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Performance Investigation of Different Dispersion Compensation Methods in Optical Fiber Communication

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Authors' contributions

This work was carried out in collaboration among all authors. Author MBH designed the study, wrote the protocol and wrote the first draft of the manuscript. Author AA managed the simulation analysis. Author TZK managed the literature searches. The final manuscript is read and approved by all authors.

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ABSTRACT

In optical fiber Communication system dispersion compensation has become one of the major topics of importance and research nowadays. This is because any presence of dispersion might leads to pulse spreading which might cause inters symbolic interference (ISI) and which leads to signal degradation. In this paper six different model are considered for dispersion compensation. Dispersion compensation fiber (DCF) is used to design first three models by using its three different configurations of pre-compensation, post-compensation, symmetrical compensation and Fiber Bragg Gratings (FBG), uniform FBG, IDCFBG are used for designing rest of three dispersion compensation models. Single channel optical system length of 100 km with data rate of 2.5 Gbps and 10 Gbps is used to design each model and is simulated by using optisystem software package. All the designs are compared with respect to the quality factor (Q-factor) and bit error rate (BER). With the outcome of the simulations results it is seen that post–compensation DCF model is the promising approach.

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Keywords: Fiber Bragg Gratings (FBG); Dispersion Compensation Fiber (DCF); Q-factor; BER; dispersion; IDCFBG.

1. INRTODUCTION

When an information carrying signal is transmitted over the optical fiber communication system some losses occurs due to distortion, attenuations, dispersion, absorptions etc [1]. One of the foremost limiting factors in fiber optic communication which accounts for the degradation in the performance is dispersion. When optical pulses are travels through single mode fiber a broadening of optical pulse is observed due to the dispersion. With the increment of data rate, these broaden pulses may overlap with each other causing inter symbolic interference and crosstalk which causes errors during reception of the signal at the receiver side of optical link [2]. In single mode fiber chromatic dispersion and polarization mode dispersion are the main reason for occurring dispersion [3]. The reason for chromatic dispersion is the dependence of refractive index and hence the group velocity of silica on the wavelength used for data transmission [4]. Erbium Doped Fiber Amplifier (EDFA) can be used to compensate dispersion in a optical fiber [1]. DCF and FBG are other techniques which can be used for compensation of dispersion in optical fiber link. In order to compensate dispersion, a very high negative dispersion coefficient in a narrow band frequency is required by the DCF [5]. The information signal which enters the grating is reflected back at different distances inside of the grating in FBG. Signal with larger wavelength travels a longer distance inside the grating before reflection and the signal having smaller wavelength travels shorter distance in grating before reflection. As a result of this the pulse at input of the FBG is compressed at the output and hence dispersion is compensated by the FBG [6]. Electronic Equalizer and Digital Filters are also used for dispersion compensation. In this paper investigation has been done on three configuration (pre, post and symmetrical) of DCF and also for uniform FBG, FBG and IDCFBG model. Our main objectives are to find a best dispersion compensation model among the six pre specified dispersion compensation model. Since it is very difficult and costly to experiment in real environment. We use optisystem software to design each of the six model and simulate each model to examine the performance of each model from the simulation results. A fiber optic length of 100 km with dispersion 17 ps/nm-km and DCF length of 10 km with dispersion -170 ps/nm-km is used for designing each DCF model. The frequency and bandwidth of 193.1 THz and 125 GHz are used in uniform FBG. The linear chirp function represents the best behavior and leads to efficient research of FBG [7]. Tanh is used as apodization function and a 6mm length of grating is used for designing FBGs model. For Ideal dispersion compensation FBG a dispersion of -1700 ps/nm-km is considered for simulation. The organization of rest of the paper is as follows; in section 2, the dispersion compensating technique and related works are discussed in detail. Experimental details are described in section 3. The results and discussion is discussed in section 4 and section 5 presents conclusion of the paper.

2. DISPERSION COMPENSATION TECHNIQUES

Due to inter symbolic interference the data rate cannot be increase of the fiber optic communication link beyond a certain limit. As a result dispersion is a controlling factor on data rate of fiber optic communication link. In order to achieve high data rates, dispersion compensation is the most important prerequisite in fiber optic communication link. Dispersion Compensating Fiber (DCF), Fiber Bragg Gratings (FBG), Electronic Dispersion Compensation (EDC) and Digital Filters are most available techniques in literature for dispersion compensation [3].

2.1 Dispersion Compensating Fiber

The basic idea of dispersion compensation using DCF is to use a large negative dispersion values with the standard one. The amount of light dispersed by a normal fiber in reduced or in some case nullified by using a dispersion compensating fiber having a very large value of dispersion of opposite sign as compared to that of standard fiber [6]. There is a relationship between the negative dispersion of the DCF and the positive dispersion of the standard single mode optical fiber (OF) the net dispersion will be zero:

$$D_{OF}\times L_{OF} = - D_{DCF}\times L_{DCF} \tag{1}$$

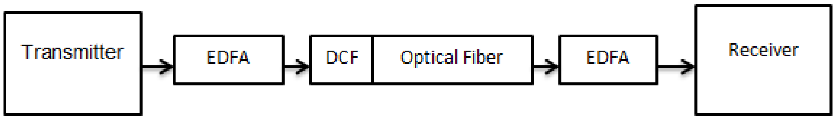
Where, D is the dispersion and L is length of each fiber Segment [8]. Generally three schemes can be used to design a dispersion compensating fiber-pre, post or symmetrical compensation model [3]. In pre compensation technique DCF is placed in the loop before the standard mode fiber as shown in Fig. 1(a). DCF is placed in the loop after the standard fiber as depicted in Fig. 1(b) in post compensation technique and in symmetrical compensation DCF is placed both before and after the standard mode fiber as shown in Fig. 1(c) [9].

2.2 Fiber Bragg Gratings

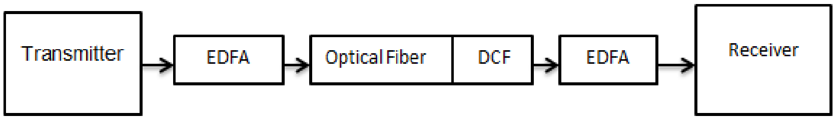
FBG is one of the most popular dispersion compensation techniques nowadays. The periodic perturbation of refractive index of the core of optical fiber along its length formed by exposure to an intense optical interference pattern is Fiber Bragg grating. The formation of permanent gratings in an optical fiber was first demonstrated by Hill et al. in 1978 at the Canadian Communications Research Centre (CRC), Ottawa, Ont., Canada [10]. The principle behind FBG is reflecting wavelengths that satisfy the bragg condition and transmitting the desired wave lengths. The unwanted wave length selected by changing the grating period. Therefore, FBG is a low-cost filter for wave length selection [2]. Fig. 2 shows the basic principle of FBG. The equation relating the grating periodicity, bragg wave length (λ_b) and effective refractive index of the transmission medium is given by:

$$\lambda_b = 2n\Delta \tag{2}$$

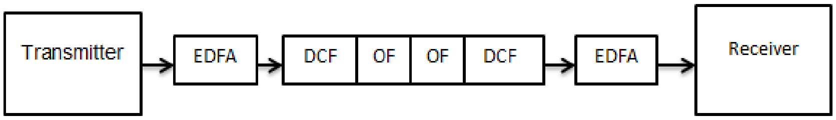
Where Δ is the grating period and n is the effective refractive index of the grating in the fiber core. The main advantage of utilizing Fiber Bragg Grating as technique to compensate dispersion is that it requires a very less space and has a low value of insertion loss and they are compatible with single mode fiber and are very cost effective. FBG also find its application in different field such as WDM add/drop filters, pump lasers and wavelength stabilizers [3].



a) Pre-Compensation



b) Post-Compensation



c) symmetric-Compensation

Fig.1. Different DCF compensation model

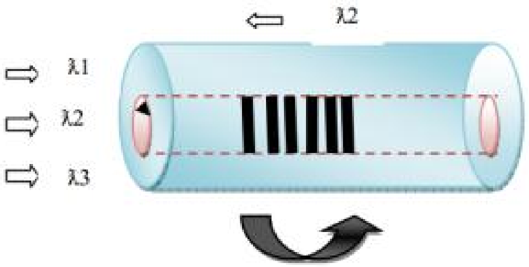


Fig. 2. Principle of fiber bragg gratings [11]

In uniform fiber Bragg grating unvarying grating periods are used [12]. Uniform means grating period and refractive index are constant throughout the length of grating. Ideal dispersion compensation (IDCFBG) is also known as chirped grating. In this type of FBG there is additive fluctuation in the grating period. It has an advantage of large chip parameter which causes decrease in reflection power [13]. In general case of FBGs model linear chirp function and Tanh as apodization function are used. The performance of Pre, Post and symmetrical configuration of DCF and FBG for high speed data rate is analyzed in A. Sharma et al. [14]. In Ali, Ameer et al. [7] they used different length of gratings in FBG and find a optimum length for best performance and compare DCF and FBG for dispersion compensation. Mehtab Singh [1] analyzed the performance of pre, post and symmetrical compensation of DCF for 2.5 Gbps data speed. Singh et al. [15] they used DCF to compensate the dispersion of the signal. Three different compensation methods were used pre-post and symmetric compensation was simulated in [15].

3. EXPERIMENTAL DETAILS

The implementation of dispersion compensation in optical communication using Optisystem 13.0 software for single channel is described in this section. Different dispersion compensation techniques of various configuration of DCF (pre-compensation, post-compensation, and symmetrical compensation) and FBG (FBG, uniform FBG and IDCFBG) model are used for simulation. Transmitting end of the simulation setups for both DCF and FBG configurations consist of pseudo random bit sequence generator, nonreturn to zero (NRZ) modulation format, continuous wave laser (CW) used as a source of light and a Mach–Zehnder (MZ) modulator used for the modulation of the optical signal. Optical pulses are sent at a transmission rate of 2.5 Gbps and 10 Gbps and a single frequency of 193.1 THz is used for the simulations. A pin detector photodiode is used at the receiving end to detect the optical pulses and to convert it to the electrical signals. During the simulations carried out using DCF, the component of model is relocate to configure it as previously defined in Fig. 1 for pre-compensation, post-compensation, and symmetrical compensation. For clarify simulation diagram for pre-compensation is shown in Fig. 4. Here EDFA is utilized for the compensation of the attenuation after each DCF components. Simulation diagram for uniform FBG model is shown in Fig. 3. All other model of FBG and IDCFBG model are implemented by replacing uniform FBG with FBG and then IDCFBG and setting up their corresponding parameter value. We simulate six different types of dispersion compensation model in this experiment and find the corresponding eye diagram. The results of simulations are compared in terms of Q-factor and BER. Default simulation parameters of single channel optical system, DCF parameters, and FBG parameters are tabulated in Tables 1, 2, and 3 respectively.

Table 1. Default simulation parameters of single channel optical system

Parameters	Values
Dispersion	17 (ps/nm/km)
Bit rate	2.5 Gbps, 10 Gbps
Dispersion slope	0.075 (ps/nm^2/km)
Attenuation index	0.2 (dB/km)
Length	100 km
C/W input power	15 dBm
C/W laser frequency	193.1 (THz)
Reference wave length	1550 (nm)
Mach-zender modulator with of extinction ratio	30 (dB)
EDFA gain	10 (dB)
EDFA noise figure	4 (dB)
PIN responsivity	1 (A/W)
PIN dark current	10 (nA)

Table 2. DCF parameters

Parameters	Values
Length of DCF(km)	10
Reference wavelength (nm)	1550
Length of DCF (km)	10
Attenuation (db/km)	0.2
Differential slope (ps/nm ^{2} /km)	0.075
Dispersion (ps/nm/km)	-170

Table 3. FBG parameters

Model	Parameter	Values
IDCFBG	Dispersion (ps/nm)	-1700
	Insertion loss(dB)	0
Uniform FBG	Frequency(THz)	193.1
	Reflectivity	0.99
	Bandwidth(GHz)	125
FBGs	Effective index	2
	Grating length(mm)	6
	Tanh Parameter	4
	Linear parameter	0.0001

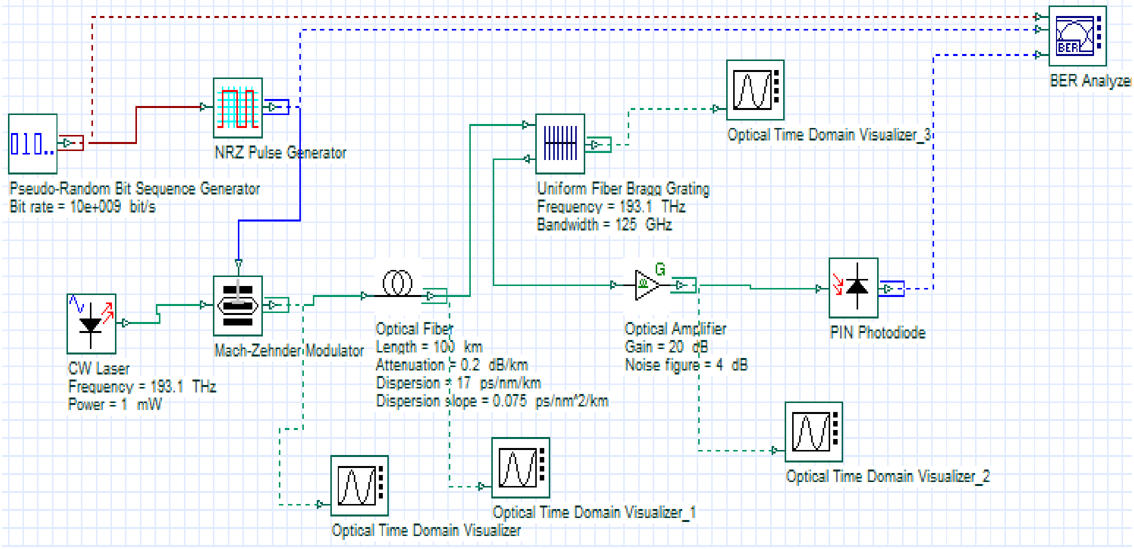


Fig. 3. Compensation using uniform FBG simulation model

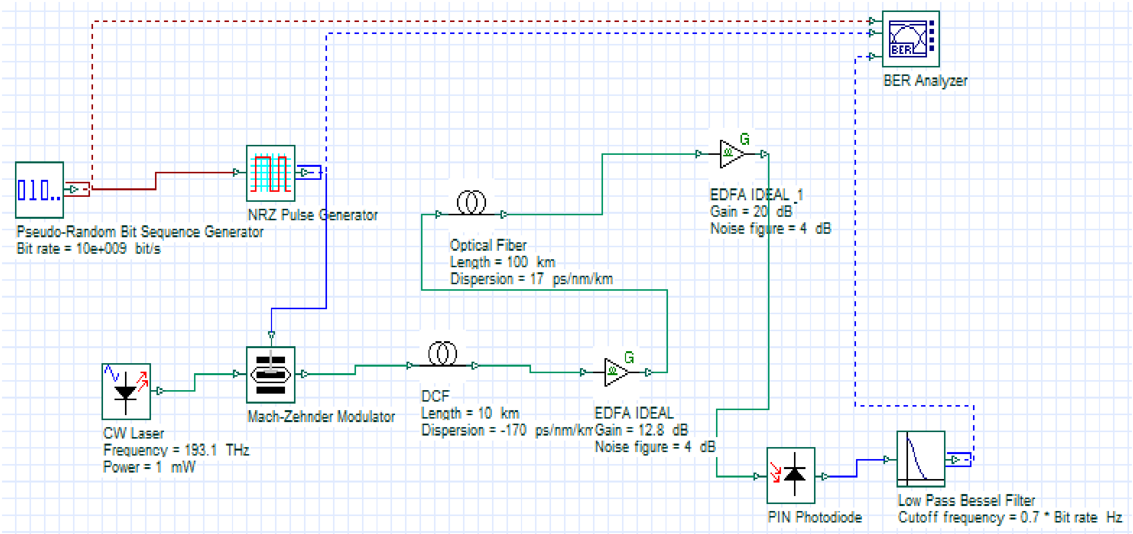


Fig. 4. Pre-compensation using DCF simulation model

4. RESULTS AND DISCUSSION

In this study two popular dispersion compensation method DCF and FBG with various configuration (i.e Pre, Post, Symmetrical compensation of DCF, uniform FBG, FBG and IDCFBG) are considered for dispersion compensation in optical communication. The simulation result for various configurations with different bit rate is given in the following figure. Fig. 5, Fig. 6 and Fig. 7 represents the corresponding eye diagram of Pre-DCF, Post-DCF and Symmetry-DCF model with bit rate 2.5G bps and 10 Gbps.

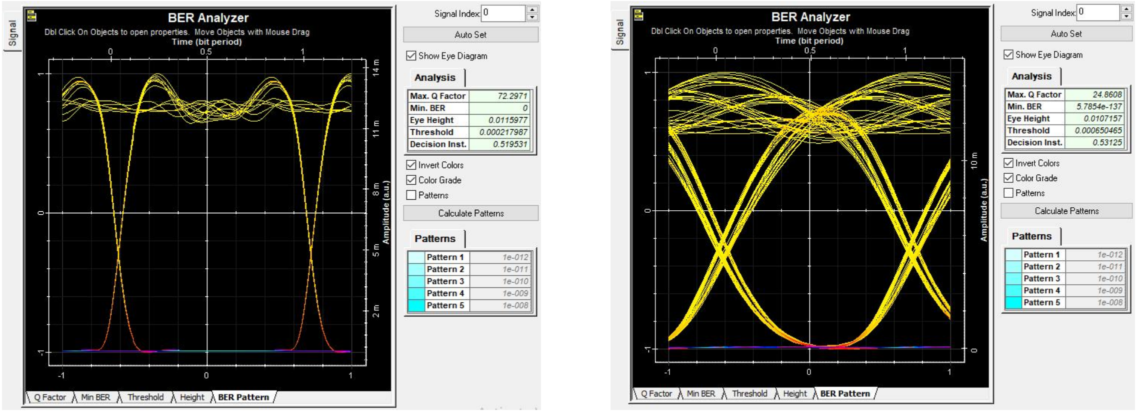
Fig. 8, Fig. 9 and Fig. 10 represents the corresponding eye diagram of uniform FBG, FBG and IDCFBG model with bit rate 2.5 Gbps and 10 Gbps. Comparative value of Q factor and BER for different model is given in Table 4.

According to the simulation results for 2.5 Gbps data rate symmetrical model provides best Q-factor of 96.9504 with compare to all other model configuration in this study. For the case of more data rate which are considered here of 10 Gbps post compensation DCF model provides best Q-factor than other’s model. In the case of FBG model only IDCFBG provides best results in both data rate. The comparison of Q-factor for various model are shown in Fig. 11.

Uniform FBG performs very poor in high speed data rate due to it's uniform gratings distribution. On the other hand IDCFBG performs better in both rate of data speed among all others FBG models. By analyzing the results we can also conclude that the Q-factor by using the DCF is far better than using the FBGs. But for the reduction of positive dispersion in SMF a high negative dispersion coefficient is required from DCF. Due to this reason the overall cost and the non-linear effect are increased. So, FBG is more economic than DCF in compensating the dispersion.

Table 4. Simulation results of DCF and FBG model

Bit rates	DCF			FBG		
	Model	**Q-factor**	**BER**	**Model**	**Q-factor**	**BER**
2.5 Gbps	Pre	72.2971	0	Uniform	9.79921	3.29991e-23
	Post	95.2829	0	FBG	7.6936	6.17588e-15
	Symmetrical	96.9504	0	IDCFBG	14.9165	9.37102e-051
10 Gbps	Pre	24.8608	5.7854e-137	Uniform	0	1
	Post	41.401	0	FBG	2.39784	0.0073207
	Symmetrical	28.8432	1.8722e-183	IDCFBG	7.97722	5.24034e-016



☑ Show Eye Diagram

Analysis

Max. Q Factor	72.2971
Min. BER	0
Eye Height	0.0115977
Threshold	0.000217987
Decision Inst.	0.519531

☑ Invert Colors
☑ Color Grade
☐ Patterns

Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

☑ Show Eye Diagram

Analysis

Max. Q Factor	24.8608
Min. BER	5.7854e-137
Eye Height	0.0107157
Threshold	0.000650465
Decision Inst.	0.53125

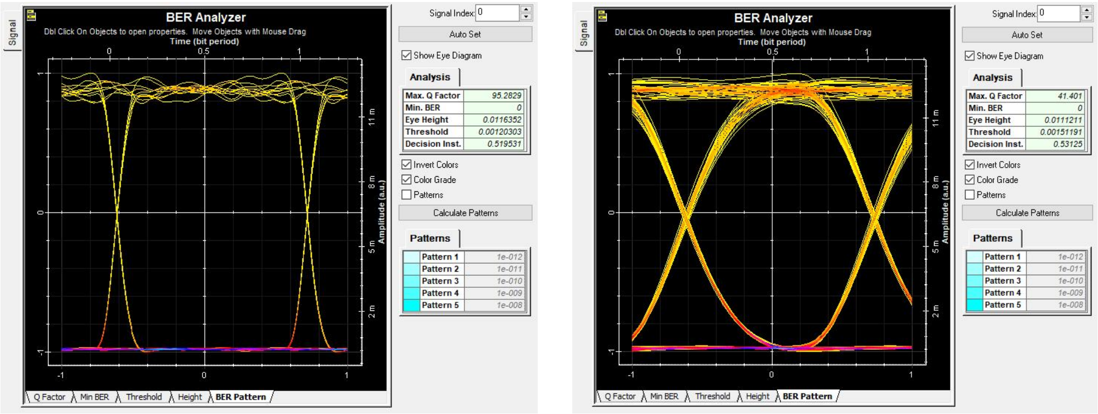
☑ Invert Colors
☑ Color Grade
☐ Patterns

Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

(a) Bit rate 2.5 Gbps **(b) Bit rates 10 Gbps**

Fig. 5. DCF pre-compensation simulation results



☑ Show Eye Diagram

Analysis

Max. Q Factor	95.2829
Min. BER	0
Eye Height	0.0116352
Threshold	0.00120303
Decision Inst.	0.519531

☑ Invert Colors
☑ Color Grade
☐ Patterns

Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

☑ Show Eye Diagram

Analysis

Max. Q Factor	41.401
Min. BER	0
Eye Height	0.0111211
Threshold	0.00151191
Decision Inst.	0.53125

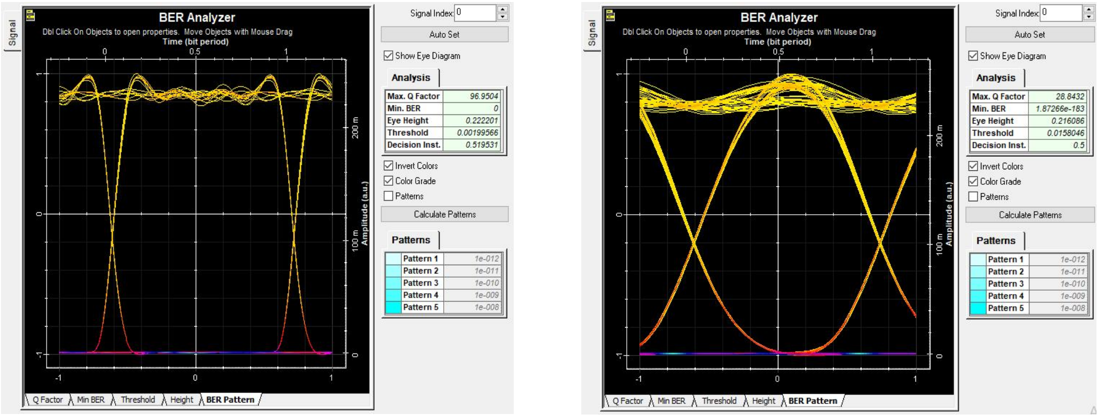
☑ Invert Colors
☑ Color Grade
☐ Patterns

Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

(a) Bit rate 2.5 Gbps **(b) Bit rates 10 Gbps**

Fig. 6. DCF post-compensation simulation results



Signal Index: 0

☑ Show Eye Diagram

Analysis

Max. Q Factor	96.9504
Min. BER	0
Eye Height	0.222201
Threshold	0.00199566
Decision Inst.	0.519531

☑ Invert Colors
☑ Color Grade
☐ Patterns

Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

Signal Index: 0

☑ Show Eye Diagram

Analysis

Max. Q Factor	28.8432
Min. BER	1.87266e-183
Eye Height	0.216086
Threshold	0.0158046
Decision Inst.	0.5

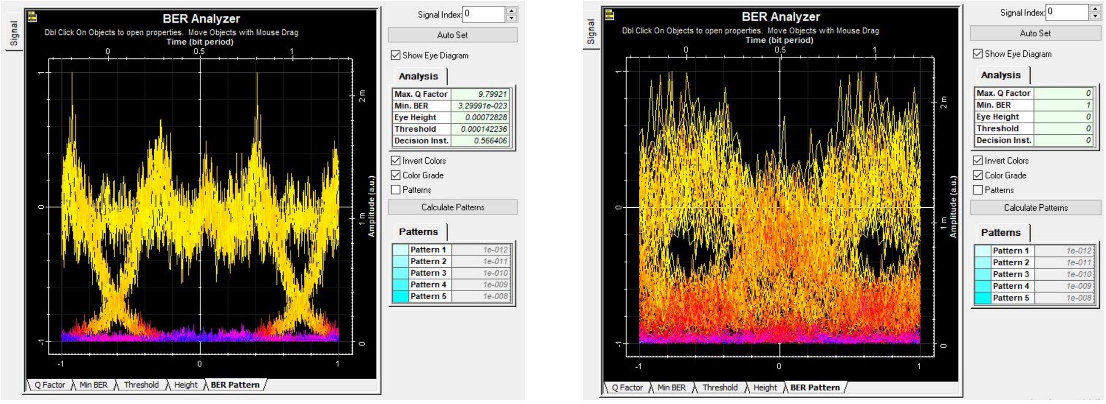
☑ Invert Colors
☑ Color Grade
☐ Patterns

Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

(a) Bit rate 2.5 Gbps **(b) Bit rates 10 Gbps**

Fig. 7. DCF symmetrical-compensation simulation results



Signal Index: 0

☑ Show Eye Diagram

Analysis

Max. Q Factor	9.79921
Min. BER	3.29991e-023
Eye Height	0.00072828
Threshold	0.000142236
Decision Inst.	0.566406

☑ Invert Colors
☑ Color Grade
☐ Patterns

Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

Signal Index: 0

☑ Show Eye Diagram

Analysis

Max. Q Factor	0
Min. BER	1
Eye Height	0
Threshold	0
Decision Inst.	0

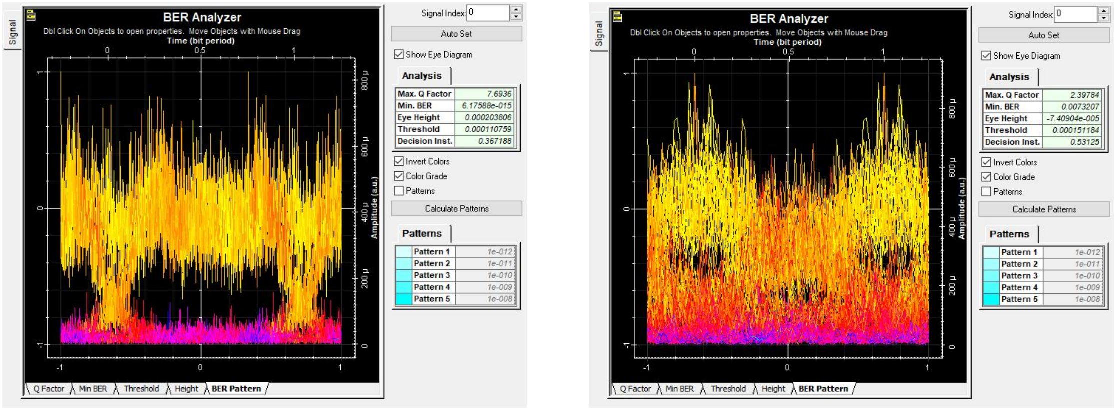
☑ Invert Colors
☑ Color Grade
☐ Patterns

Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

(a) Bit rate 2.5 Gbps **(b) Bit rates 10 Gbps**

Fig. 8. Uniform FBG simulation results



Signal Index: 0

☑ Show Eye Diagram

Analysis

Max. Q Factor	7.6936
Min. BER	6.17588e-015
Eye Height	0.000203806
Threshold	0.000110759
Decision Inst.	0.367188

☑ Invert Colors
☑ Color Grade
☐ Patterns

Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

Signal Index: 0

☑ Show Eye Diagram

Analysis

Max. Q Factor	2.39784
Min. BER	0.0073207
Eye Height	-7.40904e-005
Threshold	0.000151184
Decision Inst.	0.53125

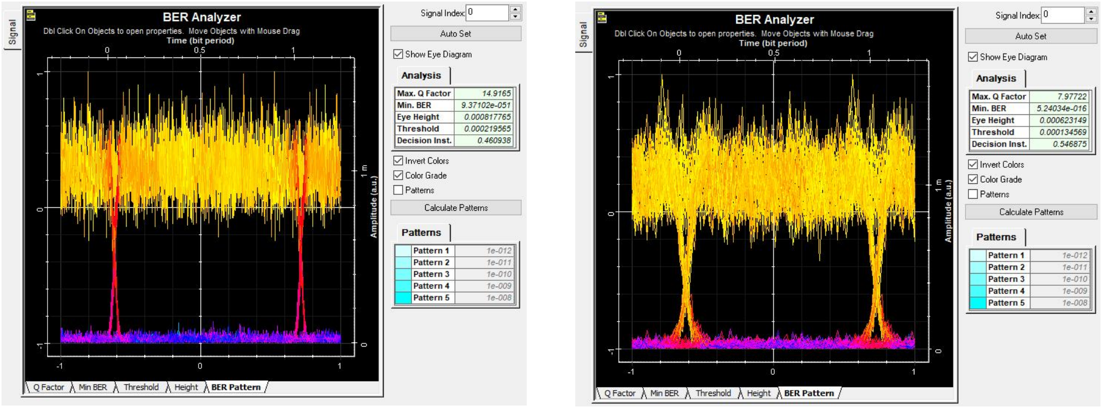
☑ Invert Colors
☑ Color Grade
☐ Patterns

Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

(a) Bit rate 2.5 Gbps **(b) Bit rates 10 Gbps**

Fig. 9. FBG simulation results



Analysis	
Max. Q Factor	14.9165
Min. BER	9.37102e-051
Eye Height	0.000817765
Threshold	0.000219565
Decision Inst.	0.460938

Patterns	
Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

Analysis	
Max. Q Factor	7.97722
Min. BER	5.24034e-016
Eye Height	0.000623149
Threshold	0.000134569
Decision Inst.	0.546875

Patterns	
Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

(a) Bit rate 2.5 Gbps **(b) Bit rates 10 Gbps**

Fig. 10. IDCFBG simulation results

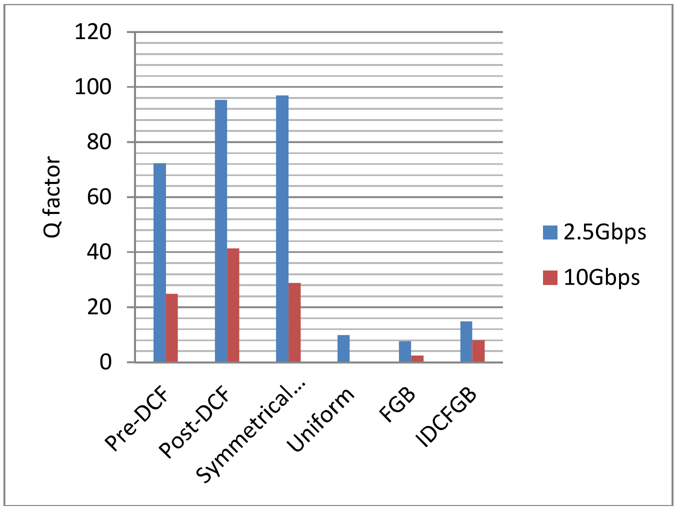


Fig. 11. Q factor vs different dispersion compensation model

5. CONCLUSIONS

The signal degradation due to dispersion is decreased with the increment of Q factor. Hence the value of Q factor is fundamental for performance measurement. In this work we mainly focused on different model performance in terms of dispersion compensation. Form the simulation results, when the data rate is 2.5 Gbps Q-factor of symmetrical model is 96.9504 and BER is 0 which is the best among all other model's Q-factor. But when the data rate is 10 Gbps Q-factor of post compensation model is 41.401 and BER is 0 which is best. It is also seen that the value of Q-factor for post compensation for 2.5 Gbps is 95.2829 which is very near to symmetrical model. So for overall consideration post compression DCF is a promising approach though it is costly to implement than FBG model.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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