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Noise Reduction in All Optical 2R Regenerator Using Self Phase Modulation

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Abstract— In this work a Comparison has been made between stages before using regenerator and after regeneration. It is observed that the degradation stage is noisier than regeneration stage. SPM induced spectral broadening has been visualized in frequency domain. 2R Regenerator performance in the regeneration stages for various transmitting power of different fiber length of SMF has been analyzed. These results are simulated in Optisystem software. The BER measurement vs. average received power curve for HNLF has been visualized in MATLAB. Results shows that as the input power increased, the regenerator performance improved with increasing distance. For a distance of up to 300 km of SMF, the values of factor Q = 6.13, BER = 10^{-11} and OSNR = 13.6 dB were found. The results confirm that the proposed 2R regenerator is efficient to suppress noise and improving the quality of the transmitted signal.

Index Terms— SMF, SPM, 2R Regenarator, HNLF, BER, OSNR & Q Factor.

1 Introduction

THE 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.. An ideal optical regenerator transforms the degraded bit stream into its original form [1]. These techniques are implemented in today's telecommunications networks in order to increase performance and gain in optical signal transmissions and receptions [2]. 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) [3]. These fibers are used to highlight the nonlinear effects of self-phase modulation (SPM), cross-phase modulation (XPM) and four-wave mixing (FWM) [4]. The nonlinear effects associated with signal regeneration techniques have resulted in several devices for the processing of optical signals, such as [4], 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) among others [5]. The regeneration of a signal can be electrical, all-optical or opto-electronic [6], but in this work we choose the second option. Since, fully optical regeneration is a technique that is constantly under investigation, it consists of treating degraded optical signals during fiber optic transmission and amplifiers and transmitting them without distortion, crosstalk and noise [4]. 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, compare has been made between signal degradation and regeneration stages for analyzing the performance of the system, Improving the noise suppression from the degraded signal to regenerated signal spectrum. Different results regarding the performance of the system, which were analyzed through the Q-factor, BER, Optical Signal-to-Noise Ratio (OSNR), eye height and eye diagram and finding the best three eye diagram respect to the transmitting power and distance. Finally analyze the BER measurement vs. average received power curve for 2R regenerator.

2 Principle of 2R Regeneration by Self Phase Modulation and Offset Filtering

Mamyshev is attributed as one of the pioneers in the publication of research papers in which 2R regeneration with HNLFs is applied [7]. The schematic shown in figure 1 is an example of a Mamyshev regenerator based on SPM, which was published in 1998 [6] and has served as a reference for new 2R and 3R regenerator designs to the present day. This classic Mamyshev 2R regenerator is a simple suppression of "zeros" and "one" amplitudes fluctuations [8], based on SPM, in which the input noisy signal is initially sufficiently amplified by an EDFA, then the pulse goes through a process of enlargement induced by SPM effect to propagate by 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.

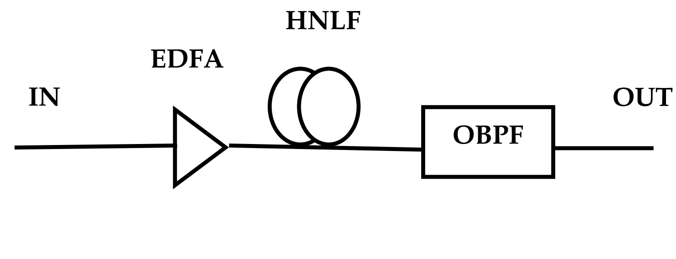

Fig. 1. Schematic of a Classic Mamyshev Regenerator.

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The main function of 2R regenerator is the reshaping function. The optimum reshaping function depends on the SPM induced spectral broadening [8]. The broadening spectrum is directly proportional to the intensity of optical pulse [9]. When the low intensity pulses (or zero level noise) enter the HNLF, the spectrum broadening is small and it does not pass through the passband of OBPF. When the high intensity pulses (or one level noise) enter the HNLF, the spectrum broadening is large enough to extend over the passband of OBPF. Thus, the amplitude noise in the one and zero level can be suppressed by means of optical filtering [10].

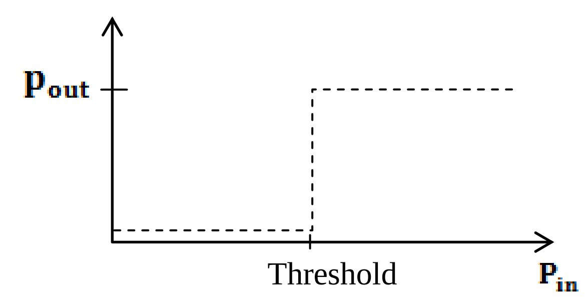

Fig. 2. Illustration of an ideal step-like power transfer function.

At low power, zero level noise is suppressed and a constant output power occurs up to a fixed threshold. The threshold value is different for different regenerators. As input power increases above the threshold value, a constant output power is obtained which shows the suppression of one level noise. The flat top region shows the performance of regenerator. Thus zero level and one level noise is suppressed by 2R regenerator [11].

3 Simulation Setup

The following layout of all optical 2R regenerator based on the ideas of Mamyshev. The scheme has three types of fibers and is also divided into three parts: Transmission, Degradation and Regeneration [12].

Regarding the layout in Figure 3 it can be said that the transmission part consists of a 10 Gb/s pseudorandom bit sequence generator (PRBS) connected to an Optical Gaussian Pulse Generator (OGPG), 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). 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. 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 and 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. We have used the following parameters to find our desired result.

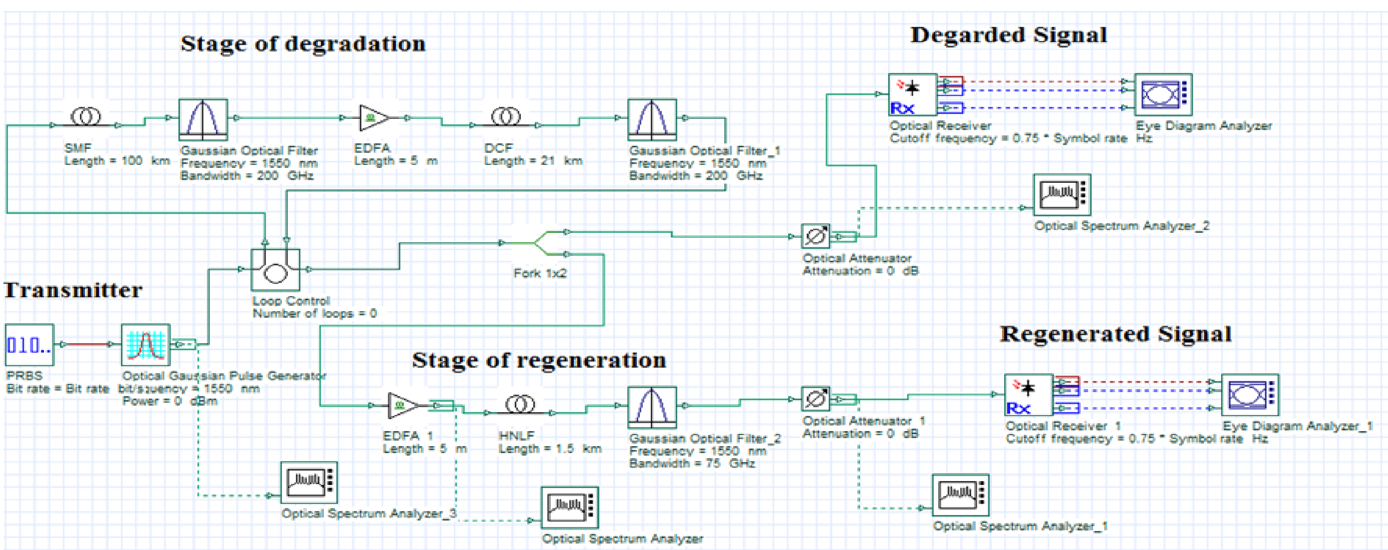

Fig. 3. Simulation Layout to analyze the effect of all of all optical 2R regenerator based on self-phase modulation.

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TABLE 1
SIMULATION PARAMETERS USING FOR DIFFERENT FIBER

Parameter(Unit)	Fiber types		
	SMF	DCF	HNLF
Nonlinear Refractive Index, $n_2(m^2/W)$	2.6×10^{-20}	2.6×10^{-20}	2.6×10^{-20}
Wave-length,λ (nm)	1550	1550	1550
Fiber length (km)	100	21	1.5
Effective area, $A_{eff}(\mu m^2)$	80	30	1.8
Bit Rate, B(Gb/s)	10	10	10
Dispersion parameter, D(ps/nm-km)	17	-80	-72
Attenuation, α(dB/km)	0.2	0.6	0.47
Dispersion slop, s(ps/nm^2-km)	0.08	0.21	-0.0075
Transmitted Power, P(dBm)	Varied	Varied	Varied

4 ANALYSIS AND DISCUSSION OF SIMULATED RESULTS

Figure 4.1 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 in Figure 4.1(a) and regeneration 4.1(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 = 36.5 and BER = 1.98×10^{-293} 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 4.1(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.

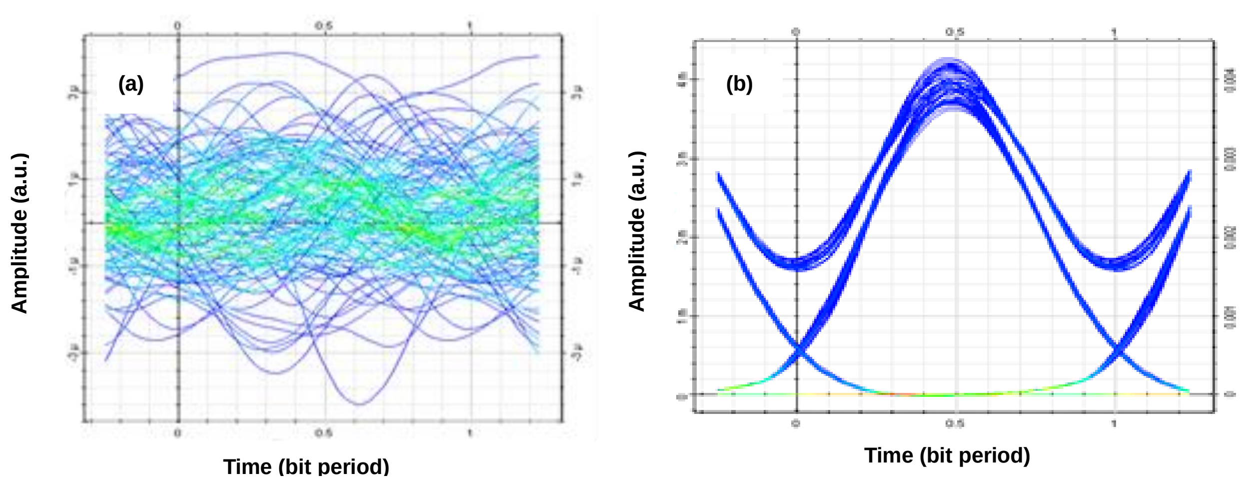

Fig. 4.1. A comparison of the signal in the degradation stages and in the regeneration stages, Eye diagrams: (a) after the stage of degradation and (b) after the regeneration stage.

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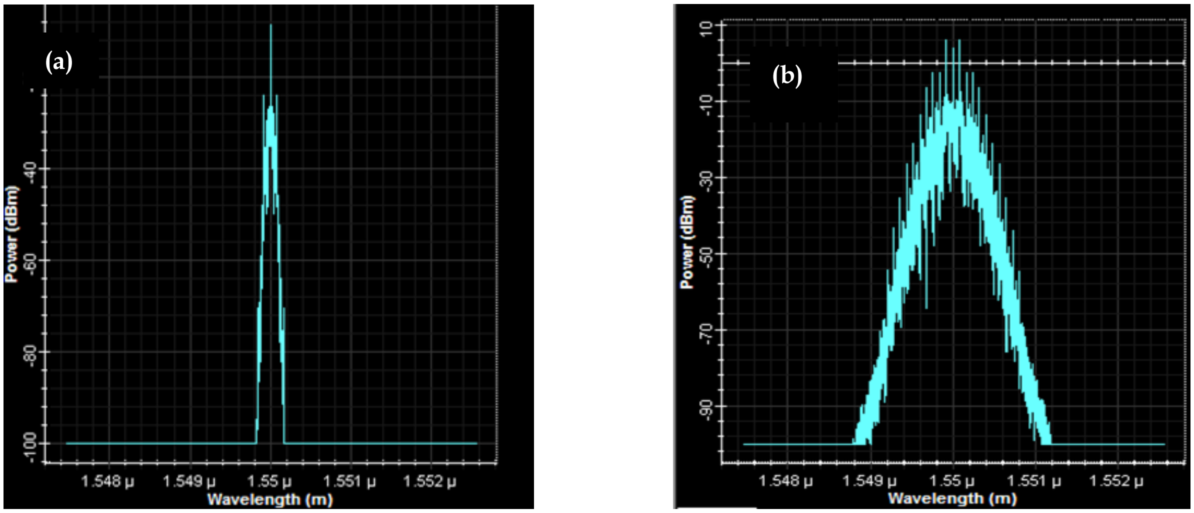

Fig.4.2.(a) The spectrum of the degraded signal, and (b) The broadened spectrum induced by SPM effect.

Fig. 4.2 shows the spectrum of the degraded signal before highly nonlinear and after highly nonlinear fiber. In Figure 4.2(b), the spectrum is wider than that in Figure 4.2(a) because of the self-phase modulation effect inside the highly nonlinear fiber. SPM gives rise to an intensity-dependent nonlinear phase shift, $\emptyset_{NL}$ which introduces chirp in the propagating signal and increases with fiber length. As a result SPM-induced chirp increases in magnitude as the pulse propagates in the fiber. It implies new frequency components are continuously generated during pulse propagation in the fiber which broadens the spectrum of the propagated pulse as compared to the input pulse The Gaussian Optical Filter selects the dominant spectral peak in the broadening spectrum. It changes from the original center wavelength. Table 2, 3 and 4 shows Regenerator performance in the regeneration stage. 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 a 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 the tables respectively.
This table 2 shows the regenerator performance regarding Q factor, BER, OSNR, Eye height and Eye diagram for a 100 km SMF with transmitting power 0, 5 and 10 dBm. After analyzing table 4.2 it can be said that the highest values of OSNR found for a 100 km SMF at 5 dBm transmission power level. At this the value of minimum BER is 0 and the best possible eye diagram is found.

This table 3 shows the regenerator performance regarding Q factor, BER, OSNR, Eye height and Eye diagram for a 200 km SMF with t ransmitting power 0, 5 and 10 dBm.

This table shows 4 the regenerator performance regarding Q factor, BER, OSNR, Eye height and Eye diagram for a 300 km SMF with transmitting power 0, 5 and 10 dBm.From table 4 it can be said that the highest values of OSNR and the best eye diagram found for a 200 km SMF at 10 dBm transmission power level. After analyzing table 4 we can see that the highest values of OSNR found for a 300 km SMF at 10 dBm transmission power level.
By comparing Table 3, 4 and 5 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. 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 = 6.13, BER = 10^{-11} and OSNR = 13.6 dB was obtained, so 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. 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 powers, so it can be suggest that 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.

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TABLE 2
REGENERATOR PERFORMANCS IN THE REGENERATION STAGES FOVARIOUS TRANSMITTING POWER OF 100 KM SMF

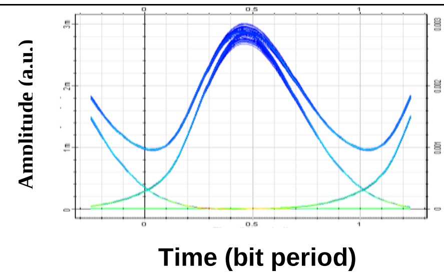
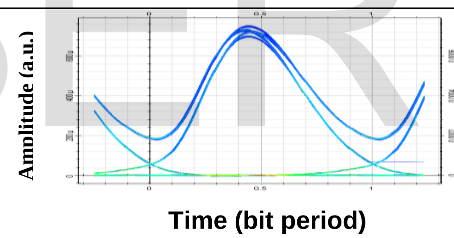
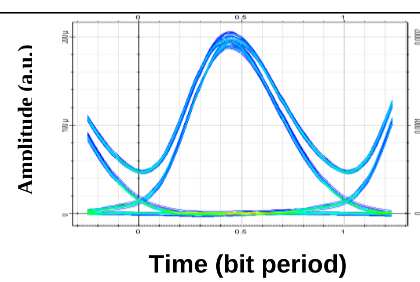
Transmitting Power		SMF distance at 100km
0 dBm	Maximum Q Factor	36.5766
	Minimum BER	1.986×10^{-293}
	OSNR	28.2 dB
	Eye Height	0.00259
	Eye Diagram	
5 dBm	Maximum Q Factor	39.0543
	Minimum BER	0
	OSNR	30.3 dB
	Eye Height	0.0047004
	Eye Diagram	
10 dBm	Maximum Q Factor	32.1229
	Minimum BER	8.4244×10^{-227}
	OSNR	28.6 dB
	Eye Height	0.000179
	Eye Diagram	

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TABLE 3
REGENERATOR PERFORMANCES IN THE REGENERATION STAGES FOVARIOUS TRANSMITTING POWER OF 200 KM SMF

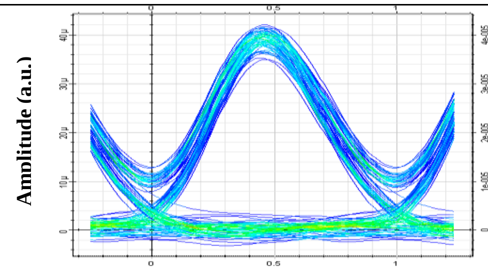
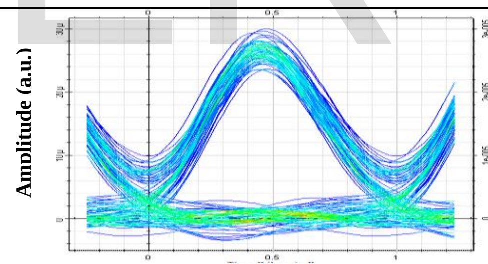
Transmitting Power		SMF distance at 200km
0 dBm	Maximum Q Factor	10.1606
	Minimum BER	1.485×10^{-024}
	OSNR	17.6 dB
	Eye Height	1.8354×10^{-005}
	Eye Diagram	 Time (bit period)
5 dBm	Maximum Q Factor	15.2006
	Minimum BER	1.72023×10^{-052}
	OSNR	20.9 dB
	Eye Height	3.67×10^{-55}
	Eye Diagram	 Time (bit period)
10 dBm	Maximum Q Factor	23.9596
	Minimum BER	3.099×10^{-127}

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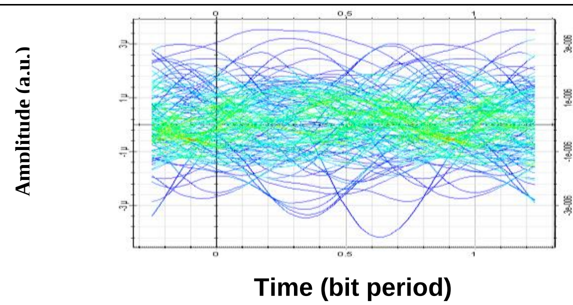
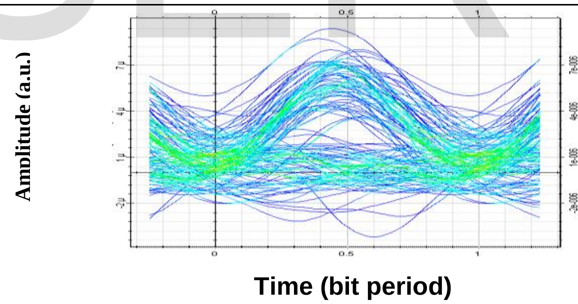
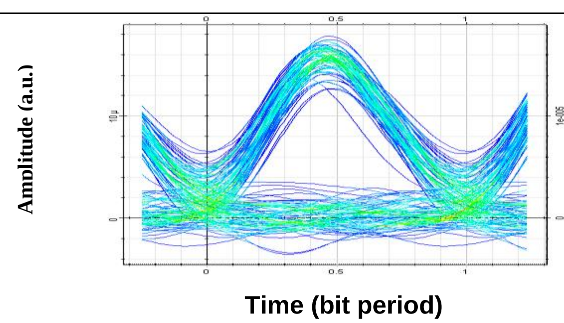
TABLE 4
REGENERATOR PERFORMANCES IN THE REGENERATION STAGES FOVARIOUS TRANSMITTING POWER OF 300 KM SMF

Transmitting Power		SMF distance at 300km
0 dBm	Maximum Q Factor	0
	Minimum BER	1
	OSNR	0 dB
	Eye Height	0
	Eye Diagram	
5 dBm	Maximum Q Factor	2.56
	Minimum BER	0.005148
	OSNR	7.05 dB
	Eye Height	-1.215×10^{-006}
	Eye Diagram	
10 dBm	Maximum Q Factor	6.13
	Minimum BER	6.13×10^{-11}
	OSNR	13.6 dB
	Eye Height	8.15×10^{-006}
	Eye Diagram	

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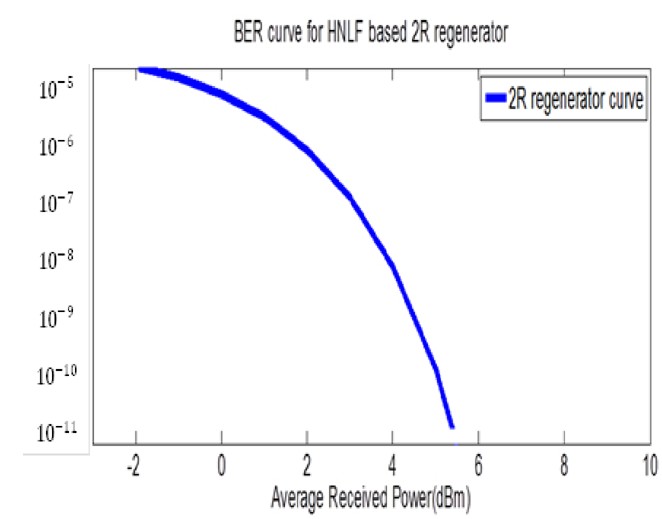

Fig.4.3. BER curve for HNLF based 2R Regenerator

From Figure 4.3. it is observed that with the increasing of average received power of 2R regenerator the value of BER decreased. For the value of -25 dBm received power the value of BER is 10^{-5} . Then it is found that the value of BER is decreased with the increasing of average received power.

5 Conclusion

An All-optical 2R regenerator is a crucial element in optical communication systems in order to increase transmission performance. The 2R regeneration of this work is capable of suppressing noise and improving the quality of the transmitted signal through the self-phase modulation effect in a highly nonlinear fiber (HNLF) .Through this method it is possible to carry out the re-amplification and reformatting of the signal, besides reducing the complexity of the system and it will be reliable for long-distance and high-speed optical transmission system.

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