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Comparison of Chromatic Dispersion Compensation in Optical Fiber with Fiber Bragg Grating (FBG) and Dispersion Compensation Fiber (DCF) for 10 Gbps and 40 Gbps

M.Tosson, Walid S. El-Deeb, A. E. Abdelnaiem

Abstract— This paper analyzes the effect of chromatic dispersion at 10 Gbps and 40 Gbps for 100km distance of optical fiber. In this paper, two different techniques to compensate this kind of dispersion have been introduced; Dispersion Compensation Fiber (DCF) and Fiber Bragg Grating (FBG). The simulation is performed in two different kind of fiber cables; NDSF (G.652) and NZDSF (G.655) using Optisystem (7) Simulator. Different comparison parameters have been considered in this analysis such as Bit error rate (BER), Q-Factor and Eye height.

Index Terms— Bit error rate, Chromatic Dispersion, Dispersion Compensation Fiber, Eye height, Fiber Bragg Gratings, Quality Factor.

1 Introduction

OPTICAL communication system is a transmission of information in the form of optical signal through a fiber cable. The three main optical components are laser diode that convert electrical signal into optical signal at transmitter, fiber cable which acts as a transmission medium and photo detector that converts the optical signal into electrical signal at the receiver. The optical communication system faces many problems as a result of increasing the Bandwidth (B.W) and the distance such as dispersion, attenuation and losses. These problems affect the performance of the optical system and limit its B.W. Several techniques have been proposed to eliminate the problems facing the optical systems. For example, amplifiers have been used to eliminate the effects of attenuation and losses such as Erbium doped fiber amplifier (EDFA) and Raman Amplifier [1].

Dispersion is the main problem affecting the performance of the optical system at high bit rate. Dispersion is the spreading of optical pulses that leads to signal distortion and pulses overlapping with each other. There are two types of dispersion; liner dispersion (chromatic dispersion) and nonlinear dispersion (polarization mode dispersion) [2]. The chromatic dispersion occurs when wavelengths travel at different speeds through the fiber. An optical source emits several wavelengths within a range as in dense wave division multiplexing (DWDM) C-band (1530nm-1565nm) [3]. When these wavelengths travel through a fiber cable, each single wavelength arrives at a different time. Since different wavelengths propagate at different speeds, different arrival times appear at the receiver, which leads to signal distortion. The chromatic dispersion increases as the square of the Bit rate increases [2]. There are two techniques to compensate for this kind of dispersion that will be illustrated in section 2 and 3.

- M. Tosson is currently pursuing master's degree program in Electronics and Communications Engineering, Faculty of Engineering, Zagazig University, Egypt. E-mail: eng.mohamedtosson@hotmail.com
- Walid S. El-Deeb received his PhD dgree from University of Calgary, Canada in 2011. He worked in the iRadio lab, University of Calgary, Canada since 2007 till 2011. Dr. El-Deeb is currently an Assistant Professor at Electronics and Communications Engineering Dept., Faculty of Engineering, Zagazig University, Egypt. E-mail: wseldeeb@zu.edu.eg
- A. E. Abdelnaiem is currently a Professor at Electronics and Communications Engineering Dept., Faculty of Engineering, Zagazig University, Egypt. E-mail: aabdelnaiem@hotmail.com.

2 Dispersion Compensation Fiber (DCF)

The idea of using dispersion compensating fibers (DCF) was proposed in 1980. DCF is a passive element of optical fiber in which the idea of using dispersion compensation fiber depends on inserting a DCF with a negative dispersion value to compensate the positive value in single mode fiber (SMF) so the average of dispersion is approximately zero.
The DCF has the advantages of being more stable, not affected by temperature, wide bandwidth and become a suitable method for chromatic dispersion compensation. There are three positions for inserting DCF; pre-DCF, post-DCF and symmetrical DCF. The pre–DCF is achieved by inserting the DCF at transmitter, the post-DCF is achieved by inserting the DCF at the receiver and the symmetrical DCF is mixing of pre-DCF and post-DCF [4].

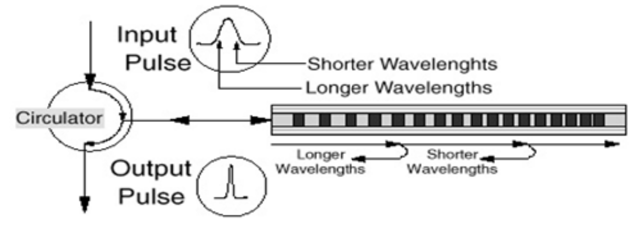

Fig. 1. A Chirped FBG with Circulator principle

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3 Fiber Bragg Grating (FBG)

The FBG can therefore be used as an optical filter to block certain wavelengths. This filter has various applications which improve the quality and reduce the cost of an optical network; there are two types of FBG (uniform FBG and chirped FBG). The principle of uniform FBG depends on a periodic variation of refractive index which can be used as a filter. For chromatic dispersion compensation, it is preferred to use a chirped FBG which depends on non-uniform variation of refractive index. The chirped FBG reflects different wavelengths at different gratings along the FBG length as shown in Fig. (1) [5]. Thus, different delays appear through the FBG according to different wavelengths. The short wavelengths (faster wavelength) arrive faster at FBG and they are reflected with long delay. While, the long wavelengths arrive slower at FBG and they are reflected with short delay. The reflected wavelengths gather at circulator and they are sent to the receiver at the same time, so the dispersion compensation is performed [5, 6].

4 Description of Simulation Setup

In the transmitter side, a Pseudo-Random bit sequence generator used to generate data in two different bit rates; 10Gbps and 40Gbps. The (Non-Return to Zero) NRZ pulse generator is a signal transmitter generates a signal that doesn't return to ZERO. Continuous wave (CW) Laser is used to generate the continuous wave optical signal with 1550nm. Mach-Zehnder modulator to modulate the electrical pulses to optical pulses by extinction ratio 30db with optical output power of 11dbm. The transmission medium length is 100 km with attenuation of 0.25 dbm/km for NDZF and attenuation of 0.185 dbm/km for NZDSF as shown in Table 1.

The receiver side for the first case contains the DCF with length 10 km and dispersion value of -170 ps/nm/km and attenuation of 0.6 dbm as shown in Table 2.

In the receiver side for the second case, the Chirped FBG is used with the characteristics shown in Table 3. A Photo detector converts the optical signal to electrical signal. The low pass Bessel filter to shape the electrical pulses. The 3 types of regenerator are used to regenerate the signal in three stages; re-amplifying the signal's amplitude, re-shaping the pulses(noise reduction) and re-timing the pulses as shown in Fig. (2) and Fig. (3).

Table 1
Simulation parameters for NDSF and NZDSF

Parameters	NDSF	NZDSF
Length	100 km	100 km
Ref. wavelength	1550 nm	1550 nm
Attenuation	0.25 db/km	0.185 db/km
Dispersion value	17.75 ps/nm/km	4.575 ps/nm/km
Dispersion slope	0.085 ps/nm²/km	0.01 ps/nm²/km

Table 2
Simulation parameters for DCF

Parameters	Value
Length	10km
Dispersion	-170 ps/nm/km
Dispersion slope	0.21 ps/nm²/km
Attenuation	0.6 dbm
Length	10km

Table 3
Simulation parameters for FBG

Parameters	Value
Dispersion	-1700 ps/nm/km
Frequency	1550 nm
Depth (max. att. value)	100 db

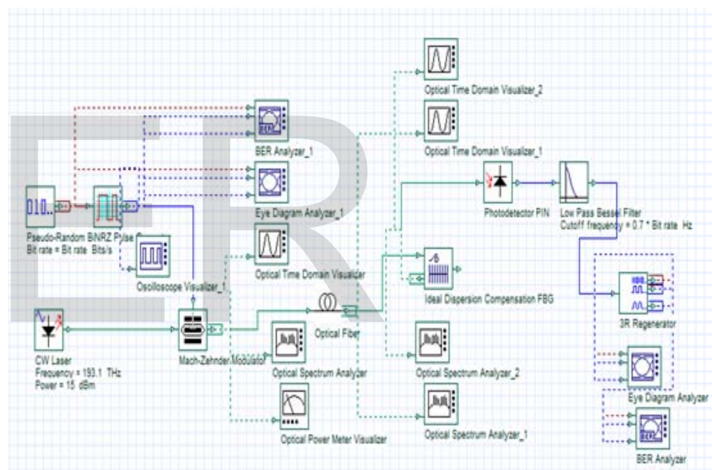

Fig. 2. Simulation model system with FBG

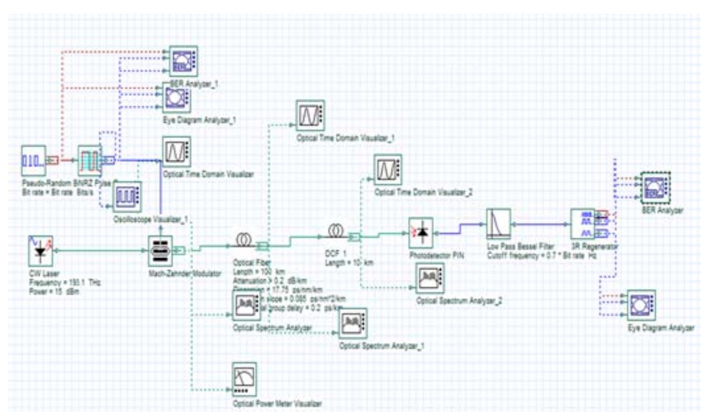

Fig. 3. Simulation model system with DCF

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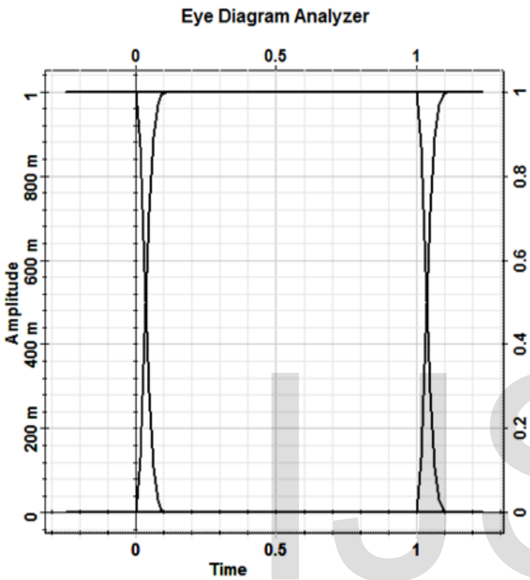
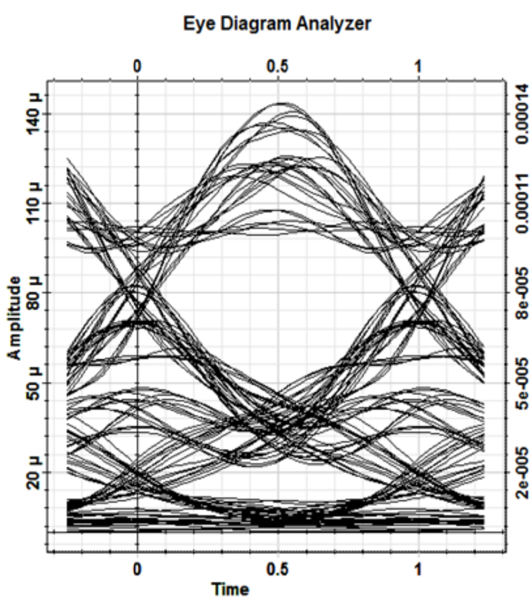
5 Simulation Results and Discussion

5.1 At 10 Gbps without Compensation

Fig. 4(a) and Table 4 show the signal characteristics before travelling with high Q-factor, minimum BER and pulse without dispersion effect at the Mach-Zehnder modulator. Fig. 4(b) and Table 4 describe the signal properties after travelling with the dispersion effect on the pulse, high BER and minimum Q-factor. The results of the two cases are summarized in Table 4 to show the deference between the signals before and after travelling.



(a)



(b)

Fig. 4. (a) Eye diagram of the signal before travelling at Mach-Zehnder Modulator (b) Eye diagram of the signal after travelling 100km without dispersion compensation for 10Gbps

TABLE 4

THE RESULTS OF THE SIGNAL BEFORE TRAVELLING AND AFTER TRAVELLING AT 10 GBPS

	BER	Q-Factor	Eye height
Before travelling	0	$1e^{+50}$	1
After travelling	0.000922142	3.0394	$4.60238e^{-6}$

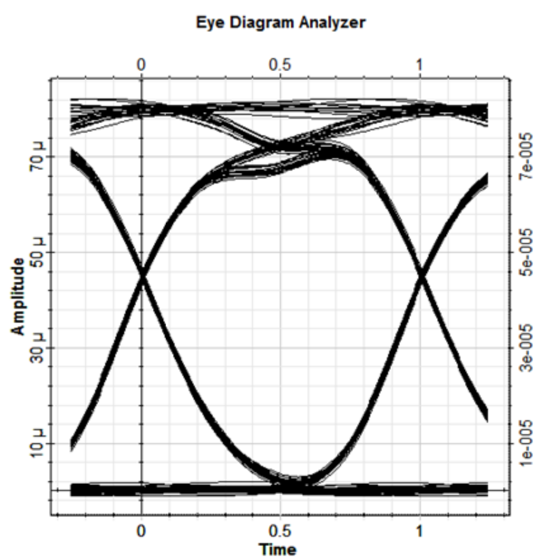
5.2 At 10 Gbps with dispersion compensation

As shown in Fig.5 (a), the pulse after travelling with DCF compensation shows improvement in the BER and Q-factor. Fig.5 (b) shows the effect of dispersion compensation for the same signal using FBG. The result of the two techniques are summarized in Table 5 showing that, the compensation with FBG is giving better results compared to the compensation.

TABLE 5

THE RESULTS AND COMPARISON BETWEEN DCF AND FBG COMPENSATION TECHNIQUES AT 10 GBPS

	BER	Q-Factor	Eye height
DCF	$6.8279e^{-50}$	14.7886	$5.786e^{-5}$
FBG	$5.12055e^{-54}$	15.4069	0.000232697



(a)

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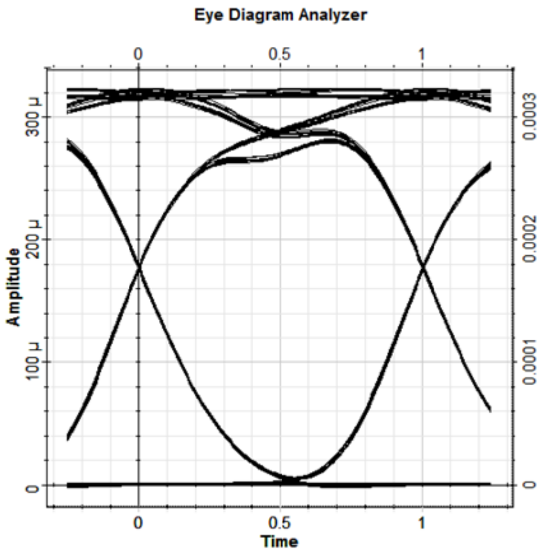


(b)

Fig. 5. (a) Eye diagram of the signal with DCF as the dispersion compensation technique (b) Eye diagram of the signal with FBG as the dispersion compensation technique

5.3 At 40 Gbps without compensation

With the increasing of the bit rate, the chromatic dispersion increases with high BER and minimum Q-factor as shown in Fig. (6) And Table 6.

TABLE 6

THE RESULTS OF THE SIGNAL BEFORE TRAVELLING AND AFTER TRAVELLING AT 40 GBPS

	BER	Q-Factor	Eye height
Before travelling	0	$1e^{+50}$	1
After travelling	1	0	0

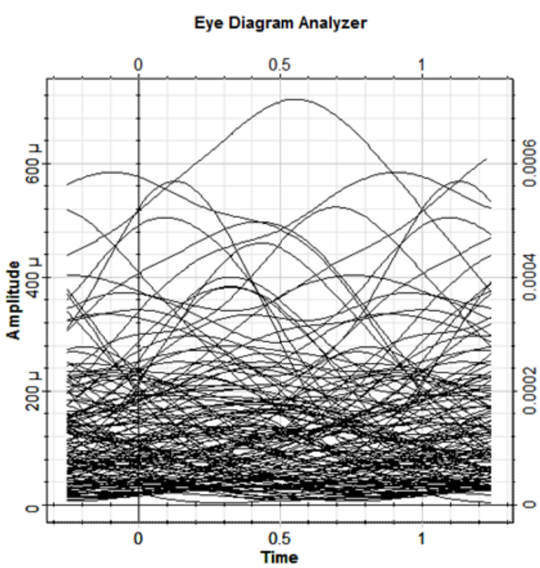


Fig. 6. Eye diagram of the signal after travelling over 100km without Compensation for 40Gbps.

5.4 With dispersion compensation

Fig. 7(a) and Fig. 7(b) show the effect of the dispersion compensation on the signal after travelling using DCF and FBG, respectively. It is clear that, both techniques are capable to solve the problem of chromatic dispersion and to improve overall performance of the optical system. The results of the two techniques are summarized in Table 7 showing that, the FBG technique is still better than the DCF technique.

TABLE 7

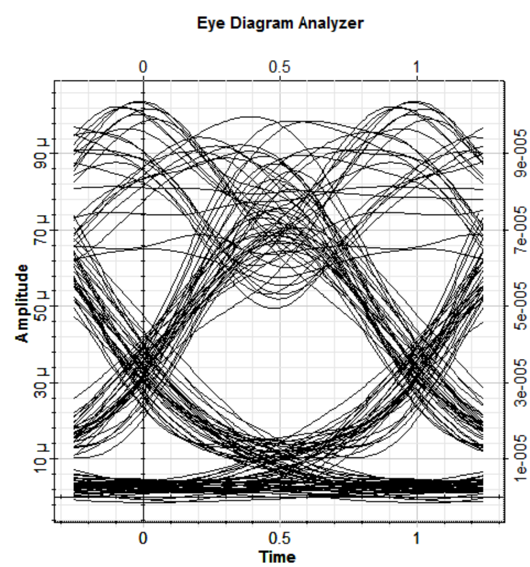
THE RESULTS AND COMPARISON BETWEEN DCF AND FBG TECHNIQUES FOR NDSF CABLE AT 40 GBPS

	BER	Q-Factor	Eye height
DCF	$8.40577e^{-6}$	4.27479	$1.95026e^{-5}$
FBG	$5.53789e^{-6}$	4.3676	$8.06416e^{-5}$

TABLE 8

THE RESULTS AND COMPARISON BETWEEN DCF AND FBG TECHNIQUES FOR 40GBPS WITH NZDSF CABLE

	BER	Q-Factor	Eye height
DCF	$1.82056e^{-16}$	8.14321	0.000151497
FBG	$3.26197e^{-17}$	8.34838	0.000237986



(a)

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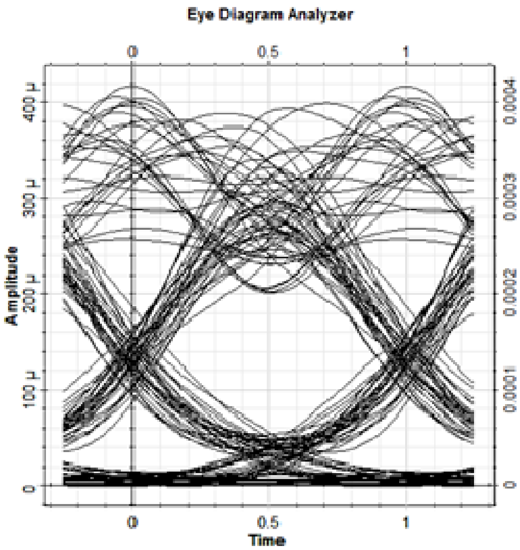


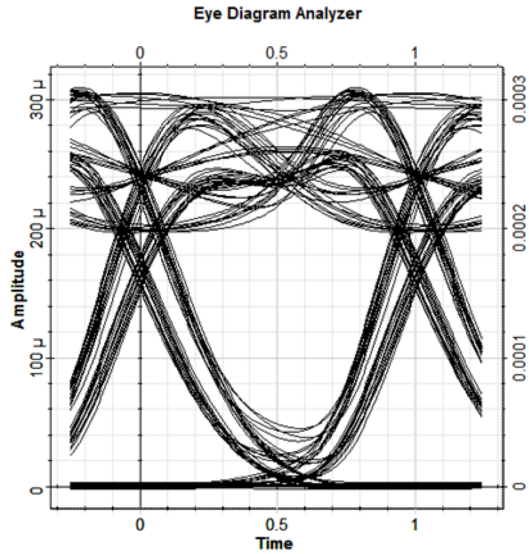
(b)

Fig. 7. (a) Eye diagram of the signal with DCF as the dispersion compensation (b) Eye diagram of the signal with FBG as the dispersion compensation technique

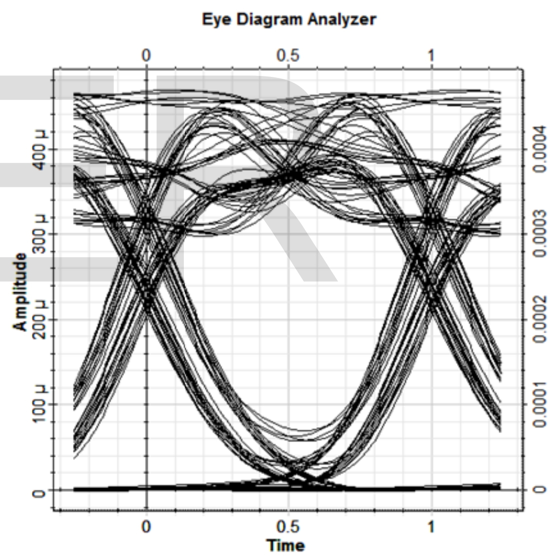
Studying the results shown in the above figures and tables, it is obvious that, the signal distorted at high bit rate and this kind of distortion can be compensated using either FBG or DCF at 10 Gbps with NDSF fiber cables. As the rate increased to 40 Gbps, the chromatic dispersion increases subsequently affecting the BER and the Q-factor. The two compensation techniques still applicable but the BER and the Q-factor do not reach the desired values with the NDSF cables. So, it is recommended to use NZDSF cables with this high bit rate (40 Gbps) to give better results with the FBG and DCF compensation techniques. Fig. 8 and Table 8 show the improvement of the BER, the Q-factor and the shape of the signal using NZDSF cable with the FBG and DCF compensation techniques.

6 Conclusion

In this paper the effect of chromatic dispersion appears at high bit rate 10 Gbps and intensely at 40 Gbps in the transmitted signal, which leads to signal distortion and overlapping. The dispersion increases as the bit rate increase as shown in 40Gbps case. Two different techniques have been applied to compensate for the chromatic dispersion using DCF and FBG with NDSF and NZDSF cables. It has been observed that the FBG is better than DCF at 10 Gbps and 40 Gbps to compensate for this kind of distortion. To improve the performance at 40 Gbps, it is recommended to use NZDSF (G.655) with FBG compensation technique to improve the signal quality. This system is analyzed without using any amplifiers but with high power signal.



(a)



(b)

Fig. 8: (a) Eye diagram of the signal with DCF as the dispersion compensation technique with NZDSF cable (b) Eye diagram of the signal with FBG as the dispersion compensation technique with NZDSF cable

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