

Mach-Zehnder Interferometer of Highly Non-Linear Photonic Crystal Fiber for All Optical 3R Regeneration

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Abstract— This work will be presented the project of a 3R regenerator based on Mach-Zehnder Interferometer, simulations, and analyses disputed the results through the use of commercial software Optisystem. There are numerous signs of regeneration techniques fully optics, but in this work is investigated fully optical 3R regeneration through the Kerr effect in a Mach-Zehnder Interferometer, whose one of the arms is a Photonic Crystal fiber highly non-linear, which is described in the article.

Keywords—Kerr effect, Power, 3R Regenerator, degradation, regeneration.

I. INTRODUCTION

Any network of fiber-optic communication and other components are passive losses that can be light or serious, they are caused by attenuation, dispersion and nonlinear effects. The Group velocity dispersion may lead to enlargement and bad formation of the wrist, resulting in an increase of the bit error rate (BER), low quality factor (Q) and OSNR low.

When the optical signal propagates from the transmitter to the receiver, your quality is degraded due to obstructions in the physical layer of the network [5]. These problems are responsible for limiting the transmission rate and the distance from the optical link. So the complete regeneration is necessary, to resolve the damaging communication systems for light waves.

On the exposed, through this work, it was implemented a 3R regenerator based on the configuration of a wavelength converter using a Mach-Zehnder Interferometer (MZI), with the purpose of making a complete regeneration (Reamplifying, Retiming and Reshaping) of the signal through the non-linear effects to a bit rate of 10 Gb/s and the wavelength of 1550 nm, track on which have less attenuation optical fiber.

The project developed by numerical simulations in Optisystem software, aims to implement a fully optical regenerator with features similar to those of conventional electrical regenerators, though with a difference as regards not the conversion of optical signals for electronics, as this is very expensive for telecommunications systems.

The design of the regeneration System 3R MZI-based to optical signal regeneration fully Optics is divided into three

sections: transmission, degradation and regeneration. For that goal to be fulfilled the pulse has gone through three stages. The signal emitted by the transmitter goes through SMF and DCF fiber amplifiers EDFAs followed and gaussians filters in cascade and finally the signal is regenerated in the Mach-Zehnder Interferometer consisting of a HNL-PCF and a gaussian filter. A more detailed description of the system proposed in this work and also the entire process of transmission, before regeneration and regeneration will be presented in the next few sections. All the parameters of the simulation were introduced according to the references and default of Optisystem.

II. MODEL AND PARAMETERS OF THE 3R REGENERATOR PROPOSED

The regenerator operating regime is based on the interferometry scheme, consisting of a simple system, which did not require the use of any CW laser and optical filter at the transmitter output. Our scheme is a modified version that includes a MZI with a HNL-PCF in one arm, as proposed in [3]. Were exploited the advantages of non-linear effects of amplified noise emitted by EDFAs.

The 3R regenerator proposed is divided into three parts: the first is the transmission, the second degradation and the third signal regeneration.

To be best displayed the evolution of the process, an intermediate step will also be included, which in this case will be denoted by before regeneration, which does not influence the process because it is only to collect more data and to a possible comparison. There are a number of signal regeneration techniques in a totally optical manner, but in this work the full 3R regeneration through Kerr effects in a fiber optic telecommunications network is investigated, which will be described next.

A. Transmission Section

For this project, as shown in the schematic in figure 1 system complete, the transmitter consists of a Pseudo Random Bit Sequence Generator (PRBS) with initial transmission rate

of 10 Gb/s connected to a Optical Gaussian Pulse Generator (OGP) that in simulations, have varied power 0 to 10 dBm at the wavelength of 1550 nm, to analyze the efficiency of the functioning of the 3R regenerator with a total of 10 interactions in simulations on Optisystem. Figure 1 shows the transmitter used.

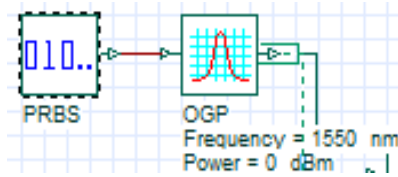


Fig. 1. Transmitter.

B. Degradation Section

The party responsible for the degradation is composed of an SMF 100 Km long, with dispersion coefficient of 17 ps/nm.Km dispersion slope of 0.08 ps/nm²/Km, attenuation coefficient of 0.25 dB/Km, the area of 80 μm^2 , core refractive index of $2.6 \times 10^{-20} \mu\text{m}^2/\text{W}$ and non-linearity coefficient of $1.3 \text{ W}^{-1} \text{ km}^{-1}$.

The signal is degraded in any link that makes up the SMF and the amplifiers. After the SMF has a dispersion compensating fiber (DCF) with 20 Km in length and that has as parameters: coefficient of 0.5 dB/km attenuation, dispersion coefficient of -80 ps/nm.Km, 0.21 dispersion slope ps/nm².Km, the area of 30 μm^2 and refractive index of $2.6 \times 10^{-20} \mu\text{m}^2/\text{W}$. Figure 2 shows the degradation section.

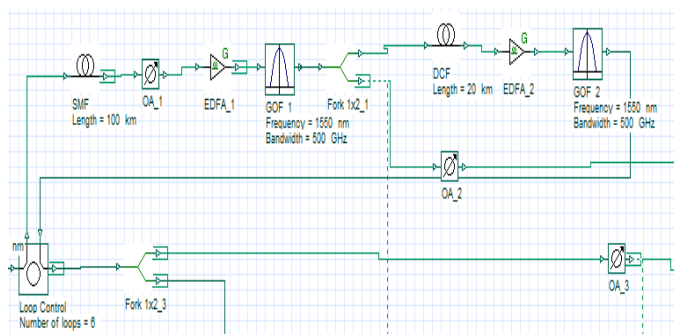


Fig. 2. Degradation Section

After the SMF and DCF, were used the erbium doped fiber amplifiers (EDFAs) high power, with a gain of 20 dB and 12 dB, both with 4 dB noise figure, which are used to recover the losses, after each EDFA, gaussian filter is inserted with 500 GHz bandwidth to reduce the effects because the noise amplified spontaneous emission (ASE) issued by EDFAs. After filtering the signal is released for the signal is divided into two parts, passing by the module clock recovery, through the extraction of wavelength, so walking to the signal regeneration process.

C. Regeneration Section

The main part of the regenerator is shown in figure 3, which consists of a Mach-Zehnder Interferometer, which has one of arms consisting of a Photonic Crystal Fiber Highly Non-Linear (HNL-PCF) with 1.3 Km long, scattering coefficient -1216 ps/nm.Km dispersion-slope 0.26 ps/nm²/km attenuation

coefficient of 5 dB/Km, $1.81 \mu\text{m}^2$ effective area, refractive index of $2.6 \times 10^{-20} \mu\text{m}^2/\text{W}$ (silicon fiber).

Soon after being divided into the two arms of the MZI, the signal is resynchronized, through a pumping laser with initial power of 100 dBm, and 1560 nm frequency, which will serve for extraction of clock (clock recovery).

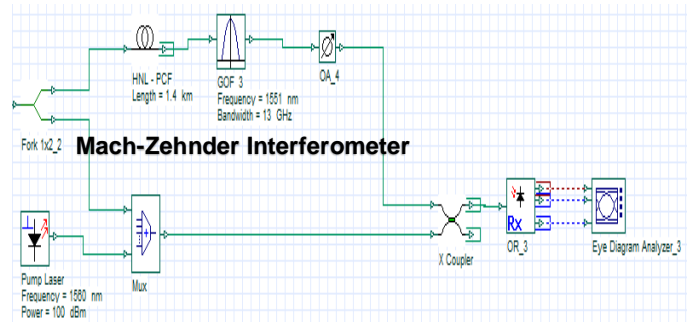


Fig.3. Mach-Zehnder interferometer with HNL-PCF.

The pumping power is higher than the signal is used for resynchronization happen. The signal is released to the HNL-PCF, which is used to eliminate much of the noise through the SPM effect, along with a gaussian filter with central wavelength shifted to remove the amplified spectrum, resulting in a data signal and a wavelength conversion during the regeneration process.

The reason for the choice of HNL-PCF was due to your non-linearity coefficient, which in most cases is greater than that of silica SMF [3], as well as the fact that kind of fiber reduce average power capability of the control pulses and also the problem of group velocity mismatching, because many short lengths are required, which can reach a sufficient number of non-linear effects and also improves system integration [1]. The receiver has optical responsivity of 0.7 A/W and dark current of 10 mA.

III. RESULTS AND DISCUSSIONS

The results will appear according to the three stages of the process, which are: transmission and degradation of signal regeneration. So the graphics of the same category will be arranged next to each other for a better visualization and comparison of results. The bit error rate (BER), optical spectrum analyzer, power meter and the time domain optical visualizer will be the components used for the measurements and analyses will be made according to your answers in each step of the process of regeneration 3R based on Mach-Zehnder interferometer.

A. Pulse Shapes in the Output of the Transmitter and Eye Diagrams

Figure 4 shows the shape of the gaussian pulse in the output of the transmitter, in step and degradation in the regeneration step. Note that the sign on the stage of degradation is noisy, that due to loss of power caused by the dispersion and attenuation induced in the loop of 100 Km of SMF. The sign in the color pink represents the power of noise present in the input signal after pulse propagation in the degradation, this interference greatly reduced the power of the input signal. The degraded

signal causes severe damage to system performance, as shown by figure 4 stressed eye (a).

Figure 4 (c) shows the pulse modulation format after the regeneration process, i.e. after the passage of the interferometer by HNL-PCF. There was an increase in the amplitude of the pulse, a considerable noise reduction and consequently energy gain compared with the signal in figure 4 (b).

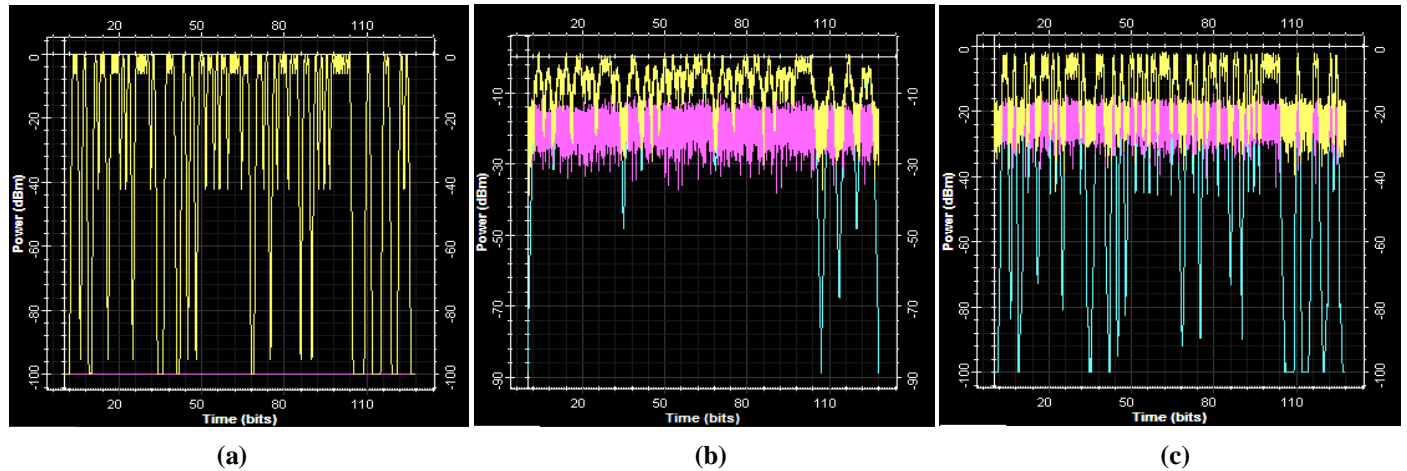


Fig. 4. Waveforms: (a) transmitter output signal, (b) after degradation, (c) signal after the regeneration.

For eye diagram analysis, was conducted a sweep in the output power of the transmitter, in the range of 0 dBm to 10 dBm, was executed for the modulation format chosen. The values of BER and Q factor were obtained for each level of power injected into the process of degradation and signal regeneration.

Figure 5 shows the evolution of the process, in this case with the input signal power 0 dBm, the values of the quality factor and bit error rate obtained in the process of degradation were of Q factor equal to 3 and BER of 1.3×10^{-3} . In pre regeneration process was obtained as a result a Q factor equal to 4.3 and a BER of 8×10^{-6} and in the final process of regeneration was obtained a value of Q factor equal to 26 and a BER of 2×10^{-143} . Comparing the degraded signal with the regenerated, there were a total of 140 regeneration orders of magnitude.

degraded signal (eye stress) with height of eye of -2.6×10^{-7} , despite the offset filtering performed by the first gaussian filter.

The eye diagram 5 (b) refers to what happened to the pulse after passing by the DCF fiber, before regeneration process in which it is possible to observe an improvement of the signal with an opening of 3.7×10^{-6} , but the noises of levels "0" and "1" are still present, due to the re-amplification process.

The eye diagram 5 (c) refers to sign after passing by Mach-Zehnder Interferometer to HNL-PCF, in that the reshaping of the signal, the short size HNL-PCF was sufficient to reduce the nonlinear and dispersive effects. Because the results of both the quality factor, as bit error rate showed a significant improvement in the process of signal regeneration through the XPM effect noise has been reduced, this was justified by the High Q factor and low BER on output in the receiver, so the opening of the eye has increased 3.4×10^{-4} coming.

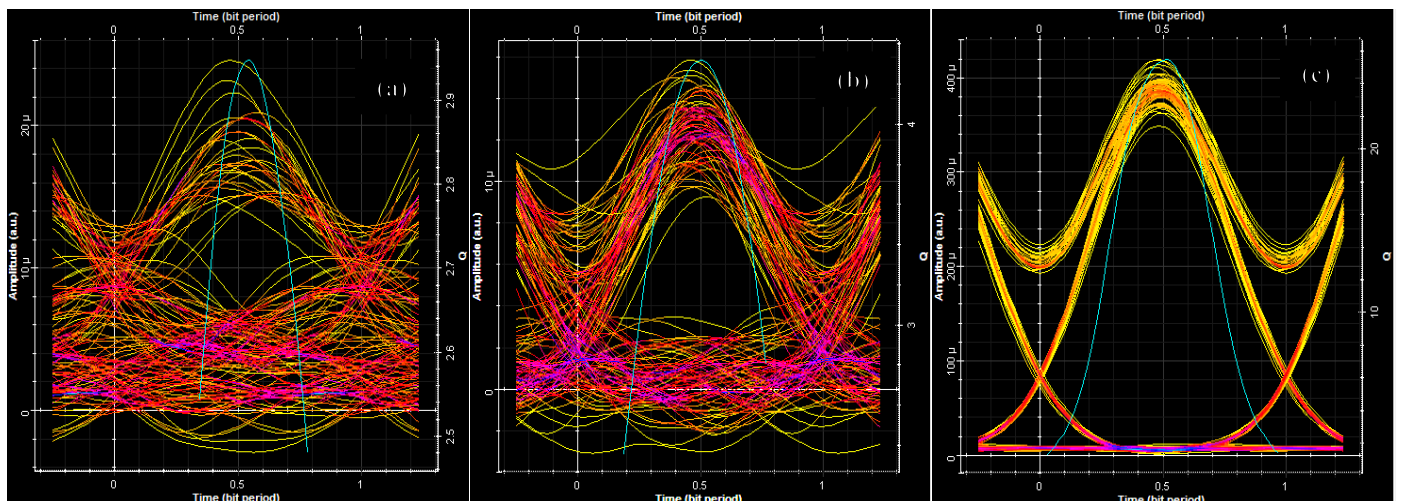


Fig. 5. Eye diagrams: (a) Section of degradation, (b) Section of before regeneration and (c) Section of regeneration.

The OSNR for the degradation section was 8.2 dB, already for the regeneration section was 25.5 dB.

From the existing relationship of these values to the eye diagram, it is stated that the BER decreased and the OSNR increased, so this guarantees the efficiency of the system as the complete regeneration of the degraded signal.

B. Variation of Transmitter Power

In any fiber optic communications system, the value of the quality factor should be the largest possible for an optimal value of transmitter power. As for low power levels, the Q-factor is limited by noise and high power levels by non-linear effects [1]. The 3R regeneration system proposed here, was used for the analysis of this affirmation, where the power of the transmitter was varied from 0 to 10 dBm. The graphics of the BER and log performance of the Q-factor of the regeneration section depending on the variation of power are shown in figure 6.

In the BER performance analysis and Q-factor on regeneration section was by figure 6 charts that the Q-factor initially increases with power, but, after reaching a threshold, then decreases as the power increases. So, for this case the maximum value for the quality factor in the power range given was $Q=35$ and the minimum bit error rate was of $BER=9 \times 10^{-266}$ for a 6 dBm input power.

The OSNR regeneration section also had the best value being of 28 dB. Therefore, in case of signal propagation in the regeneration, the bit error rate increases with increasing levels of power from the threshold of 6 dBm, this occurs due to nonlinear effects, which degrade the signal, resulting also in low quality factors.

The same test was also made to the section of degradation, the graphics of figure 7 show the log of BER performance and the Q factor for this case.

It was observed that the BER for all input powers of the transmitter to the degraded signal reaches the highest value to the power of 4 dBm and from this threshold the curve reverses your tendency, i.e. the signal begins to improve compared with the initial power 0 dBm. So too the OSNR increased from 8.2 to 10.2 dB, thus the Q factor also increased from 2.9 to 3.9 and BER decreased from $1,3 \times 10^{-3}$ to 4×10^{-5} , as shown in figure 7.

So there was an improvement in the signal section of degeneration when it increased the power of the transmitter.

We emphasize that the comparisons made here about the BER and the Q-factor in sections of regeneration and degradation were individually, so this does not invalidate the good performance of the regenerator, because the improvements that have occurred in the section of degradation were useful to counteract the problems of Nonlinear and dispersive effects on regeneration section.

Namely in this scheme the nonlinear effects of SPM, XPM and FWM were used to signal regeneration. This was proven by the values of bit error rates, signal noise and relations of the factors of quality of the regeneration section, as shown in the graphs in figure 6 (a) and 6 (b), although individual losses, these values are higher than those of degradation shown in figure 7 (a) and 7(b).

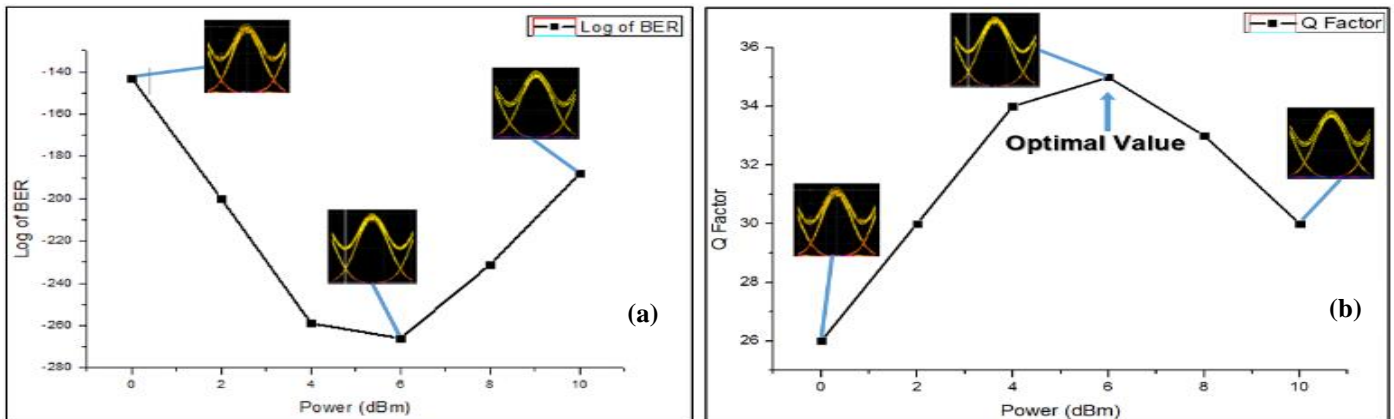


Fig. 6. Performance of Log BER and Q factor on regeneration section.

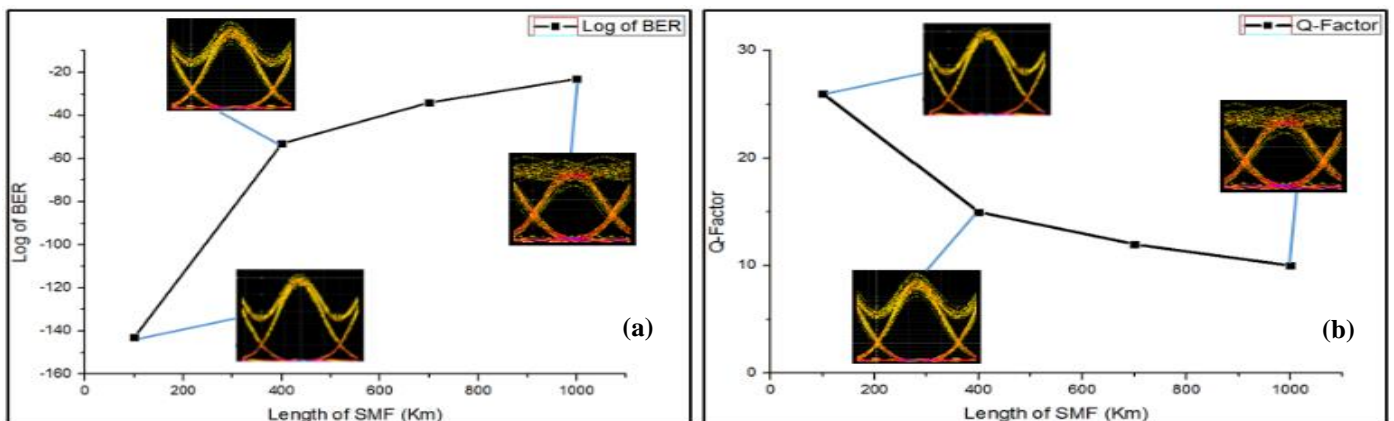


Fig. 7. Performance of Q Factor and BER degradation section.

C. Variation of Fiber Length SMF

For this case the transmitter power was maintained at 0 dBm, in order to avoid the increase of non-linear effects [5] on the network. The parameters of the fibers, EDFAs, filters, and also of the system remain the same as the initial simulations.

Figure 8 shows the performance of the system in the regeneration, through the values of the Bit error rate (BER) and the quality factor (Q-Factor) for this event that moved the length of the link.

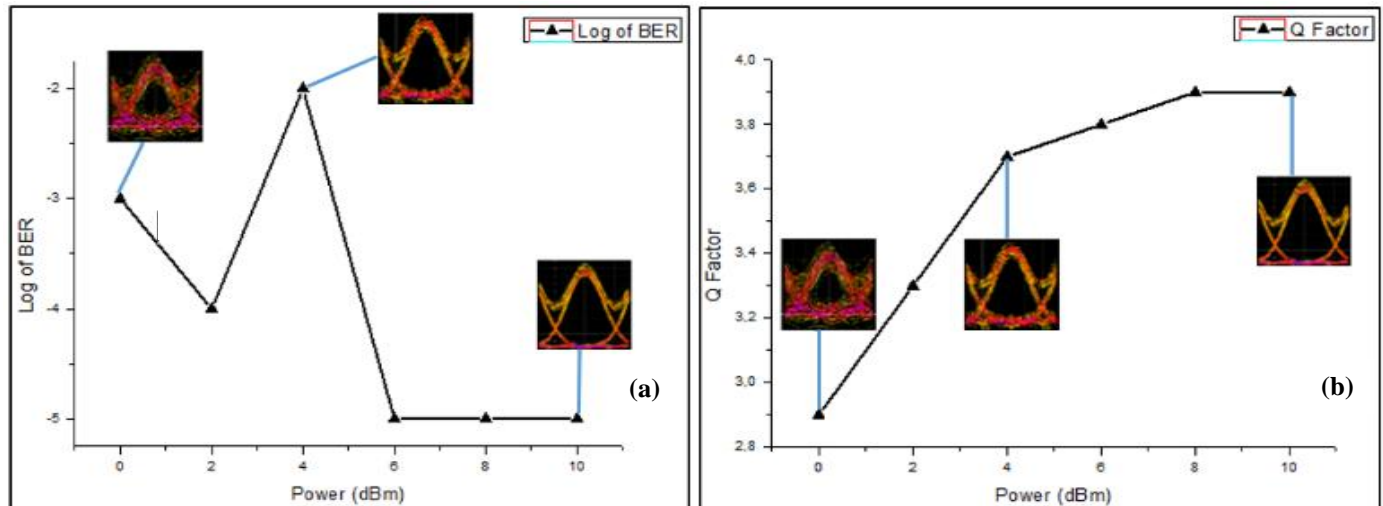


Fig. 8. System performance for SMF length variation.

In figure 2 is shown the section of volume in shown in a loop, in that your value can be changed to possible system performance test, through the variation of the length of the link.

In this simulation the pulse went through a circuit, where the variation in relation to the length of the SMF was 100 to 1000 Km, with the purpose of evaluating the performance of regenerator for long distances.

You can see the graph in figure 8 (a) and 8 (b) to increase the length of the marriage, the value of the quality factor decreases from 26 to 10 and the bit error rate increases from 2×10^{-143} to 1.4×10^{-23} .

What occurs in this process is not only the increased length of the fibers, but also increasing the amount of EDFAs in link, this causes also increase the effects of ASE noise emitted by each of the new amplifiers entered into the system. However, even with the insertion of undesirable noises, the amplifiers are essential for the implementation of systems of long distance, being both applied in transoceanics links and metropolitan networks.

Any losses management technique based on optical amplification has your bad side, because it degrades the OSNR bit sequence [5]. In these simulations was obtained as a result a

OSNR equal to 26 dB and 18 dB to the SMF link of 100 Km and 1000 Km respectively. That is, the signal has been distorted from 1 to 10 transmission intervals, so that the degradation process is largely the same as a real-world system. Therefore, the measure that the ASE is increased, the gain of the amplifier is reduced, and the OSNR too, so the quality factor values were low when it increased the length of the fibers and number of EDFAs in breakdown section.

Despite the losses the value of BER for the regeneration section in this case, is above the acceptable value for a system with bit rate of 10 Gb/s, because values of bit error rate equal to 10^{-15} , can be considered to ensure customers a high quality service [4]. In this sense, for the system proposed here, it can be affirmed, through the results of the simulations, that its effectiveness has been proven for long distances.

IV. CONCLUSIONS

With the results obtained so far, we can conclude that from the methodology used for analysis and optimization of network performance, it was possible to design a 3R regenerator with a Mach-Zehnder interferometer with only 1.3 Km from PCF, able to provide reasonable gains, to remove much of the noise, which resulted in high OSNR and Q factor and consequently low levels of BER. Displaying, eye diagram reduced penalties. It was evident that the use of DCF in the before regeneration served to provide compensation of dispersion introduced by 100 km of SMF. So through this simple method was possible significantly, reamplifying, retiming and reshaping the signal in such a way that increased the reliability of the system and also reduced the complexity and cost of the project. Therefore, the system presented here may someday be used for the transmission of long distance and high speed.

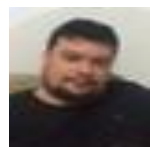
REFERENCES

- [1] HNAUNG, Soe Soe. Design and Implementation of 10 Gbps All Optical 2R. International Journal of Scientific and Research Publications, ISSN: 2250-3153, vol. 4, 6 de june, 2014
- [2] MAT YAACOB, S. N. S. et al. 10GB/S NRZ based on self-phase modulation in all optical 2R regeneration. ARPN Journal of Engineering and Applied Sciences, vol. 10, n° 19, october, 2015.
- [3] Xu, S. X., 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] KEISER, Gerd. Optical Fiber Communications. Mcgraw Hill. Fourth Edition, 2008.
- [5] Agrawal G. P. Fiber-Optic Communication Systems, 3rd ed., John Wiley Sons, Inc., New York, NY, 2002.
- [6] Bhusari Shraddha N.; Deshmukh Vikas U.; Jagdale Shantanu S. Analysis of SPM, XPM, and FWM in Fiber Optic Communication Using OptiSystem. IJSTE - International Journal of Science Technology & Engineering | Volume 2 | Issue 07 | January 2016.
- [7] CASTELLANI, Carlos Eduardo Schmidt. Amplificadores Raman em fibras microestruturadas. Dissertação de Mestrado. Centro Tecnológico da Universidade Federal do Espírito Santo, 2009.



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APPENDIX

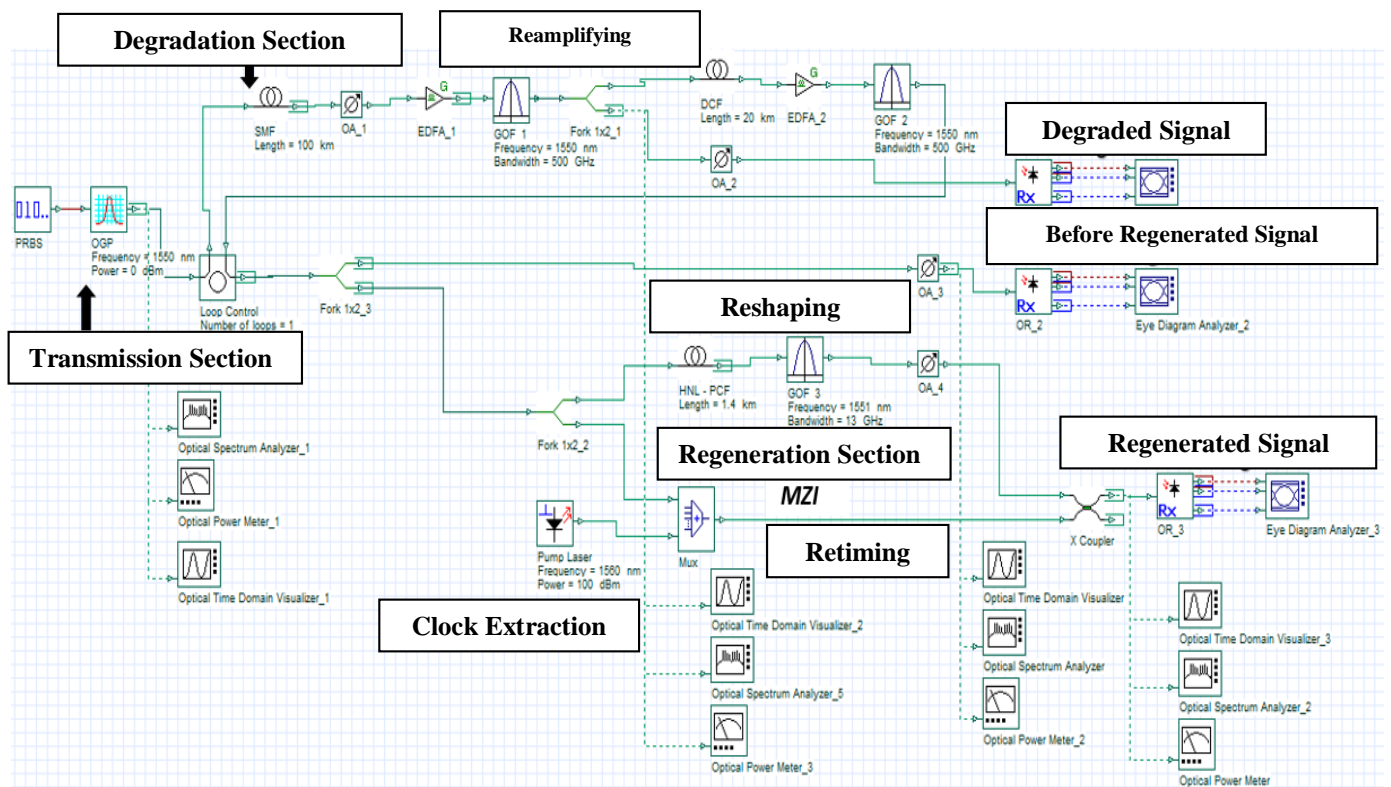


Fig. 9. Complete schematic of the 3R regeneration system.