Comparison of pre and post-dispersion compensation schemes with RZ, NRZ and Gaussian modulations for 10 GBPS and 40 GBPS transmission rates

Comparação de esquemas de compensação pré e pós-dispersão com modulações RZ, NRZ e Gaussina para as taxas de transmissão de 10 GBPS e 40 GBPS

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ABSTRACT
In this paper, we investigate two dispersion compensation methods: post-compensation, and pre-compensation for transmission rates from 10Gbps to 40Gbps with return to zero (RZ), non-return to zero (NRZ) and Guassian modulations using single fiber mode-fiber (SMF) and dispersion compensating fiber (DCF). The influence of the DCF compensator dispersion with different transmission rates was studied in order to evaluate the performance of the proposed systems. The simulation results were validated through the analysis of the quality factor (Q-factor) and the bit error rate (BER), where it was verified that the post-compensation system with Gaussian modulation offered better performance results in function of the transmission rate variation.

Keywords: OptiSystem, dispersion compensation, dispersion compensating fiber, bit rate.

RESUMO
Neste paper, investigamos dois métodos de compensação de dispersão: post-compensation, and pre- compensation para as taxas de transmissão de 10Gbps a 40Gbps com modulações return to zero (RZ), non-return to zero (NRZ) e guassiano usando fibra single mode-fiber (SMF) e dispersion compensating fiber (DCF). A influência da dispersão do compensador DCF com diferentes taxas de transmissão foi estudada, afim de se avaliar o desempenho dos sistemas propostos. Os resultados das simulações foram validados através da análise do fator de qualidade (Q-factor) e da taxa de erro de bit (BER), onde verificou-se que o sistema de pós-compensação com modulação gaussiana, ofereceu melhores resultados de desempenho em função da variação da taxa de transmissão.

Palavras-chave: OptiSystem, compensação de dispersão, fibra compensadora de dispersão, taxa de bit.

1 INTRODUCTION

In any fiber optic communication system, it is necessary to consider some factors that may affect the performance of the system, which are related to the fiber's refractive index or dispersion. According to Sousa (2017) apud Agrawal (2012) the optical fiber when subjected to a high level of power tends to respond in a non-linear way according to the number of channels, so if the system is single-channel, self-channel phenomena may arise. phase modulation (SPM)) and stimulated Brillouin scattering (SBS), however, if the system is multichannel, the phenomena of cross-phase modulation (XPM), four-wave mixing (FWM) and stimulated Raman scattering (SRS) may arise.

In this sense, the impact of the power release and the dispersion residue can impair the performance of the single channel optical connection under the non-linear effect of SPM, however according to Singh (2015) in wavelength division multiplexing (WDM) systems with rate with 10 Gbps-RZ transmission and 100 km optical link, it is possible to significantly reduce FWM frequencies when unequal channel spacing is used, together with an optimal chromatic dispersion level.

Dispersion compensation techniques consist of using an SMF (positive scattering element) followed by a DCF, a fiber Bragg grating (FBG) or a highly nonlinear photonic crystal (HNL-PCF) (scattering elements). negative). As pointed out by Kaler et al. (2002) and Luz et al. (2019) the dispersion compensation techniques are defined as: Post-compensation, Pre-compensation and Symmetrical or mixed compensation.

Some researchers have tried to solve the problems of dispersion and non-linear effects, through dispersion compensation techniques, using DCF or FBG. In this sense, Saurabh Kumar et al. (2013) studied the influence of dispersion in relation to continuous wave (CW) laser power increase through post, pre and symmetric/mix compensation methods using DCF, SMF and FBG for 40 Gbps NRZ bit rate and power signal of 5 – 10 dBm. In the results obtained by them in the OptiSystem 11.0 numerical simulator, they verified that the performance of the post-compensation system was the best for a signal power of 5 dBm and dispersion of the FBG compensator of -2000 ps/nm. However, Oliveira et al. (2022) studied through numerical simulations the performance of waveguide grid (AWG) and FBG demultiplexers in a fiber optic network in a special fiber class called photonic crystal fiber (PCF) considering the nonlinear effects and dispersive.

According to Verma et al. (2013) and Kumar et al. (2013) the performance of a DCF dispersion compensation system can be better than the FBG compensation system, as it offers better Q-factor values for long-distance networks. However, studies by Kumar et al. (2013) revealed that the FBG can be used in the three dispersion compensation methods for the transmission rate of 40 Gbps with modulation not reset to zero and with input power ranging from 5 dB to 10 dB. And Sousa et al. (2021) studied the influence of dispersion with increasing signal power in a dispersion compensation system for transmission rates of 10 and 40 Gbps with RZ and NRZ modulation formats using SMF and DCF. They found that in the proposed system, the two modulation formats used had the best performance when operating at a transmission rate of 10 Gbps.

Here we propose dispersion compensation techniques using the OptiSystem software in two basic configurations: post and pre for transmission rates from 10Gbps to 40Gbps with return to zero (RZ), non-return to zero (NRZ) and guassian modulations using of SMF and DCF. Discussions and data comparisons were based on Bit Error Rate (BER) and Q-factor as a function of transmission rate variation. In section 2, the block diagrams of the two configurations are defined, as well as the simulation parameters. In section 3, the results of the comparison between the two compensation methods studied were reported and, finally, in section 4, the conclusions and references.

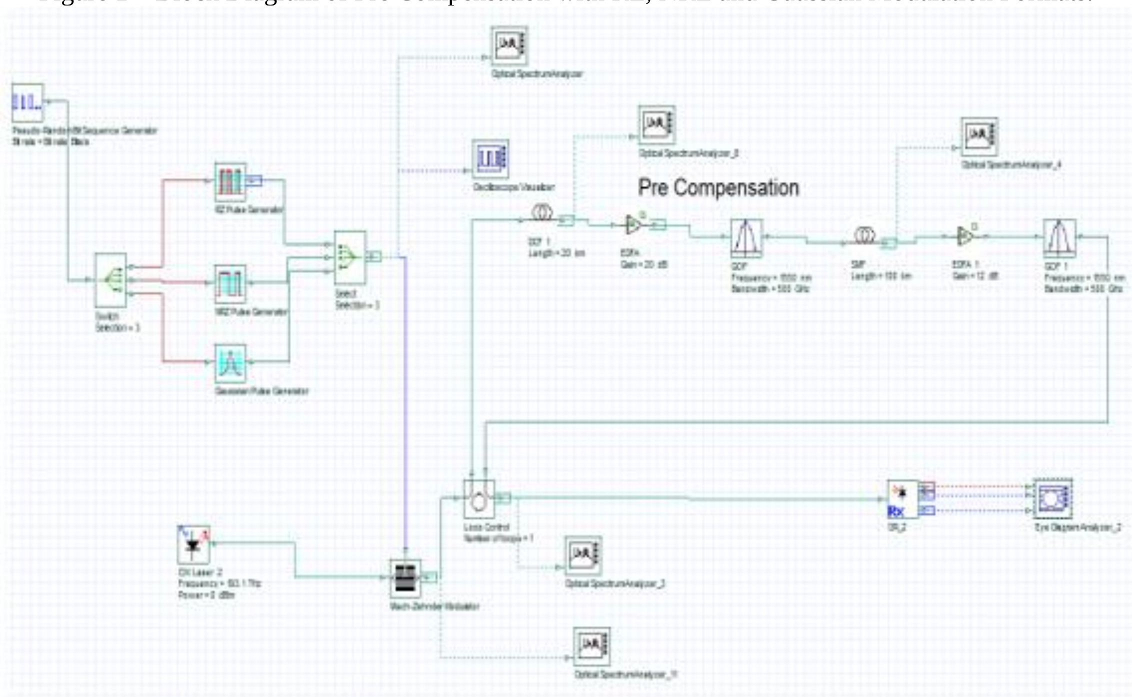
2 MATERIAL AND METHOD

2.1 DESIGN AND SIMULATION

The dispersion compensation techniques proposed here were based on projects already defined on the OPTIWAVE website and on those already presented by Sousa et al. (2021) and Luz (2019), they took into account the position of SMF (positive dispersion element) in relation to DCF (negative dispersion element). Figures 1 and 2 present the layouts of the dispersion compensation systems projects with RZ, NRZ and Gaussian modulation formats for transmission rates of 10Gb/s and 40Gb/s, which were developed and simulated in OptiSystem 17.1 software.

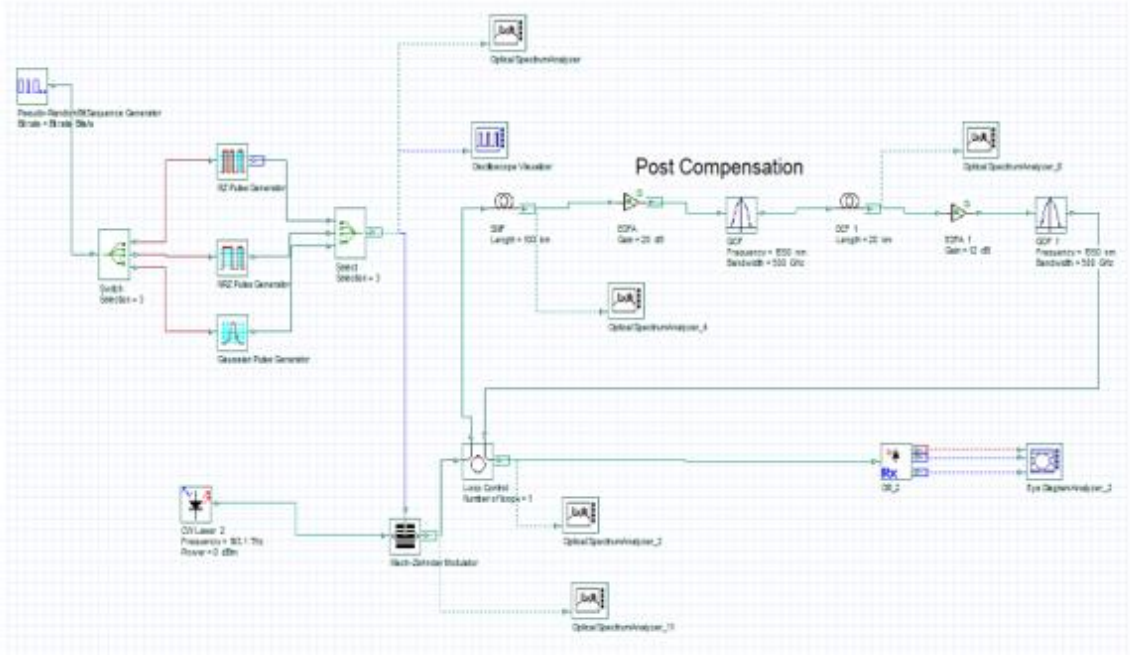
Figure 1 shows the block diagram of the pre-compensation scheme, where a DCF was used first to disperse the optical signal negatively, then an EDFA to amplify the signal, an SMF to compensate for the dispersion of the optical signal and Gaussian filters to filter ASE (Amplified Spontaneous Emission) noise at the outputs of EDFAs. Figure 2 shows the block diagram of the post-compensation scheme, where first an SMF was used, then a DCF to compensate for optical signal dispersion and also EDFAs and Gaussian filters with the same functions as the previous system.

Figure 1 – Block Diagram of Pre Compensation with RZ, NRZ and Gaussian Modulation Formats.



Source: Sabino et al. (2022).

Figure 2 - Block Diagram of Post Compensation with RZ, NRZ and Gaussian Modulation Formats.



Source: Sabino et al. (2022).

The SMF and DCF used in the schemas have the parameters according to table 1 below:

Table 1 Simulation Parameters of Optical Fibers

Parameters		SMF	DCF
Attenuation	dB/km	0.25	0.6
Effective Area	□m^2	□□	30
Dispersion	ps/nm/km	□□	-85
Length	Km	□□□	20
Wavelength	nm	□□□□	1550
Refractive index	m^2/W	$2{,}7\times10^{-20}$	3×10^{-20}
Power Transmitter	dBm	0	
Bit rates	Gbps	10, 20, 30 and 40	

Source: Sabino et al. (2022)

EDFAs with 20 dB and 12 dB gain and GOFs with 500 GHz bandwidth were used, which were used before and after DCF. In this sense, the EDFAs served to amplify the signal and the GOFs to filter the ASE noises emitted by the EDFAs. Receiver responsiveness is 1 A/W. The BER analyzer was used in order to obtain the Q-factor and BER values. Ideally, through these projects, systems with zero total dispersion are created, but with a certain amount of local dispersion along the optical link. Thus, it is necessary to investigate through simulations how the residual dispersion of the system affected the two types of dispersion compensation presented here. The analysis of the two systems proposed here was performed through the variation of the BER and the Q-factor in relation to the variation of the transmission rate from 10 Gbps to 40 Gbps.

In the two dispersion compensation schemes proposed here, the transmission rate was varied, in order to optimize the designs of the dispersion compensation systems proposed here. An externally modulated CW laser with a carrier wavelength of 1550 nm and a line width of 10 MHz and input power set at 0 dBm was used as optical source.

The DCF length was defined as a function of the SMF length, according to the following equation (Sousa et al., 2021):

$$D_{SMF} \cdot L_{SMF} = -D_{DCF} \cdot L_{DCF} \tag{1}$$

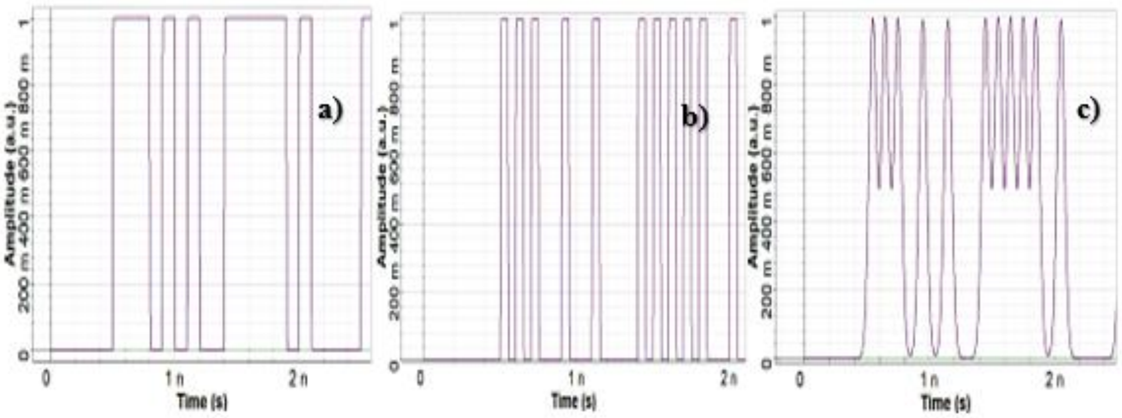
where D_{SMF} is the positive dispersion of the single-mode fiber with length L_{SMF} and $-D_{DCF}$ is the dispersion of the dispersion compensating fiber with length L_{DCF}.

3 RESULTS AND ANALYSIS

3.1 MODULATIONTECHNIQUES

The simulation results were obtained through the analysis of the pulse shapes and the eye diagram, in order to determine the performance of the proposed system. In this case, Q-factor and BER parameters were used for different bit rates.

Figure 3 - Modulation Formats (a) RZ and (b) NRZ (c) Gaussian.



Source: Sabino et al. (2022).

The graphs of the three optical modulation formats RZ and NRZ and Gaussian in the time domain are shown in figure 3 (a), 3 (b) and 3 (c), respectively, it can be observed that in both cases there is no presence of non-linear effects, as these results were collected at the transmitter output.

In another article Sousa et al. (2021) also analyzed a system with these three modulation formats studied here. According to Darwin et al. (2019) the NRZ and RZ techniques are considered the most common, where the former requires less bandwidth and is not sensitive to laser phase noise. Thus Payal (2017) tells us that in the NRZ format, the pulse remains on (bit 1) in the entire bit slot, its amplitude does not return to zero between two or more successive bits and the pulse width varies according to the bit pattern, however in RZ format each pulse representing bit 1 is shorter than the slot bit and its amplitude drops to zero before the end of the bit duration and the pulse width remains the same.

In the simulations, the three types of modulation were used alternately according to the simulation parameters indicated in Table 1. The performance analyzes of the systems were carried out through the results collected from the pulse shape and the eye diagram as a function of the variation of the transmission rates of 10, 20, 30 and 40 Gbps. The results that were collected and evaluated are presented in the following sections.

3.2 PERFORMANCE RESULTS OF THE DISPERSION PRE-COMPENSATION SYSTEM

Figures 4, 5, 6 and 7 present the eye diagrams for the scatter pre-compensation system proposed here, where initially a comparison of the transmission rates of 10, 20, 30 and 40 Gbps, respectively for the formats of RZ, NRZ and Gaussian modulation, both at an input power of 0 dBm and with 120 km of optical link length (20 km of DCF plus 100 km of SMF). And all the Q-Factor and BER results obtained in the simulations are presented in table 2.

In the analysis of the simulation results of the dispersion pre-compensation system, it can be observed that the best performance among the four transmission rates used was the system with NRZ modulation format and with a transmission rate of 10 Gbps, as also shown the eye diagram of figure 4 (b), which obtained Q-factor equal to 26.3 and BER equal to $8.9x10^{-153}$. However, the dispersion compensation system with Gaussian modulation obtained the best performance results for the transmission rates of 20, 30 and 40 Gbps as also shown in table 2 and the eye diagrams of figures 5 (c), 6 (c) and 7(c), respectively.

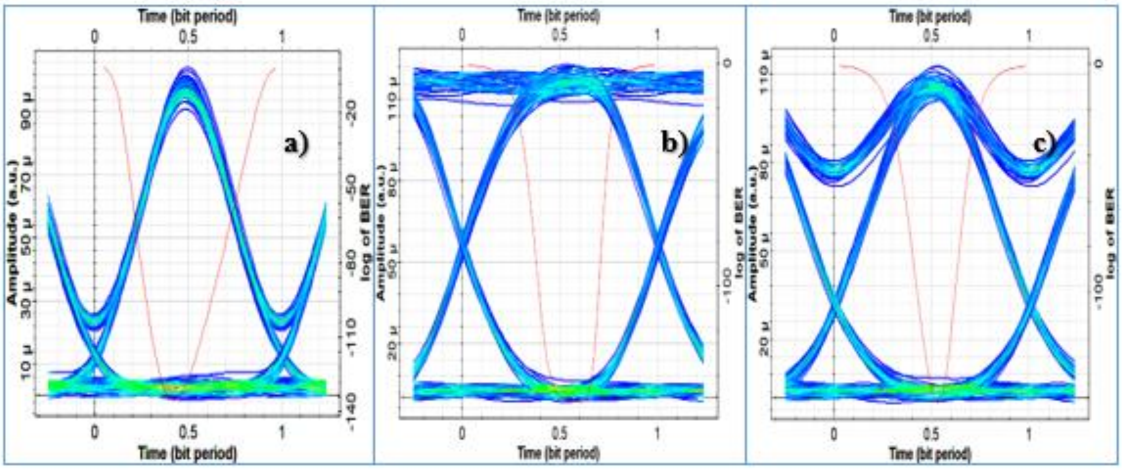
In general, most modulation formats used in the dispersion pre-compensation system for the baud rates used, obtained excellent performance results, except for the system with RZ modulation and with a baud rate of 40 Gbps, which obtained Q -factor equal to 5.2 and BER equal to $1.2x10^{-7}$ which can be considered a bad performance, as shown in the eye diagram of figure 7 (a).

Table 2 Performance of the dispersion pre-compensation system with RZ, NRZ and Gaussian modulation formats with transmission rates of 10, 20, 30 and 40 Gbps.

Modulation Format	**Parameters**	**Bit Rate (Gbps)**			
		10	**20**	**30**	**40**
RZ	**Q-Factor**	24.8	14.7	9.2	5.2
	BER	$5.24x10^{-136}$	$3.0x10^{-49}$	$1.9x10^{-20}$	$1.2x10^{-7}$
NRZ	**Q-Factor**	26.3	16.8	10.3	8.5
	BER	$8.9x10^{-153}$	$7.6x10^{-64}$	$3.8x10^{-25}$	$7.4x10^{-18}$
Gaussian	**Q-Factor**	25.9	19.3	14.7	12.6
	BER	$2.7x10^{-149}$	$1.5x10^{-83}$	$4.8x10^{-49}$	$1x10^{-36}$

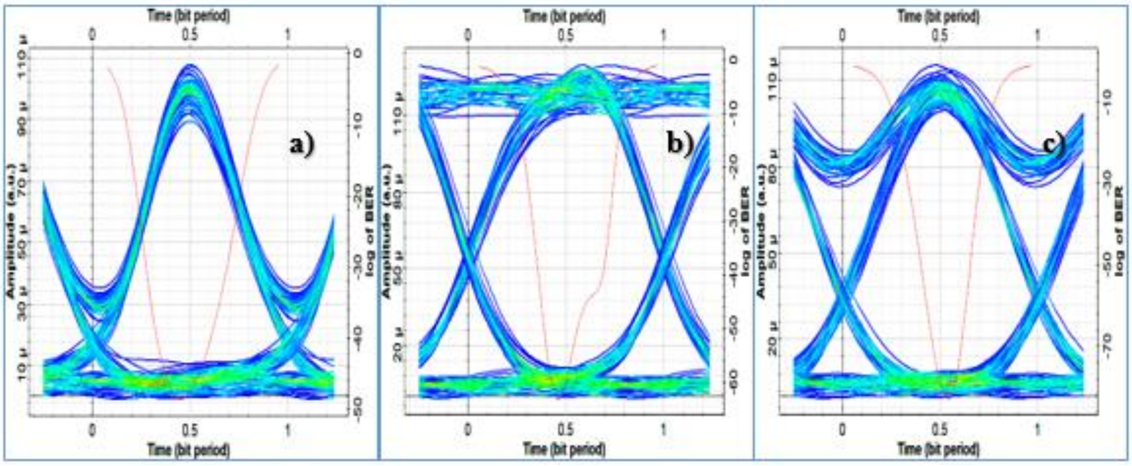
Source: Sabino et al. (2022).

Figure 4 - Eye Diagrams for Pre-Compensation System with RZ (a), NRZ (b) and Gaussian (c) modulation format, respectively and 10 Gbps bit rate.



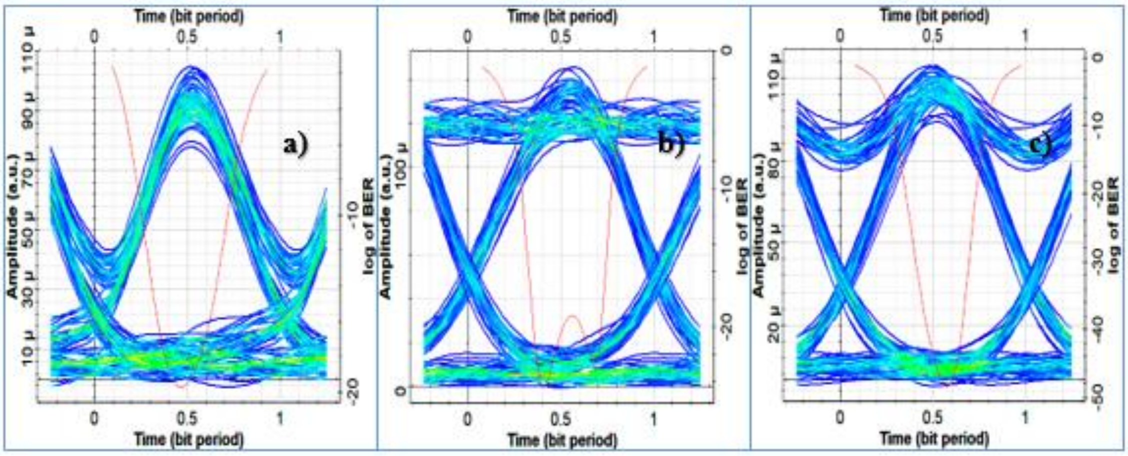
Source: Sabino et al. (2022).

Figure 5 - Eye Diagrams for Pre-Compensation System with RZ (a), NRZ (b) and Gaussian (c) modulation format, respectively and 20 Gbps bite rate.



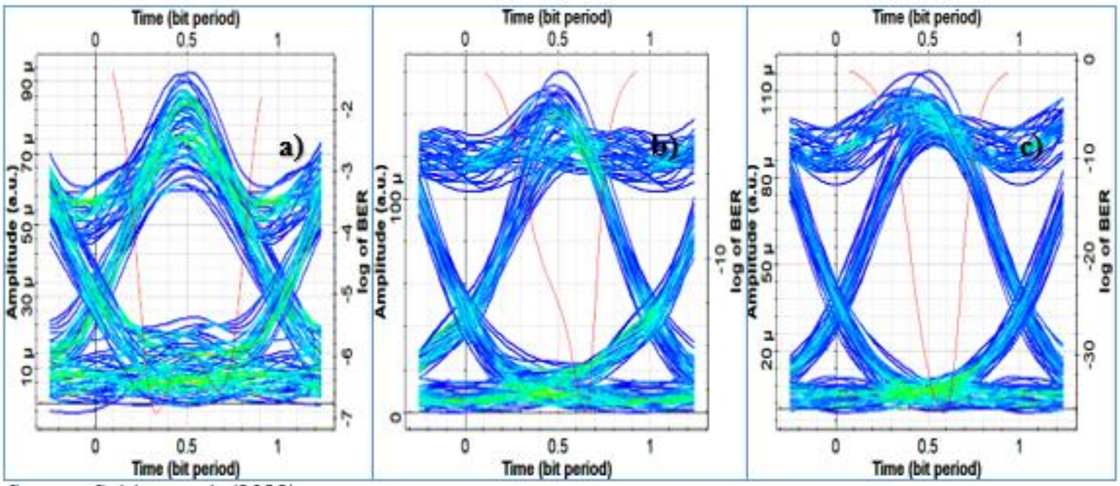
Source: Sabino et al. (2022).

Figure 6 - Eye Diagrams for Pre-Compensation System with RZ (a), NRZ (b) and Gaussian (c) modulation format, respectively and 30 Gbps bite rate.



Source: Sabino et al. (2022).

Figure 7 - Eye Diagrams for Pre-Compensation System with RZ (a), NRZ (b) and Gaussian (c) modulation format, respectively and 40 Gbps bite rate.



Source: Sabino et al. (2022).

3.3 PERFORMANCE RESULTS OF THE DISPERSION POST-COMPENSATION SYSTEM

Figures 8, 9, 10 and 11 present the eye diagrams for the scattering post-compensation system proposed here, where initially a comparison was made of the transmission rates of 10, 20, 30 and 40 Gbps, respectively for the formats of RZ, NRZ and Gaussian modulation, both at an input power of 0 dBm and with 120 km of optical link length. And all Q-Factor and BER results obtained in the simulations are presented in table 3. In the analysis of the results of the simulations of the dispersion post-compensation system, it can be observed that the best performance among the four transmission rates used was the system with NRZ modulation format and with a transmission rate of 10 Gbps, as also shown the eye diagram of figure 9 (b), which obtained Q-factor equal to 19.9 and BER equal to 6.9×10^{-89}.

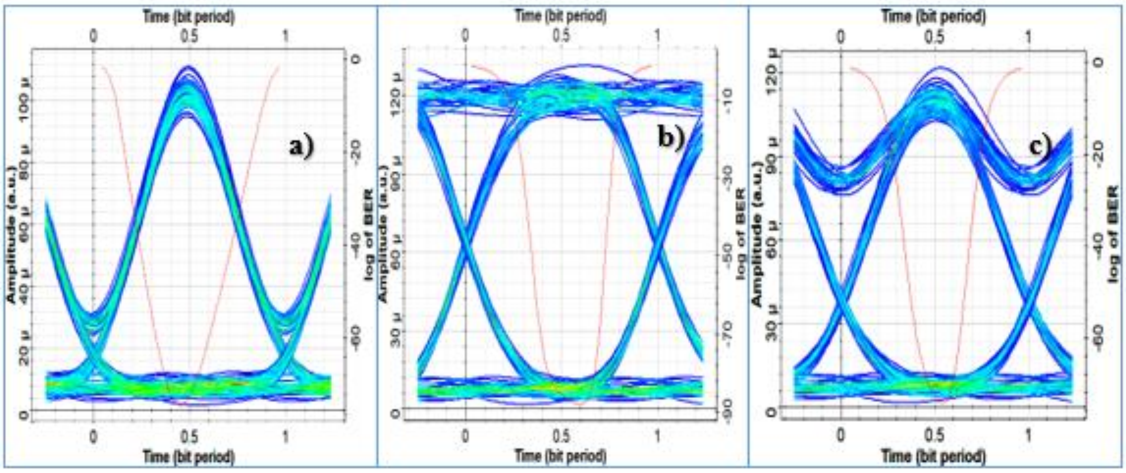
However, the dispersion compensation system with Gaussian modulation again was the one that obtained the best performance results, but for all the baud rates used here, as also shown in Table 3 and the eye diagrams of Figures 8 (c), 9(c), 10(c) and 11(c). In general, most modulation formats used in the dispersion post-compensation system for the baud rates used, obtained excellent performance results, except for the system with RZ modulation and with a baud rate of 40 Gbps, which obtained Q -factor equal to 4.1 and BER equal to 1.7x10-5 which can be considered a poor performance, as shown in the eye diagram of figure 11 (a).

Table 3 Performance of the dispersion post-compensation system with RZ, NRZ and Gaussian modulation formats with transmission rates of 10, 20, 30 and 40 Gbps.

Modulation Format	Parameters	Bit Rate (Gbps)			
		10	20	30	40
RZ	Q-Factor	18.3	9.9	6.7	4.1
	BER	4.2×10^{-75}	8.1×10^{-24}	1.2×10^{-11}	1.7×10^{-5}
NRZ	Q-Factor	19.9	13.2	8.3	6.7
	BER	6.9×10^{-89}	6.1×10^{-40}	3.6×10^{-17}	7.6×10^{-12}
Gaussian	Q-Factor	18.3	13.5	10.1	8.7
	BER	6.4×10^{-75}	6.9×10^{-42}	1.6×10^{-24}	1.5×10^{-18}

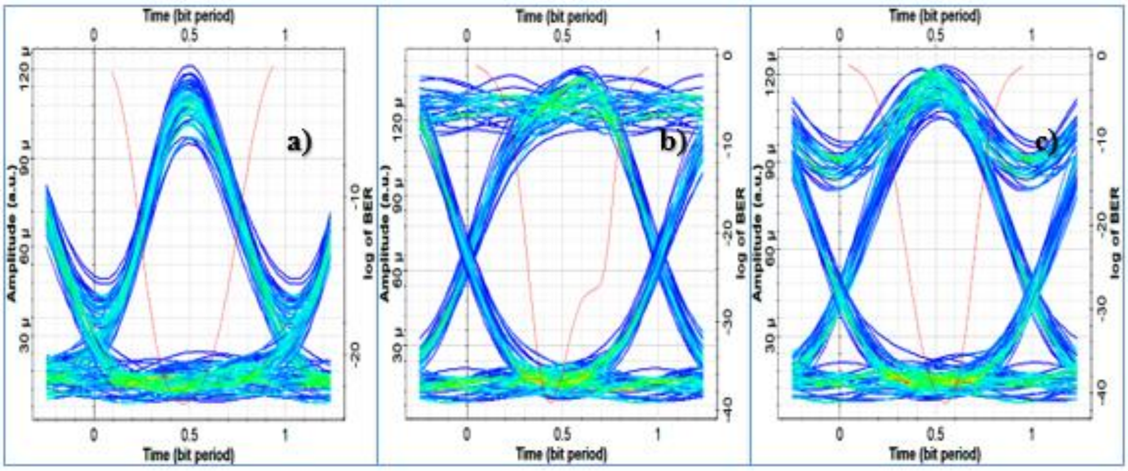
Source: Sabino et al. (2022).

Figure 8 - Eye Diagrams for Post-Compensation System with RZ (a), NRZ (b) and Gaussian (c) modulation format, respectively and 10 Gbps bite rate.



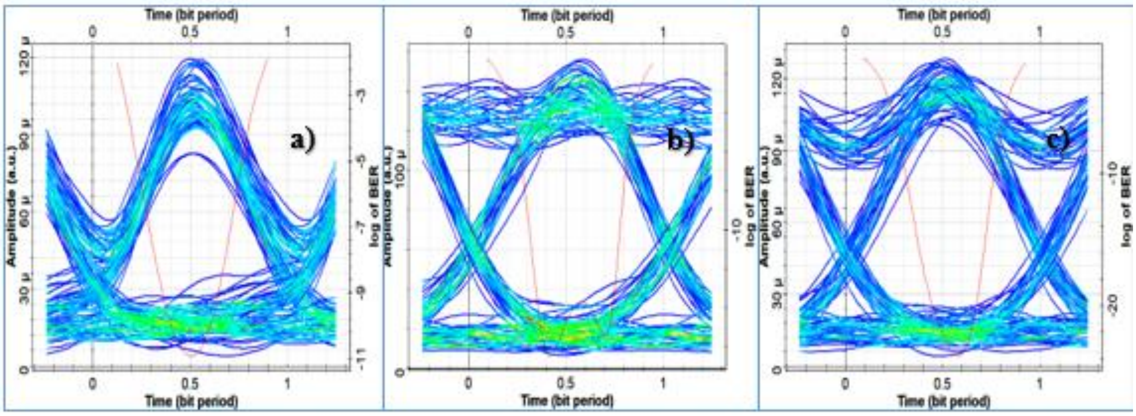
Source: Sabino et al. (2022).

Figure 9 - Eye Diagrams for Post-Compensation System with RZ (a), NRZ (b) and Gaussian (c) modulation format, respectively and 20 Gbps bite rate.



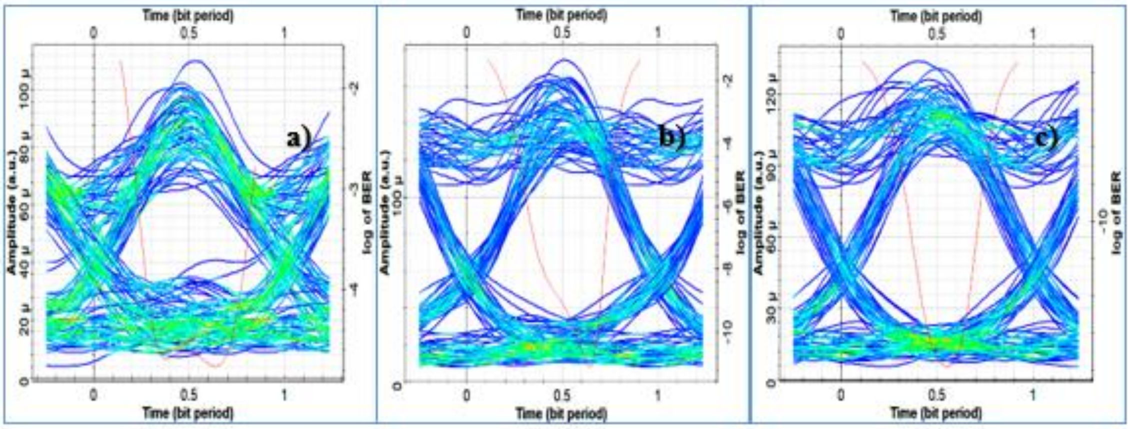
Source: Sabino et al. (2022).

Figure 10 - Eye Diagrams for Post-Compensation System with RZ (a), NRZ (b) and Gaussian (c) modulation format, respectively and 30 Gbps bite rate.



Source: Sabino et al. (2022).

Figure 11 - Eye Diagrams for Post-Compensation System with RZ (a), NRZ (b) and Gaussian (c) modulation format, respectively and 40 Gbps bite rate.



Source: Sabino et al. (2022).

4 CONCLUSION

In this work, two dispersion compensation systems with RZ, NRZ and Gaussian modulation formats were studied, where a 20 km DCF was used for this purpose. The Q factor and BER values were compared and analyzed for transmission rates of 10, 20, 30 and 40 Gbps. It was found that the pre-compensation system obtained higher performance values, so the post-compensation system was considered the best. It is also worth highlighting that the Gaussian modulation format was the one that presented the best performance values in the two dispersion compensation techniques studied here. Therefore, it is expected that the results and projects presented here can serve as references for future work.

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