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Dispersion Compensation Techniques for DWDM Optical Networks

M.Tosson[1], Walid S. El-Deeb[2], A. E. Abdelnaiem[3]

Telecom, Egypt[1]

Department of Electronics and Communication, Zagazig University, Zagazig, Egypt[2,3]

Abstract: Dense Wavelength Division Multiplexing (DWDM) is a promising technology introduced to enhance the channel capacity and increase the bandwidth of the optical fiber communication system. The DWDM technology is based on sending multiple information channels with different wavelengths on a single fiber cable. With high-speed transmission and long distance cables, the information signal faces undesired kind of dispersion called chromatic dispersion. This paper presents two different techniques using Fiber Bragg Grating (FBG) and Dispersion Compensation Fiber (DCF) to compensate for such kind of dispersion. This study has been performed and simulated using Optisystem7 tacking many parameters into consideration such as; Bit Error rate (BER), Quality factor (Q-factor) and Eye height. The simulation has been performed for bit rate of 40 Gbps and cable length of 150 Km.

Keywords: Bit error rate (BER), Chromatic dispersion, DCF, EDFA, FBG, NDSF, NZDSF Q-Factor.

I. INTRODUCTION

The rapid development in telecommunication system and the speed limitation for single wavelength have led to increase of using the DWDM technology. DWDM depends on multiplexing and transmitting different channels with different wavelengths onto a single fiber link at the same time [1]. Each channel is transmitted with bit rate starting from 2.5 Gbps up to 100 Gbps with different wavelengths to prevent interference between the channels [1]. The DWDM can transmit different protocols simultaneously so DWDM is transparent to the incoming signals [1].

For DWDM, The number of channels in DWDM can reach up to 128 channels depends on the channel spacing. The common channels spacing may be 200, 100, 50, 25 Giga Hertz. For the Huge DWDM bandwidth, the DWDM used in the design of metro and backbone optical network and in the different topology network such as ring topology and mesh topology which provide more protection for transmitted data[2].

At the receiver, the DWDM de-multiplexer separates the received signal to the different wavelengths and each wavelength is sent to its receiver port. DWDM system needs optical amplifier to amplify the optical signal. Erbium Doped Fiber Amplifier (EDFA) is one of these amplifiers that can be used for this purpose. The principle of EDFA depends on using doped optical fiber to give a medium gain to amplify the optical signal [3]. The signal to be amplified and a pump laser are multiplexed into the doped fiber and the optical signal is amplified through the interaction with the doping ions [3].

Because of high bit rate and long distance there are many kinds of optical signal distortion. The chromatic dispersion (CD) and the polarization mode dispersion (PMD) appear as liner effects. The four wave mixing (FWM), the cross-phase modulation (XPM), the self-phase modulation (SPM) and the stimulated Raman scattering (SRS) appear as nonlinear effects [4]. The Chromatic dispersion appears when many wavelengths travel through a fiber cable and 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 [5].

The chromatic dispersion increases as the square of the Bit rate increases so the chromatic dispersion of 40 Gigabits per second increases by a factor of 16 compared to 10 Giga bits per second [6].

In this paper, a comparative study between DCF and FBG as two different techniques to compensate for this kind of dispersion, will be introduced.

II. DISPERSION COMPENSATION TECHNIQUES FOR DWDM SYSTEM

A. Dispersion Compensation Fiber (DCF)

DCF is used to improve the optical transmission quality. The standard fiber cable, whose chromatic dispersion value is positive during transmission, is followed by a DCF whose dispersion value is negative to compensate for the dispersion value as shown in Fig. (1) [7].

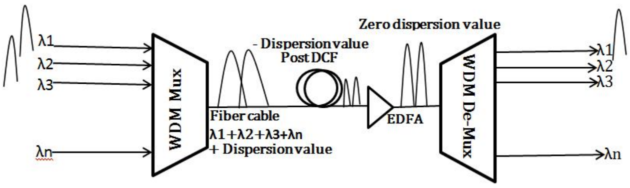

Fig.1. Principle of DCF [7]

B. Fiber Bragg Grating (FBG)

In the normal optical fiber, the refractive indices of the core and the cladding don't change along the length of the fiber. In the Fiber Bragg grating the refractive indices vary along the length of the fiber, which leads to the scattering of the propagating signal. In a uniform FBG the period of the refractive index variation is constant along the length

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of the grating. If the period of the grating varies along its length, this is referred to as a chirped fiber Bragg grating. Chromatic dispersion is compensated by chirped fiber Bragg grating. Wavelengths will get reflected at different positions along the grating; this will lead to different wavelength having different time delays. The chirped FBG with circulator can compensate for the differential delay of different wavelengths accumulated while propagating through an optical fiber link as illustrated in Fig. (2) [8].

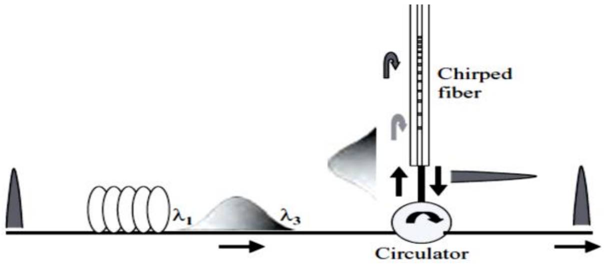

Fig. 2. A Chirped FBG with Circulator principle [8]

III. SIMULATION SETUP

The transmitter side consists of DWDM transmitter with 8 channels at different wavelengths starting from 1552.52nm to 1546.91nm, with channel spacing of 0.8nm and optical channel power of 10dbm. Channel bit rate is 40Gbps, with non-return to zero (NRZ) line modulation type. The transmission medium length is 150 km with attenuation of 0.25 dBm/Km for NDSF and 0.185 dBm/Km for NZDSF as described in Table 1.

TABLE 1: SIMULATION PARAMETERS FOR NDSF AND NZDSF

Parameters	NDSF	NZDSF
Length	150 Km	150 Km
Ref. wavelength	1550 nm	1550 nm
Attenuation	0.25 dB/Km	0.185 dB/Km
Dispersion value	16.75 ps/nm/Km	4.575 ps/nm/Km
Dispersion slope	0.085 ps/nm^2/Km	0.01 ps/nm^2/Km

The receiver side for the DCF compensation technique contains the DCF with length of 10 Km and dispersion value of -251.25 ps/nm/Km and attenuation of 0.6 dBm with EDFA amplifier with power of 10dBm as illustrated in Table 2.

TABLE 2: SIMULATION PARAMETERS FOR DCF

Parameters	Value
Length	10Km
Dispersion	-251.25 ps/nm/Km
Dispersion slope	0.21 ps/nm^2/Km
Attenuation	0.6 dBm

In the receiver side for FBG compensation technique, the FBG is used for each individual channel with the characteristics shown in Table 3. A Photo detector converts the optical signal to electrical signal which contains low pass Bessel filter to shape the electrical pulses and the 3R regenerator to re-shaping, re-timing and re-amplifying the received signal.

TABLE 3: SIMULATION PARAMETERS FOR FBG

Parameters	Value
Frequency	193.1 to 193.8 GHz
Bandwidth	125GHz
Dispersion	-2512 ps/nm/Km

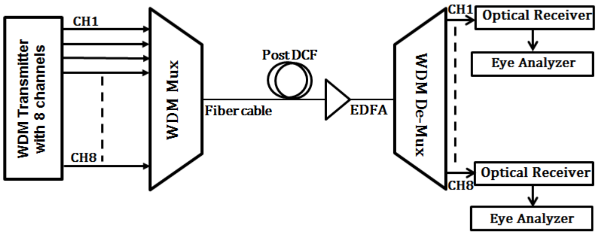

Fig. 3. Block diagram of DWDM compensation technique with DCF

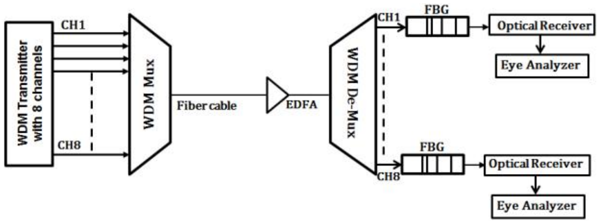

Fig. 4. Block diagram of DWDM compensation technique with FBG

Figs. 3 and 4 describe the block diagrams of the two applied compensation techniques using DCF and FBG, respectively, this blocks diagram show when using DCF compensation we insert one DCF at receiver before DE-multiplexing for WDM link; when using FBG we insert FBG per channel after DE-multiplexing to compensate. Figs. 5 and 6 illustrate the simulation models for the two techniques using Optisystem7.

IV. DISCUSSION OF THE SIMULATION RESULTS

A. Without Compensation: Fig. 7(a) and Table 4 describe the signal at optical transmitter with high Q-factor and minimum BER. Fig. 7(b) and Table 4 describe the signal at receiver with the dispersion effect with high BER and minimum Q-factor, which becoming unacceptable at optical receiver so that the chromatic dispersion should be compensated to improve the signal quality.

TABLE 4: THE RESULTS OF THE SIGNAL AT THE TRANSMITTER AND THE RECEIVER

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

TABLE 5: THE RESULTS FOR CHANNELS 1, 4, 6 AND 8 WITH DCF COMPENSATION TECHNIQUE USING NDSF

Channel	BER	Q-Factor	Eye height
CH1	1.95547e^{-13}	7.23979	0.00255579
CH4	7.11335e^{-12}	6.73654	0.002859901
CH6	5.87583e^{-11}	6.41305	0.00297069
CH8	4.26842e^{-13}	7.14028	0.00356108

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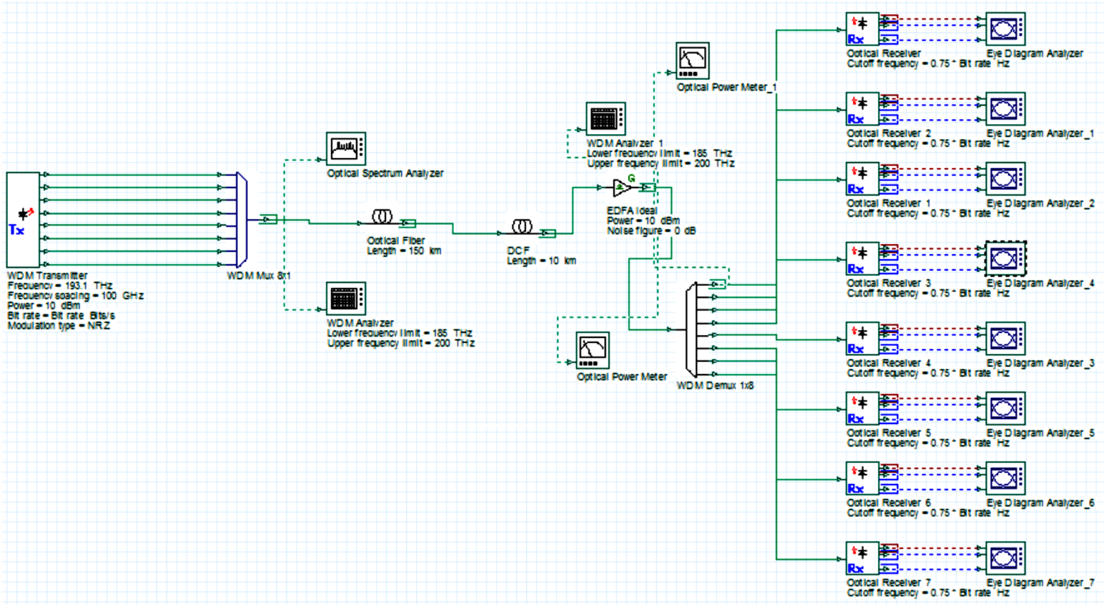

Fig. 5. DWDM Simulation model for the compensation technique with DCF

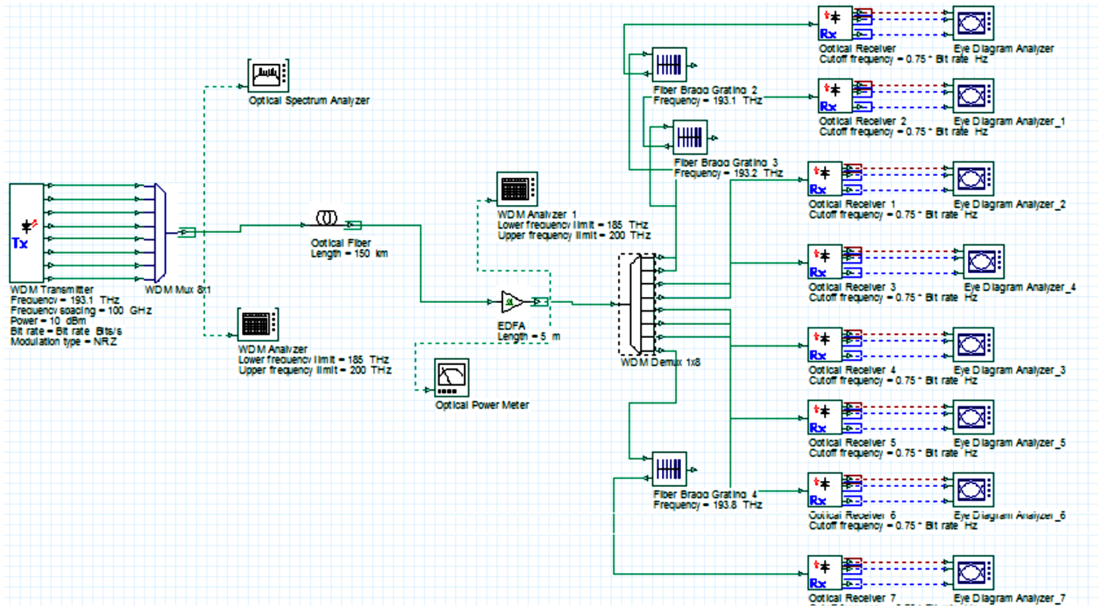

Fig.6. DWDM Simulation model for the compensation technique with FBG

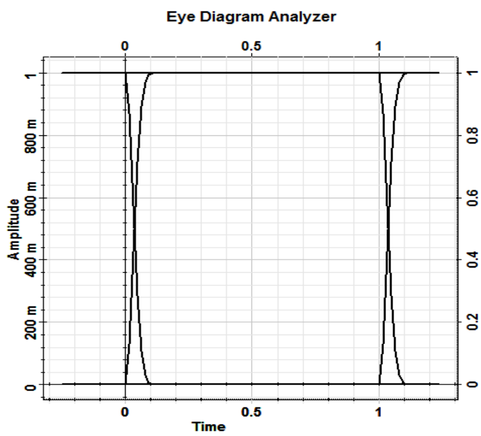

Fig. 7. (a) Eye diagram of the signal at the optical transmitter

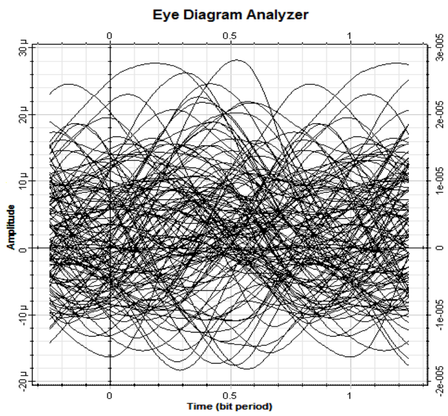

FIG. 7. (b) Eye diagram of the signal at the optical receiver without dispersion compensation

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B. Dispersion compensation fiber (DCF) with NDSF:

Fig. 8 illustrates the pulse with DCF compensation with improvement in the BER and Q-factor for channel 1 and 8. The results of the selected four channels are summarized in Table 5.
The above results prove that DCF with NDSF improve the distorted transmitted signal and make acceptable at the receiver.

TABLE 6: THE RESULTS FOR CHANNELS 1, 4, 6 AND 8 WITH FBG COMPENSATION TECHNIQUE USING NDSF

Channel	BER	Q-Factor	Eye height
CH1	$2.92877e^{-41}$	13.3866	0.00749634
CH4	$1.49351e^{-28}$	10.9816	0.0069173
CH6	$5.7676e^{-30}$	11.2803	0.00733586
CH8	$9.9203e^{-23}$	9.72884	0.00757526

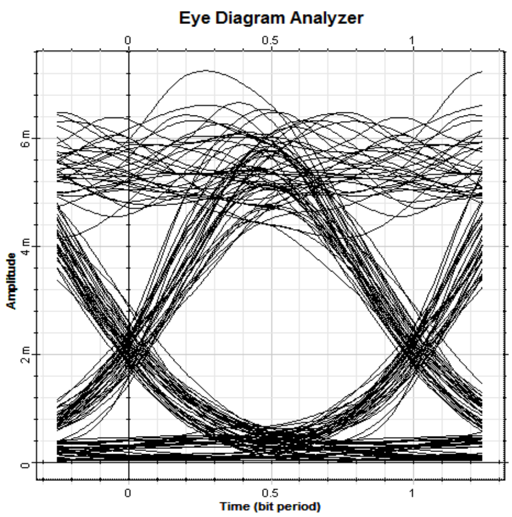

Fig. 8. (a) Eye diagram of the channel l with DCF as the dispersion compensation technique using NDSF

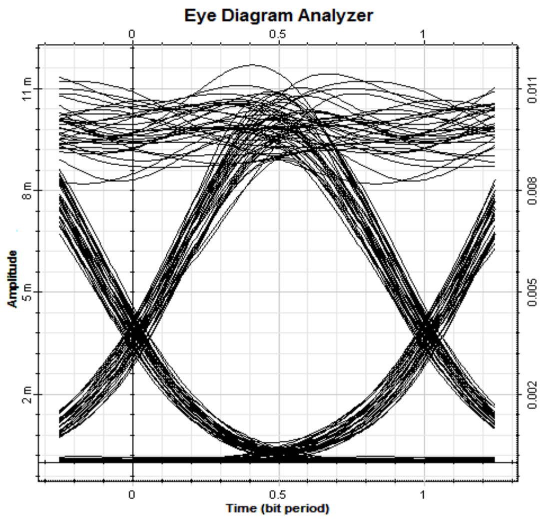

Fig. 9. (a) Eye diagram of the channel l with FBG as the dispersion compensation technique using NDSF

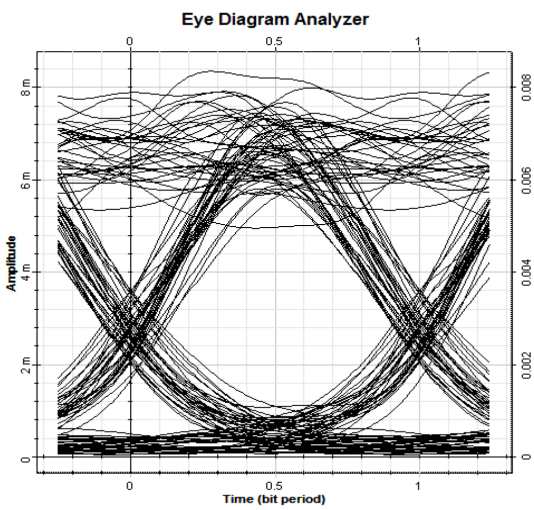

Fig. 8. (b) Eye diagram of the channel 8 with DCF as the dispersion compensation technique using NDSF

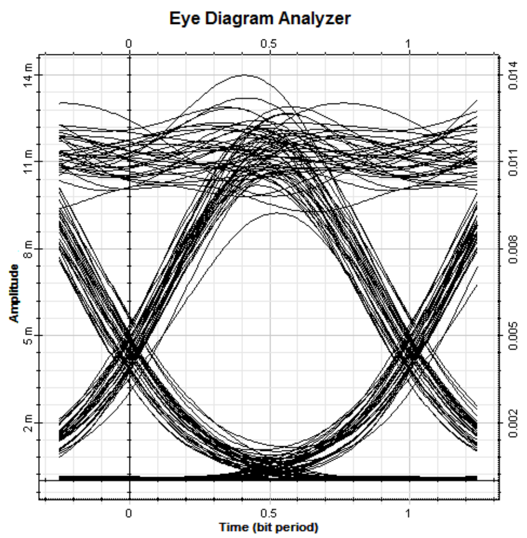

Fig. 9. (b) Eye diagram of the channel 8 with FBG as the dispersion compensation technique using NDSF

C. Fiber Bragg Grating (FBG) with NDSF:

Fig. 9 and Table 6 illustrate the effect of Fiber Brag Grating as dispersion compensation technique, showing the high improvement in BER and Q-factor for WDM channels compared to that using DCF by inserting one FBG per each channel.

D. Dispersion Compensation Fiber (DCF) with NZDSF:

For more quality signal improvement, the fiber cable NDSF can be replaced with NZDSF and by with DCF. Fig.10 and Table 7 show the results with the new conditions. The BER and Q-factor improved and became more and more acceptable at receiver and the overall system has become more stable.

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TABLE 7: THE RESULTS FOR CHANNEL 1, 4, 6 AND 8 WITH DCF COMPENSATION TECHNIQUE USING NZDSF

Channel	BER	Q-Factor	Eye height
CH1	$3.304e^{-23}$	9.83685	0.00461108
CH4	3.6858e-^{17}	8.33059	0.0046624
CH6	$5.00461e^{-15}$	7.7271	0.0045943
CH8	$3.8943e^{-21}$	9.34726	0.00539014

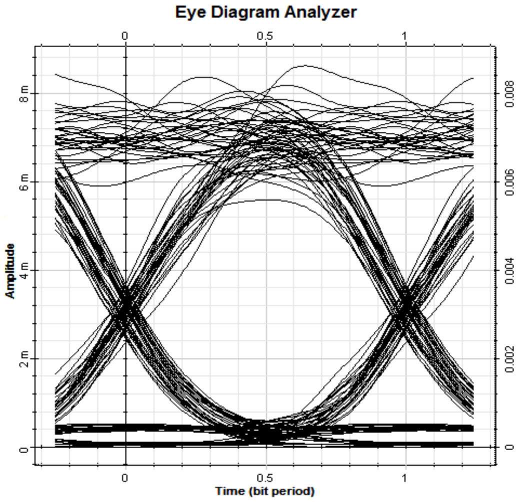

Fig. 10. (a) Eye diagram of the channel l with DCF as the dispersion compensation technique using NZDSF

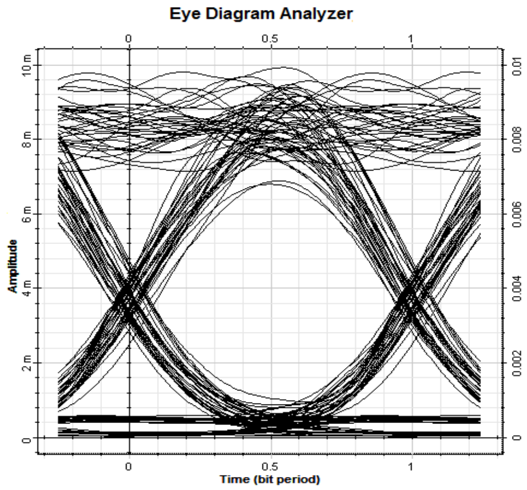

Fig. 10. (b) Eye diagram of the channel 8 with DCF as the dispersion compensation technique using NZDSF

E. Fiber Bragg Grating (FBG) with NZDSF:

Table 8 and Fig. 11 illustrate the BER and Q-factor values after FBG compensation by using NZDSF. The system has become more stable compared to that using with the same compensation technique.

TABLE 8: THE RESULTS FOR CHANNEL1, 4, 6 AND 8 WITH FBG COMPENSATION TECHNIQUE USING NZDSF

Channel	BER	Q-Factor	Eye height
CH1	6.7851e-80	18.8734	0.0090241
CH4	5.6946e-65	16.9629	0.00927639
CH6	2.34655e-55	15.6064	0.0092586
CH8	9.13022e-58	15.9645	0.00937589

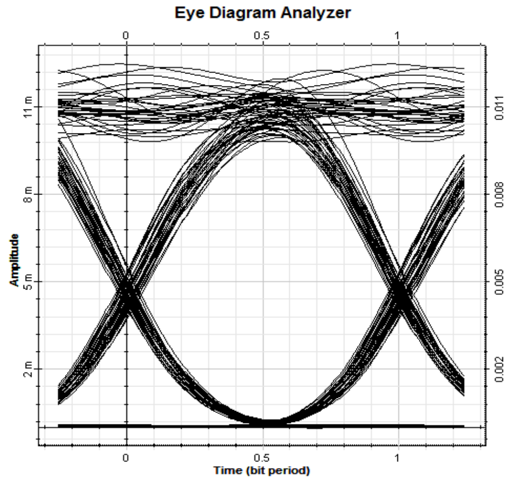

Fig. 11. (a) Eye diagram of the channel l with FBG as the dispersion compensation technique using NZDSF

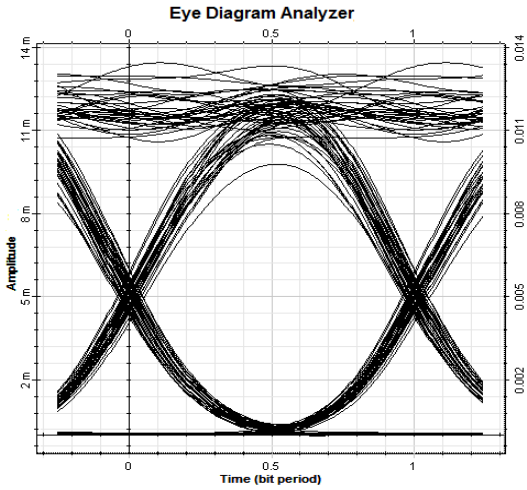

Fig. 11. (b) Eye diagram of the channel 8 with FBG as the dispersion compensation technique using NZDSF

V. CONCLUSION

WDM system provides high Bandwidth for the long telecommunication links. Many problems affect on the performance and the quality of the transmitted optical signal. One of these problems is a chromatic dispersion which leads to the overlapping of the signals with each other and cause inter symbol interference (ISI), which leads to unacceptable signal at the receiver. In this paper, two different techniques, using DCF and FBG, have been introduced to compensate for the chromatic dispersion. The techniques have been applied on the optical system with two different optical cables, NDSF and NZDSF.

The simulation results show that, the FBG with the two different cables shows better results compared to DCF but it is not practical with DWDM. This is because with FBG technique it is required to insert FBG for each channel separately after WDM de-multiplexer to compensate for the dispersion, which increases the cost of building the DWDM system using FBG as compensation technique. So it is recommended to use DCF compensation technique with the DWDM optical network.

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The results also illustrates that, the NZDSF optical link gives better results in the BER and Q-factor compared to NDSF optical link. Therefore, the NZDSF links are preferred to improve the overall performance and quality of the DWDM optical systems.

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BIOGRAPHIES

M.Tosson got the BSc in electronics and communications engineering from the University of Zagazig, Egypt, in 2000. He joined to TelecomEgypt Company as a Transmission Operation and Maintenance Senior Engineer up to date. He took the WDM course in Alcatel-lucent University in France. Currently, he is pursuing the master's degree program in Electronics and Communications Engineering from the University of Zagazig, Egypt.

Walid S. El-Deeb received the M.Sc. degree in electronics and communications engineering from the University of Zagazig, Egypt, in 2004. He joined iRadio lab, University of Calgary, Calgary, Canada as PhD student and research and teaching assistant in Jan. 2011. He received his PhD in Electrical and Computer Engineering from University of Calgary in Mar 2011. Dr. El-Deeb worked as Post-Doctoral Fellow in University of Calgary till Aug. 2011. He is currently an Assistant Professor with the Department of Electronics and Communications Engineering, Faculty of Engineering, Zagazig University, Egypt.

A. E. Abdelnaiem received his PhD degree from USSR, Leningrad on 1978. He worked as the head of Electronics and Communications Engineering Department from 1998 up to 2001. Dr. Abdelnaiem is currently a Professor at the Department of Electronics and Communications Engineering, Faculty of Engineering, Zagazig University, Egypt.