the regeneration.

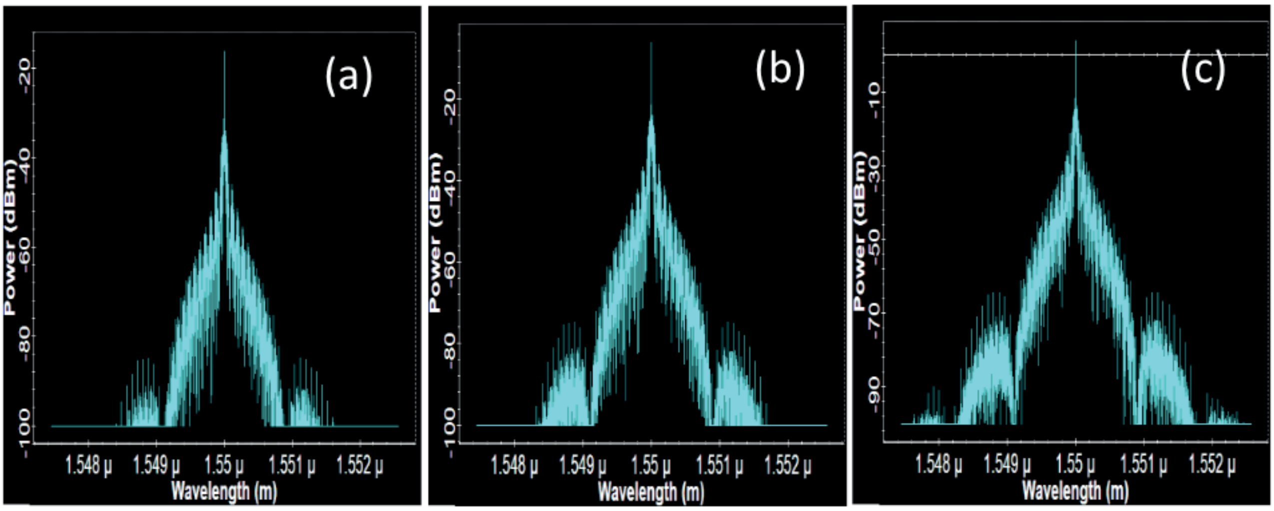


Figure 4 - Optical spectrums at (a), (b), and (c) both after AOF (signal amplified by SPM induced due to variation of input signal power).

3.1 Signal Input Power Impact

The performance of the proposed 2R-MZI-AOF as a function of input power was performed with a 120km transmission length and power was varied from -10dBm to 10dBm. In this case, it was verified that with the increase of the signal power, the performance of the system was compromised, where the quality factor reduced and the bit error rate increased, this was due to the increase in the non-linear effects of SPM which resulted in distortions in the signal.

Figure 5 compares the eye diagrams for the signal at the output of the degradation section and also for the regeneration section as a function of the input power variation. Figure 5 (a) shows that for the input power of -10dBm the Max. Q-factor was equal to 3.7

and the Min. BER was equal to $1.02x10^{-4}$. Other low performance values were also found for 0dm and 10dBm, which obtained values of Max. Q-Factor equal to 4.5 and 5.4 and Min. BER equal to $3.74x10^{-6}$ and $2.58x10^{-8}$ in figure 4 (b) and 4 (c) respectively. These results in figures 4 (a), 4 (b) and 4 (c) refer to the performance of the system before 2R regeneration. Therefore, through the use of AOF in the system, the chromatic dispersion of the fiber was attenuated, which consequently reduced the bit error rate and increased the quality factor as shown in the following sections.

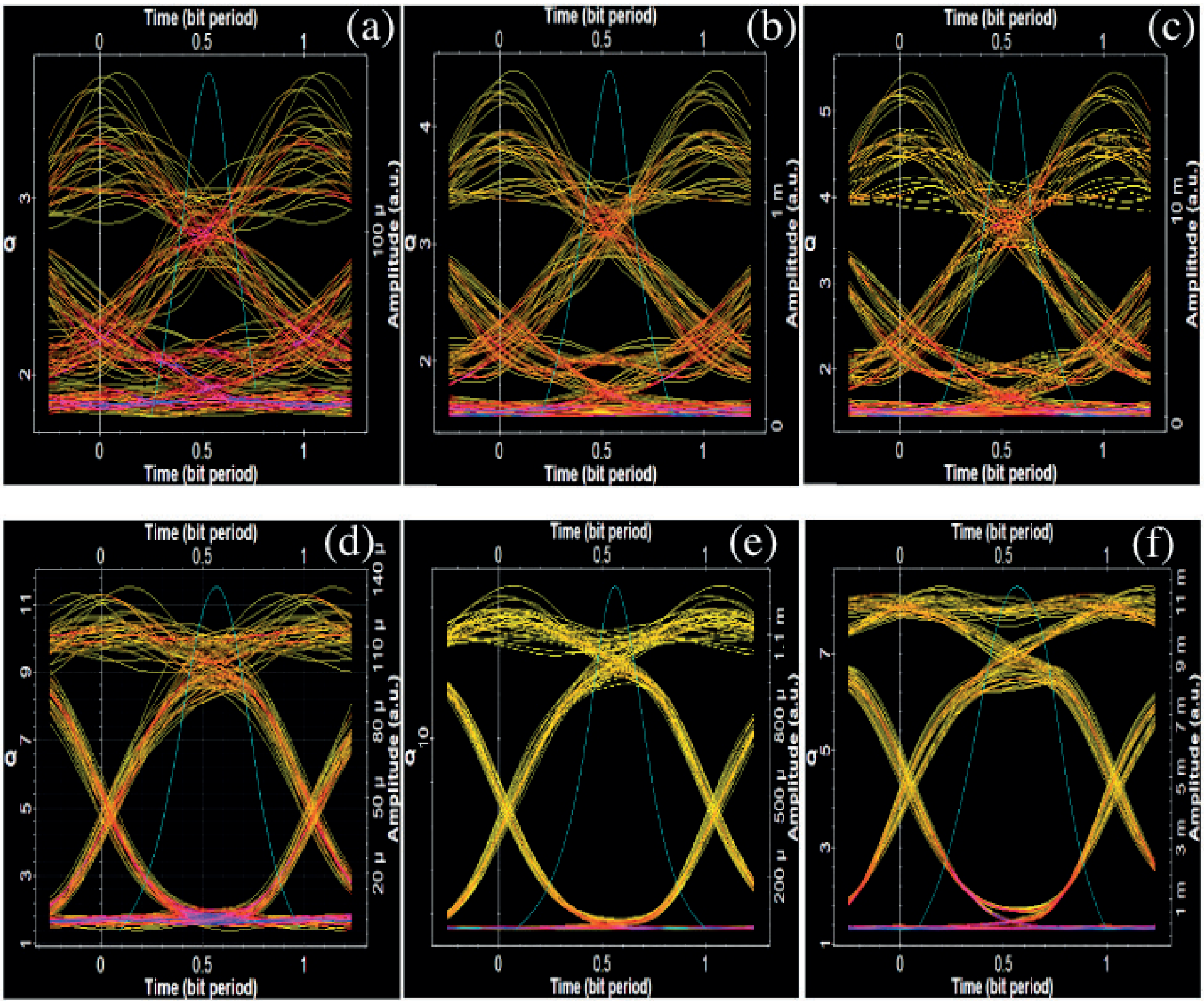


Figure 5 - Eye diagrams at, (a) and (d) - 10dBm input power, (b) and (e) 0dBm input power and (c) and (f) 10dBm input power both before and after regeneration respectively.

However, by comparing with the regeneration session exit eye digrams shown in figures 5 (d), (e) and (f) it is possible to observe a considerable contrast in the performance results of the system, where the signal from the eye diagram at the output of the regeneration section appear lighter than the eye diagrams of the degradation section. Thus, for the input power of -10dBm the Max. Q-Factor equals 11.5 and the Min. BER equals $6x10^{-31}$. For the input power of 0dBm the best performance values were obtained, where the Max. Q-Factor was equal to 17 and the Min. BER was equal to $1.22x10^{-63}$. And in figure 5 (f) shows that for the input power of 10dBm the Max. Q-factor was equal to 8.32 and the Min. BER equal to $3.6x10^{-17}$.

Therefore, as shown in the graphs of figure 6, it can be stated that with these results the 2R-MZI-AOF regeneration technique proposed here offered better performance for the system, when compared to the system without regeneration, which obtained values of Min BER above the threshold and Max. Q-Factor below the threshold.

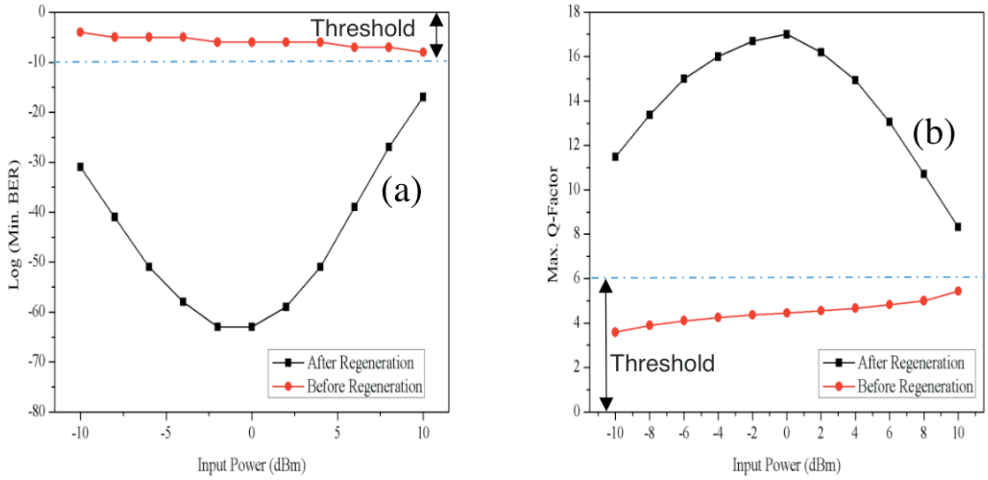


Figure 6 - Measurement Min. BER and Max. Q-Factor for 2R Regenerator in function of input power.

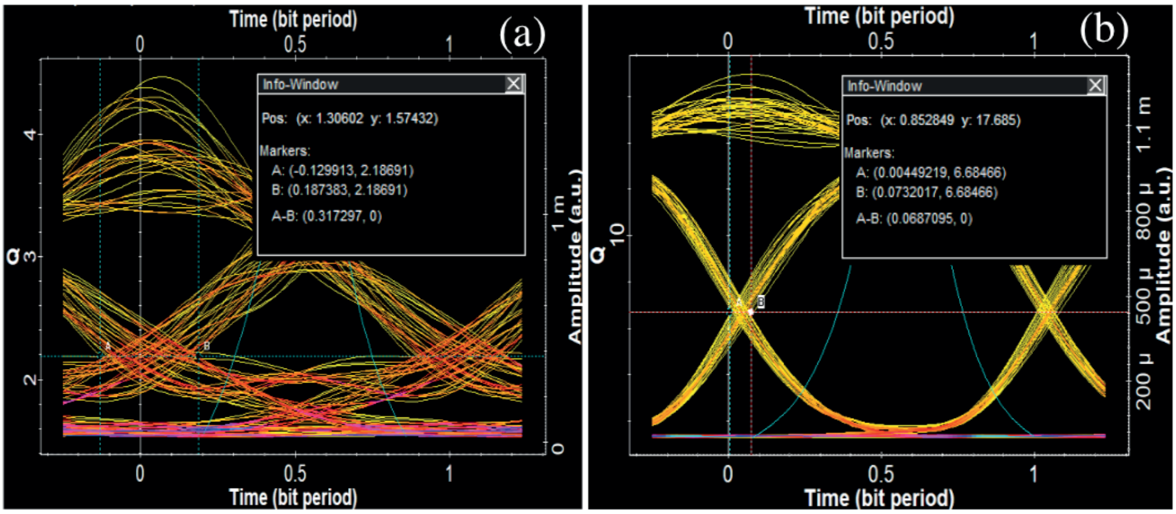


Figure 7 - Timing Jitter for degraded signal (a) and regenerated (b) for input power of 0dBm.

Figure 7 shows the timing jitter of an eye diagram, measured at the cross-point of the eye diagram, as the difference between the time values of points A and B. Figure 7 (a) and (b) show timing jitter for signal before and after regeneration 2R. Thus, we highlight that the simulation results for the input power of 0dBm show that for an ultra- short NRZ pulse with a job cycle of 5% to 10Gbit/s using the proposed 2R-MZI-AOF regeneration system it was possible to obtain a OSNR approximately equal to 43.8dB, reduce the timing jitter by approximately 78.4% and also greatly improve the height of the eye diagram to about 8.2×10^{-4} compared to the height of the eye of the signal without regeneration which was equal to 2.4×10^{-4}.

Obviously, by comparing the results for each individual case it can be stated that by increasing the power of the signal from -10dBm to 10dBm, the system OSNR decreases, at min. BER increases and the Max. Q-Factor decreases, but the results of the signals regenerated by 2R-MZI-AOF were considered favorable to the good performance of the system.

3.2 Impact of Link Length

We also analyzed the performance impacts of the proposed 2R-MZI-AOF as a function of the length of the SMF and DCF simultaneously. The length of the link was varied from 120km to 1200km for the input power of 0 dBm and with the length of the HNL-PFC fixed at 1.3km. In this sense, in this section, the nonlinear effects such as chromatic dispersion which are dependent on the fiber length is discussed.

Figure 8 shows the eye diagrams of the proposed 2R-MZI-AOF before and after the regeneration section for different fiber lengths with 120km, 600km and 1200km, respectively. Where the Max. Q-Factors before regeneration were 4.5, 0 and 0 and the Min. BERs $4x10^{-6}$, 1 and 1. However, for the signal after regeneration the Max. Q-Factors were 17, 12 and 9 and the Min. BERs were $1.2x10^{-63}$, $5x10^{-34}$ and $1.7x10^{-20}$. From figure 8 (a), (b) and (c), it is possible to state that, with the increase of the link length, there was a reduction of the system performance for both cases, factor decreased and min. BER increased. However, the results of figures 8 (d), (e) and (f) clearly show that the signal after regeneration has significantly less phase noise and amplitude fluctuation than the signal before regeneration. Therefore, the link with the proposed 2R-MZI-AOF regenerator obtained a significantly better performance than the link without the 2R-MZI-AOF, as also shown in the graph of figure 9.

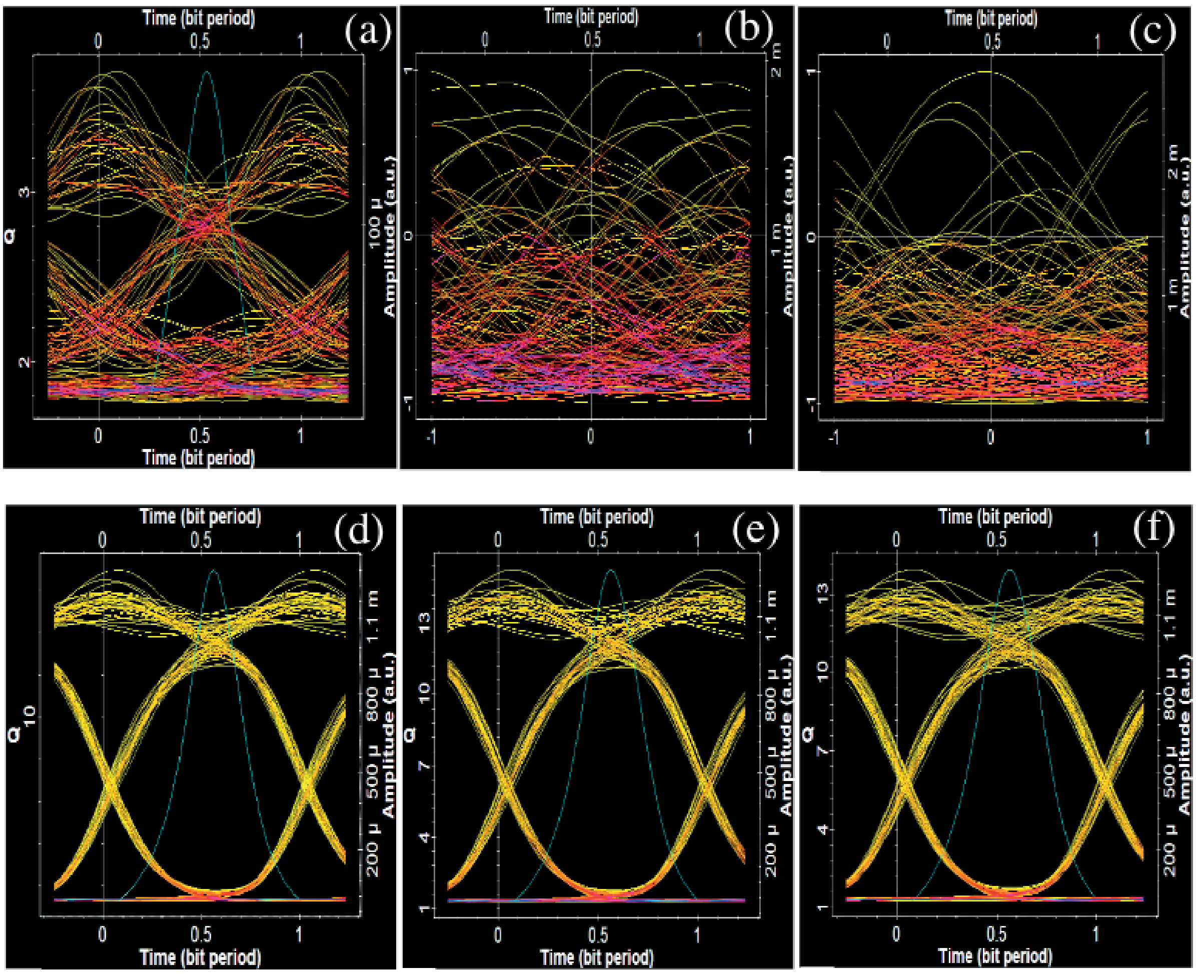


Figure 8 - Eye diagrams at, (a) and (d) 120km fiber length, (b) and (e) 600km fiber length and (c) and (f) 1200km fiber length both before and after regeneration respectively.

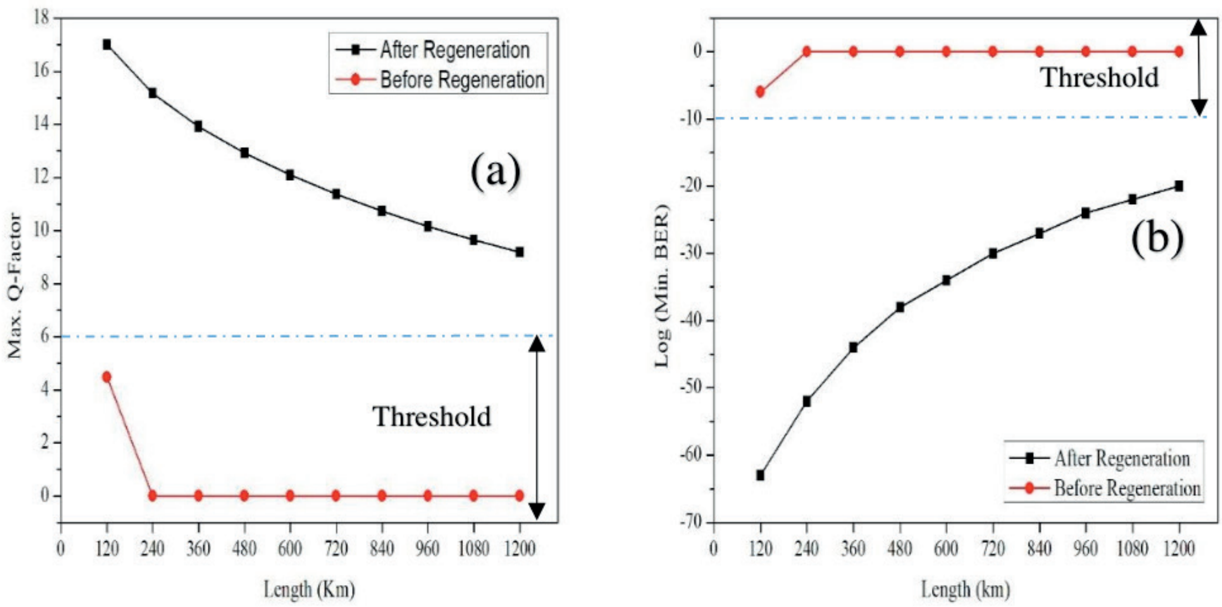


Figure 9 - Fig. 9 Measurement Min. BER (a) and Max. Q-Factor (b) for 2R Regenerator in function of length.

Figure 10 shows the calculated eye plots for the system with and without 2R-MZI-AOF. It was observed that the system with 2R-MZI-AOF obtained values of Max. Q-Factor above the threshold and also values of Min. BER below the threshold for all the measures of transmission used, so I was able to restore the deficiencies of non- linearity of the optical link and consequently reduced Total Jitter to approximately 85% for the 240km transmission system. The Total Jitter comparison is only possible for the system with a length of 120km and 240km, because for the other values of transmission length the results of this metric becomes impracticable due to signal degradation to the system without the 2R-MZI-AOF.

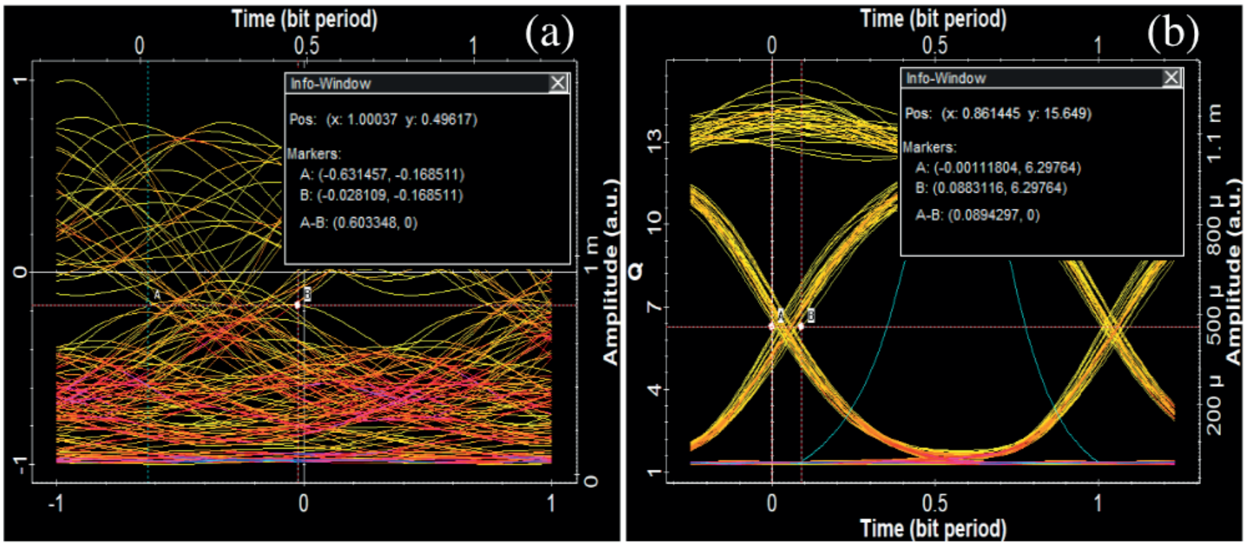


Figure 10 - Timing Jitter for the degraded signal (a) and regenerated (b) for the transmission distance of 240km.

Although OSNR was degraded to 13dB after 120km of transmission to the system without 2R-MZI-AOF, an improvement of the OSNR was achieved to 24.6dB by the 2R-MZI-AOF system. Therefore, the system without 2R-MZI-AOF can be considered as impossible to implement because the performance results were poor, where all the values of the Q. Factor were below the threshold as well as all the values of Min. BER were above the threshold, so from 240km up to 1200km of transmission the eye diagrams presented with heights equal to 0 and completely stressed.

4 I CONCLUSION

We present in this work a all-optical 2R-MZI-AOF regenerator based on SPM, which made the signal more resistant to deterioration and addition of noises. The results of the numerical simulations showed that there was a significant improvement of the signal performance when compared to the results of the system without AOF. The HNL-PCF with only 1.3km in length was able to produce substantial spectral widening through induced SPM. It has also been demonstrated that the PMS phenomenon can be used to achieve all-optical 2R regeneration in systems with 10Gb/s transmission rate through the use of an AOF in an MZI scheme where excellent performance values have been achieved, which proved the feasibility of operating the scheme in a broadband system. Therefore, our proposed 2R-MZI-AOF regenerator has the following advantages: (1) simple scheme, (2) ease of achieving high performance, (3) high tolerance for signal power fluctuation and (3) error-free detection. In this sense we can say that the 2R-MZI-AOF not only saved power, but also improved the performance and quality of service of the system.

ACKNOWLEDGMENT

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

To the Pró-Reitoria de Pesquisa e Pós-Graduação (PROPESP) da Universidade Federal do Pará (UFPA), Belém – Brasil.

REFERENCES

ABDOLLAHI, Seyed Reza; AL-RAWESHIDY, Hamed Saffa; OWENS, Thomas John. Data regeneration for an all-photonic digital radio over fibre. **IET Optoelectronics**, v. 8, n. 6, p. 256-263, 2014.

ALIPOOR, A.; MIR, A.; SHEIKHI, A. Study of DWDM-ROF link nonlinear effects using direct and external ODSB modulation formats. **Journal of Optics**, v. 47, n. 3, p. 263-271, 2018.

ALMEIDA, Léo Cesar Parente de ; SOUSA, Fiterlinge Martins de ; SOUSA, Fabio Barros de; OLIVEIRA, Jorge Everaldo de ; KUMAR, Sandeep ; PASCHOAL JUNIOR, W. G. ; COSTA, Marcos Benedito Caldas . Design and Performance Analysis of All-Optical NAND Logic Gate Using 2-D Photonic Crystal. **Advanced Science, Engineering and Medicine**, v. 11, p. 251-254, 2019.

AMEL, Mokhdar; MOHAMED, Chikhbled. Contribution to the Study of 2R Regenerators in Optical Transmission Link into Account the PMD. **Journal of Control Science and Engineering**, v. 1, p. 1-8, 2015.

AZZAM, Eman S.; ALY, Moustafa H. FWM in DCF based four-input all-optical NOR/AND gate. **Optical and Quantum Electronics**, v. 50, n. 4, p. 166, 2018.

HUI, Zhan-Qiang. All-optical 1-to-8 wavelength multicasting at 20 Gbit/s exploiting self-phase modulation in dispersion flattened highly nonlinear photonic crystal fiber. **The Scientific World Journal**, v. 2014, 2014.

KAMENEV, Oleg T.; PETROV, Yuri S.; KHIZNYAK, Ruslan V.; ROMASHKO, Roman V. Application of a two-channel fibre-optic Mach-Zehnder interferometer for deformation measurement. **Pacific Science Review**, v. 16, n. 3, p. 167-169, 2014.

OLIVEIRA, Jackson Moreira; SILVA, Hudson Afonso Batista da; OLIVEIRA, Lelis Araujo de; SOUSA, Fabio Barros de; OLIVEIRA, Jorge Everaldo de; SOUSA, Fiterlinge Martins de; COSTA, Marcio Benedito Caldas; LUZ, Fabricio Pinho da; COSTA, Marcos Benedito Caldas. New Design of All-Optical Logic Universal NAND Gate Formed by NOT (A AND B) Gates Using Michelson Interferometer Based on Semiconductor Optical Amplifier. J**ournal of Computational and Theoretical Nanoscience**, v. 16, n. 7, p. 2712-2719, 2019.

SHARAN, Lucky; AGRAWAL, Vaibhav Madangopal; CHAUBEY, Vinod Kumar. Link optimization and performance analysis of a 40 Gbps DQPSK modulated ultra DWDM system with 32 orthogonally polarized channels. J**ournal of Microwaves, Optoelectronics and Electromagnetic Applications**, v. 15, n. 4, p. 349-364, 2016.

SINGH, Surinder; S. Singh, N. Badraoui, T. Berceli, A. Alomainy. Design and analysis of all-optical up-and down-wavelength converter based on FWM of SOA-MZI for 60 Gbps RZ data signal. **Photonic Network Communications**, v. 34, n. 2, p. 288-297, 2017.

SOUSA, Fabio Barros de; SOUSA, Fiterlinge Martins de; OLIVEIRA, Jorge Everaldo de; OLIVEIRA, Jackson Moreira; PASCHOAL, Waldomiro Jr.; M.B.C Costa. All-Optical 3R Regeneration Based on an Acousto Optical Filter with Q-Factor Improvement. **Journal of Computational and Theoretical Nanoscience**, 15, n. 6-7, p. 1871-1875, 2018.

______; OLIVEIRA, Jorge Everaldo de; SOUSA, Fiterlinge Martins de; COSTA, Marcio Benedito Caldas; OLIVERIRA, Osmar Tharlles Borges; OLIVEIRA, Jackson Moreira; MARTINS, Elizete Sabino; COSTA, Marcos Benedito Caldas. Michelson interferometer system with acoustic optic filter and fiber Bragg grating for reduction of four-wave mixing. **Scientia Plena**, v. 15, n. 7, 2019.

WANG, Yiqun; PEI, Li; LI, Jing; LI, Yueqin. All optical multi-wavelength single-sideband modulated WDM radio-over-fiber systems by introducing a Sagnac loop filter. **Optical Fiber Technology**, v. 32, p. 36-42, 2016.

ÍNDICE REMISSIVO

SÍMBOLOS

A

C

D

E

F

I

Atena
Editora
2020