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A performance analysis of proposed hybrid dispersion compensation techniques for WDM optical systems

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ABSTRACT

Optical Fiber Communication (OFC) is the most widely used technique for communication purpose. It provides better transmission quality, higher bandwidth and data rate. Although OFC has several advantages, but still the performance of the optical system has been observed to degrade because of various transmission impairments. But specifically, the most dominant impairment is dispersion. Dispersion, i.e. pulse broadening further leads to Intersymbol Interference (ISI) in the signal. In literature, various dispersion compensation techniques such as Dispersion Compensation Fiber (DCF), Electronic Dispersion Compensation (EDC), Optical Phase Conjugation (OPC), compensation using digital filters and Fiber Bragg Gratings (FBG) are discussed. DCF and FBG are the commonly used techniques because of their respective advantages. On combining the Single Mode Fiber (SMF) and DCF, there are four possible schemes for compensation. These schemes are compared in accordance with their simulation results and it is concluded that the Post + Pre hybrid module has the maximum Q-factor of 29.8 for an optimum threshold of 0.48 periods and the minimum BER is 1e-194.9. A hybrid of DCF and FBG is also proposed.

Keywords: *ISI, DCF, SMF, FBG, SPM, dispersion compensation.*

INTRODUCTION

The present day optical fiber communication system has led to a constant upward surge in the data rates and the system capabilities. But, for long-haul communication purpose, the system performance degrades due to dispersion. Dispersion basically arises due to the propagation delay in the different frequencies travelling along the fiber. This results in pulse broadening of the information signal which leads to overlapping and data loss. Chromatic Dispersion and Polarization Mode Dispersion (PMD) are the two major limiting sources. PMD occurs due to the alteration in the propagation velocities of the two different orthogonal polarizations in the fiber because of the presence of the slight imperfections and distortions. The pulse broadening in the signal because of PMD can be measured by Differential Group Delay, $\Delta\tau$. Dispersion can also cause pulse distortion due to several non-linear effects such as Self-Phase Modulation (SPM), Cross-Phase Modulation (XPM), Four-Wave Mixing (FWM), etc. There is a great need to mitigate the effects of dispersion. Several techniques used for dispersion compensation are Dispersion Compensating Fibers (DCF), Fiber Bragg Gratings (FBG), use of digital filters and Optical Phase Conjugation (OPC).

In the literature, it is discussed that for a SMF, the dispersion value is 16 ps/nm-km and a 40 Gbps signal can only be transmitted upto 4 km distance without using dispersion compensation techniques. So, for further increase in the transmission distance various compensations schemes are employed and DCF and FBG techniques are compared after simulation [1].

The various compensation methods are Dispersion Compensation Fiber (DCF) which can compensate dispersion at the wavelengths of 1310 nm and 1550 nm and Fiber Bragg Grating (FBG) which can be used at 1550 nm. DCF technique increases the overall cost of the transmission system and the non-linear effects also whereas FBG helps in reducing the insertion loss and also decreases the system cost [8].

In [9] various techniques of dispersion compensation are shown. The simplest being the

DCF with opposite dispersion gives large insertion losses. The other is the Electronic dispersion compensation (EDC) which uses feed-forward and decision feedback equalizers. It provides compensation of about 1600 ps/nm (80 km) for 10 Gbps but it slows the speed of compensation. FBG compensates dispersion by recompressing the signal pulses.

The two dispersion compensators, i.e. DCF and FBG are used for an 8 channel optical network and it is analyzed for 120 km distance. DCF employs three compensation methods which are pre, post and symmetrical and the FBG technique employs two compensation methods which re pre and post. Non Return to Zero modulation format is used and after simulation it is shown that the post FBG compensation method has better performance with maximum Q-factor and minimum BER value [6].

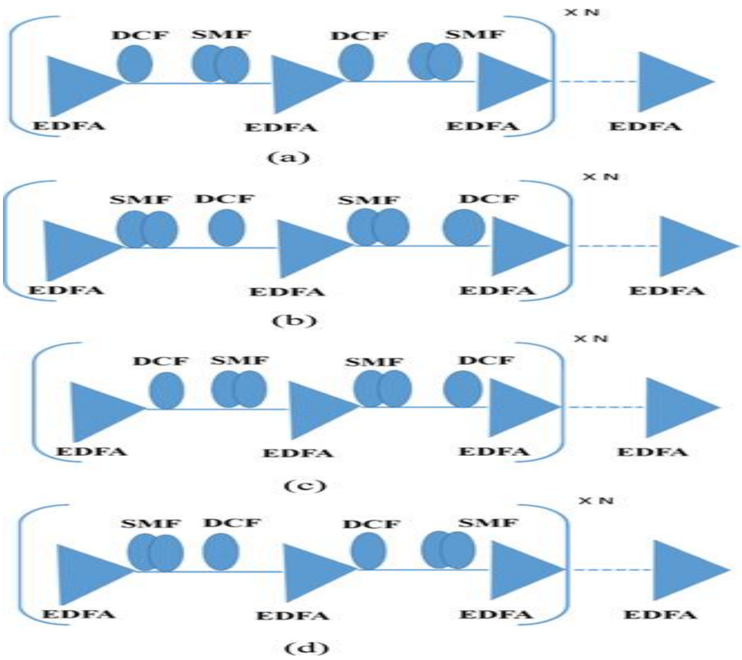
In this paper, based on the comprehensive literature survey, a hybrid of DCF and FBG for SMF has been proposed for better dispersion compensation result. The rest of the paper is organized as follows. The various dispersion compensation schemes are explained in section II. The simulation setup is given in section III. The results are discussed in section IV and conclusion is given in section V.

DISPERSION COMPENSATION TECHNIQUES

There are different techniques employed in the optical communication system for the improvement of system performance which has been influenced by dispersion.

Dispersion Compensating Fiber (DCF)

The dispersion of SMF at 1550 nm wavelength is 17 – 20 ps/nm-km. It is connected with a DCF with a high negative dispersion coefficient in the range of -70 ps/nm-km to -90 ps /nm-km which nullifies overall dispersion of the communication system. DCF cannot be easily affected by the temperature variations and bandwidth and is stable because of its negative dispersion value. The refractive index of the core also does not change at the core-cladding interface in the DCF. The DCF can be used in several schemes such as Pre-compensation, Post-compensation and Symmetrical compensation. The hybrid compensation schemes can also be obtained as shown in Fig.1.



Fig(a). *Pre-compensation scheme,* **(b)** *Post-compensation scheme,***(c)** *Hybrid compensation (Pre + Post),***(d)** *Post + Pre module [1]*

Fiber Bragg Grating (FBG)

FBG is a very simple and cost efficient device with a filter like structure which is used for wavelength selection and it improves the quality and performance of the communication system to a great extent. The reflected wavelength (λ_g) is called the Bragg wavelength, and is defined by the relationship,

$$\lambda_g = 2n\Delta \quad (1)$$

where n is the effective refractive index of the grating and Δ is the grating period. When a light pulse travels along the fiber, the light with longer wavelength lags the light with shorter wavelength, resulting in the broadening of light pulse or dispersion. So, a dispersed light pulse is made to incident on a Chirped Fiber Bragg Grating (CFBG). The light having the longer wavelength is reflected near the front of the grating of CFBG and the light with the shorter wavelength is delayed as compared to the longer wavelength light. So, the chirped FBG is being designed in such a way that the different wavelengths in the light pulse enter at the receiver end at the same time and therefore, dispersion gets compensated. The communication system incorporating the FBG compensation module is shown in Fig.2.

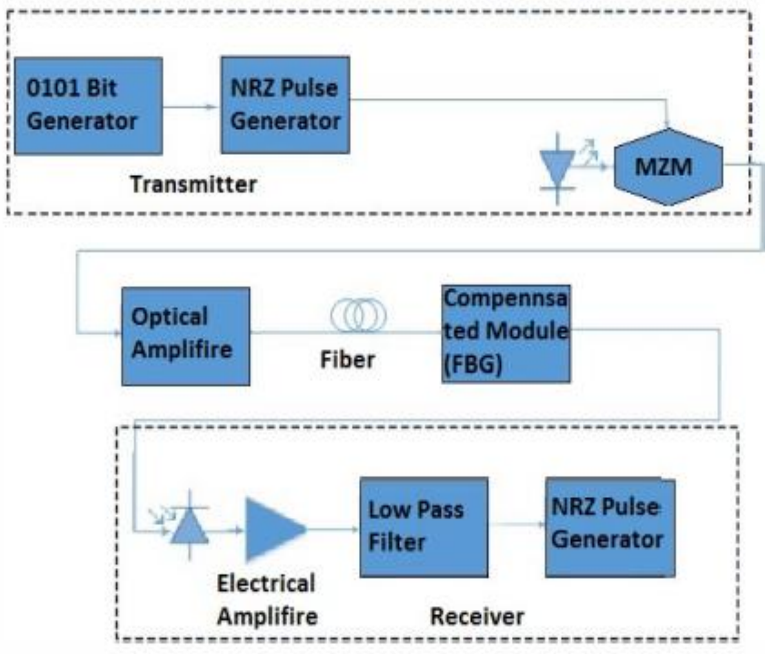


Fig2.*Optical communication system diagram with FBG compensation module [2]*

Optical Phase Conjugation (OPC)

OPC is being used for the compensation of chromatic dispersion and Kerr effect. It is also capable in mitigating the effects of Self-Phase Modulation (SPM) and Four Wave Mixing (FWM). Here, the phase distortions induced by the SPM in the system before the conjugation process are being undone by the SPM induced distortions after the conjugation.

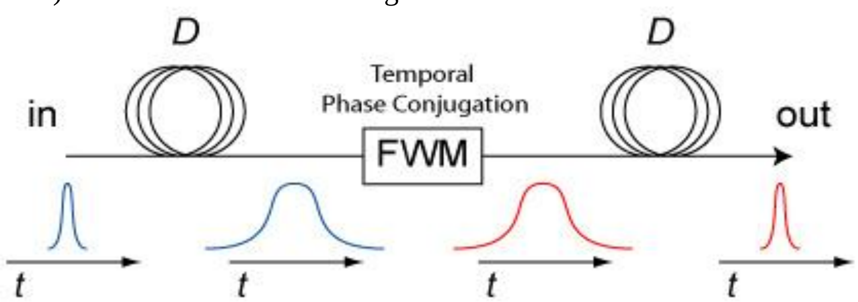


Fig3.*Optical Phase Conjugation*

Simulation Setup of Optical Transmission System

The transmitter of the system consists of a Pseudo-random sequence generator, a Non-Return to Zero (NRZ) Pulse generator, a Continuous-wave Laser (CW), a Mach-Zehnder Modulator, a binary pre-coder and a low-pass filter (LPF). The wavelength of the CW laser is 1550 nm. The cutoff frequency of the LPF is 15 GHz. The electrical information signal is being converted into optical duo-binary signal under the push-pull mode and finally it is being externally modulated through the MZM. The length of the SMF and the DCF is 100 km and 20 km in the transmission system. The receiver side consists of a PIN photodiode, a low-pass

Bessel filter, a LPF and a 3R regenerator. The regenerator circuit is employed in the system in order to completely recover the transmitted signal. The pseudo-random sequence generator sends binary sequence to the pre-coding circuit and the LPF is used for realizing the electric duo-binary coding. In the proposed scheme for dispersion compensation, the hybrid of DCF and FBG can be placed at the location of the dispersion compensating link as shown in Fig.4.

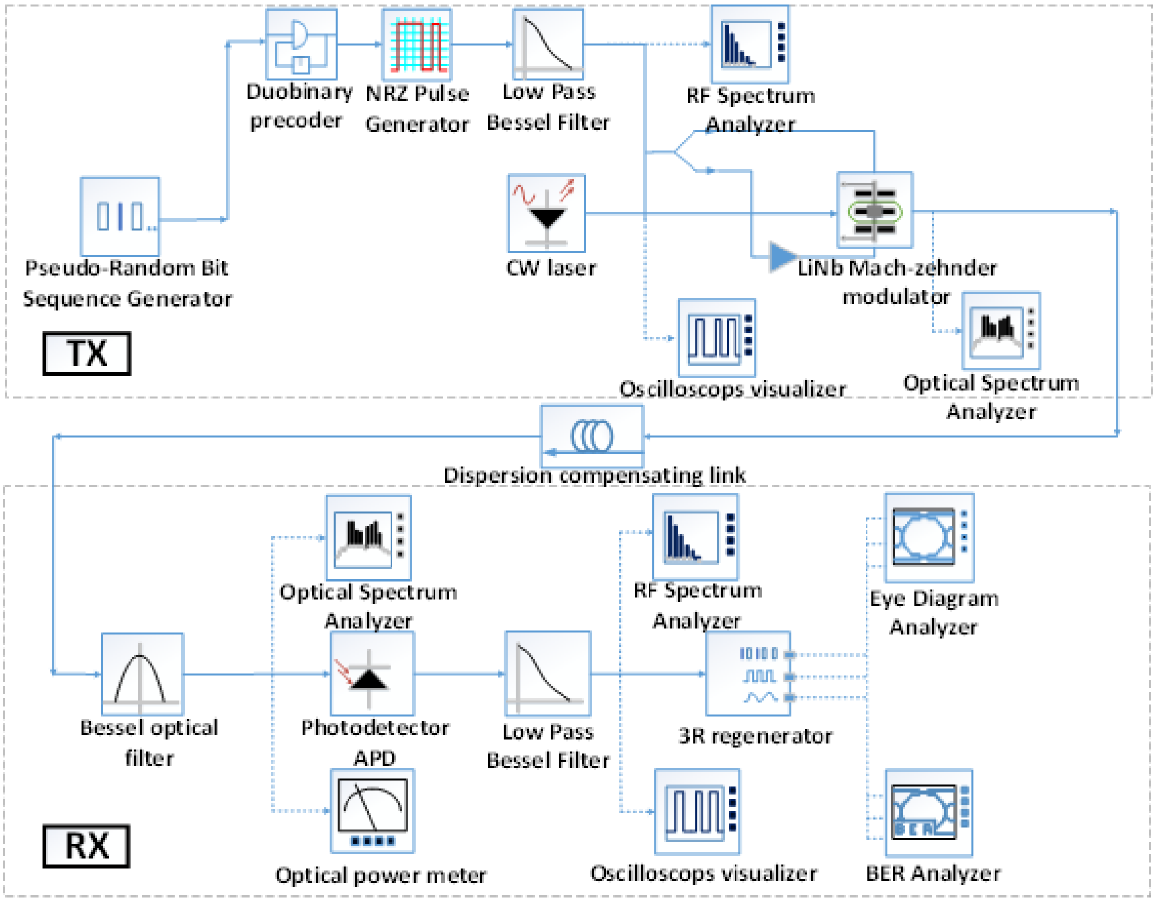


Fig4. *Simulation setup of the optical communication system [1]*

RESULTS AND DISCUSSIONS

The eye diagram and BER (Bit Error Rate) of the compensation schemes using DCF and SMF are shown in the Fig.5. Eye diagram shows the changes of a signal waveform by overlapping every symbol waveform in a cycle. It is basically used for the evaluation of the combined effects of the link noise and ISI on the performance of any system. The better quality of the eye diagram reflects that the system performance has gradually improved. On comparing all the figures and with the help of BER analyzer, the values of Q-factor and BER can be evaluated for the compensation schemes.

The graphs shown in Fig.5 depict that the maximum Q-factor for the Pre-compensation scheme is 19.6 for an optimum threshold of 0.5 periods and the minimum BER value is $1e^{-84.9}$. For Post-compensation scheme, the maximum Q-factor achieved is 22.6 for the optimum threshold of 0.48 periods and the minimum BER is $1e^{-113.2}$. The maximum Q-factor value for hybrid compensation, i.e. (Pre + Post) module is 25.4, when the optimum threshold is 0.5 periods and the minimum BER is $1e^{-142.5}$. For the second hybrid compensation scheme, i.e. (Post + Pre) module, the maximum Q-factor is 29.8 for an optimum threshold of 0.48 periods and the minimum BER is $1e^{-194.9}$. Also, for the BER value equal to $1e^{-9}$, the received power of both the Pre-compensation and Post-compensation schemes are same and equal to -15.9 dBm and the received power for hybrid compensation (Pre + Post) is equal to -16 dBm and for (Post + Pre) hybrid module, the received power is -16.3 dBm. This clearly shows that the hybrid compensation module having first Post module and then the Pre module, i.e. (Post + Pre) scheme has minimum received power and also the highest sensitivity. On the basis of the analysis of simulation results and by comparing the values of the Q-factor and BER of all the four compensation schemes, it has been proved that the hybrid scheme having (Post + Pre) arrangement has the best transmission quality. Hence, this DCF scheme of post + pre can be connected in hybrid with the FBG module for much better performance.

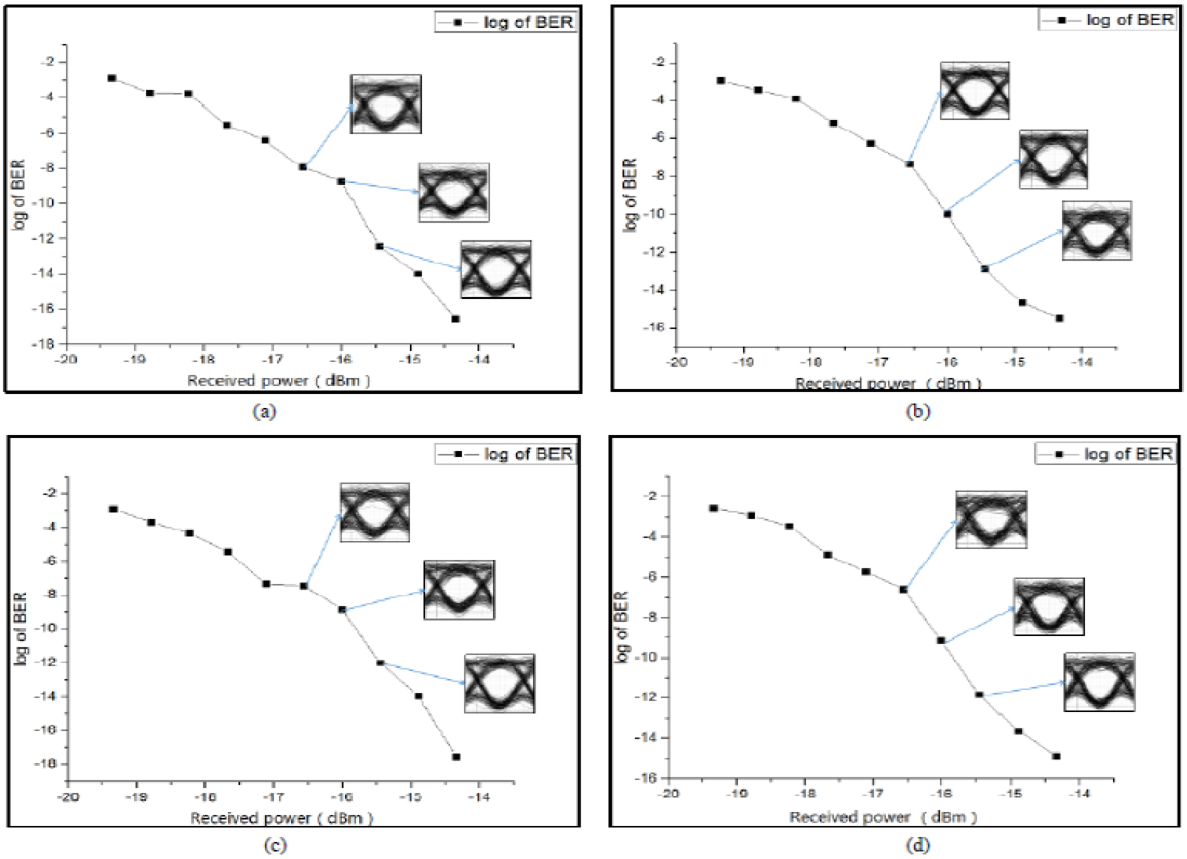


Fig5. *Eye diagrams and BER curves for* **(a)** *Pre-compensation scheme* **(b)** *Post-compensation scheme***(c)** *Hybrid compensation (Pre + Post) scheme* **(d)** *Hybrid (Post + Pre) compensation [1]*

The various parameters of the optical fiber are shown below in Table 1.

Table1. *Parameters of the optical fiber [1]*

S.No.	Parameters	Single Mode Fiber (SMF)	Dispersion compensating Fiber (DCF)
1.	Length (km)	50	10
2.	Dispersion (ps/nm/km)	16	-80
3.	Dispersion slope (μm^2)	80	30
4.	First order dispersion coefficient (ps^2/km)	-20	-20
5.	Attenuation (dB/km)	0.2	0.5
6.	Non-linear refractive index (m^2/W)	2.6×10^{-20}	2.6×10^{-20}
7.	Dispersion slope (ps/(nm^2km))	0.075	-0.45

CONCLUSION

The various arrangements of DCF and SMF are made for various compensation techniques. Apart from Pre and Post compensation schemes, two more hybrid techniques are compared and analyzed. After comparing the values of BER, Q-factor and the receiver sensitivity, it has been concluded that the Q-factor value of the hybrid combination with (Post + Pre) is of the best usage as compared to other schemes because it has the lowest BER, highest Q-factor and also the highest receiver sensitivity. It is also proposed that the hybrid of DC F and FBG can be used for dispersion compensation for better performance in WDM optical networks.

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