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Design and Comparative Analysis of OPC-DCF-FBG Dispersion Compensation Technique with RZ Pulse Generator for 300km Length of SMF

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In this paper, a 32×40Gbps optical transmission system is proposed. The proposed model is designed for 300km length of optical fiber with return-to-zero (RZ) pulse generator using different hybrid dispersion compensation techniques i.e. dispersion-compensation-fiber (DCF), DCF-FBG (Fiber Braggs Grating), OPC (Optical-Phase-Conjugation)-DCF and OPC-DCF-FBG. The performance of proposed model is calculated in terms of quality-factor (Q-factor) and bit-error-rate (BER). Performance parameters are also calculated for different input power. It is found that the OPC-DCF-FBG hybrid dispersion compensation technique gives the best performance compared to other dispersion compensation techniques.

Keywords: Dispersion compensation fiber (DCF), fiber Bragg grating (FBG), return-to-zero (RZ), Single mode fiber (SMF), Optical phase conjugation (OPC).

1. Introduction

The high data rates and large bandwidth are required for higher and fast signal transmission in present era of telecommunication industries. Whereas the optical fiber is playing an important role for fulfils this constraint. For high data rates, a dense-wavelength-division-multiplexing (DWDM) system is used by which different wavelength signals can be transmitted for long distances [1-2]. When optical signals are transmitted from transmitter to receiver for long distances, these signals are attenuated and dispersed. The amplifier can be used to minimize the attenuation problem and dispersion compensation techniques therefore to minimize the dispersion effect [3-6]. The different types of dispersion compensation techniques and hybrid dispersion compensation techniques are used in optical fiber communication system i.e. DCF (dispersion-compensation-fiber), FBG (Fiber- Braggs-Grating), OPC (optical-phase-conjugation), DCF-FBG, OPC-DCF, OPC-DCF-FBG [7-11, 28]. Aggarwal et al. [21] analysed the performance of a 32×10Gbps optical transmission system using hybrid dispersion compensation techniques but data rates of the suggested system found very less. Meena et al. [4] analysed the performance of 4×8Gbps optical transmission system using DCF technique and the data rate and channel capacity observed very low. Bhattacharjee et al. [19] investigated the system using OPC-DCF dispersion compensation techniques but channel capacity was very low, and system was designed for shorter reach also.

In this paper, proposed system is designed for 32×40Gbps optical transmission system with 300km length of SMF using different hybrid dispersion compensation techniquesi.e. dispersion-compensation-fiber (DCF), DCF-FBG (Fiber Braggs Grating), OPC (Optical-Phase-Conjugation)-DCF and OPC-DCF-FBG. The proposed system is designed for opti-system software.

2. Dispersion Compensation Techniques

2.1 Dispersion Compensation Fiber

In long haul optical communication system, the signal will be dispersed when a signal is transmitted from one side to another side. The dispersion compensation fiber (DCF) is used to minimize this problem. The SMF and DCF are two dispesion coefficient in which SMF has positive dispersion coefficient and DCF has negative dispersion coefficient. Therefore, it is used to get the original signal as shown in figure 1. Hence, the suggested model should be satisfied the following equations (1,2) for the perfect dispersion compensation [12, 13]:

$$D_{SMF} * L_{SMF} + D_{DCF} * L_{DCF} = 0 \qquad (1)$$

$$L_{DCF} = -L_{SMF}\left(\frac{D_{SMF}}{D_{DCF}}\right) \qquad (2)$$

Where, D_{SMF} = dispersion of SMF; D_{DCF} = dispersion of DCF L_{SMF} = length of SMF; L_{DCF} = length of DCF.

2.2 Fiber Bragg Grating

A small portion of an optical fiber that has a periodic variation in refractive index along the length of optical fiber can be used to design a fiber bragg grating (FBG). Two types of FBG can be used in optical communication system i.e. (1) uniform FBG and (2) non uniform FBG. Uniform FBG has a constant refractive index along the length of optical fiber as shown in figure 2 and in non-uniform FBG refractive index is linearly varied along the length of the optical fiber. Therefore, a particular wavelength signal can be reflected through FBG, and the remaining wavelength signals can be transmitted. The reflected wavelength is known as Bragg’s wavelength as given by equation (1 and 2):

$$\lambda_{Bragg} = 2 \cdot n_{eff} \cdot \Lambda \qquad (3)$$

Where, λ_{Bragg}= Bragg’s wavelength; n_{eff}= effective refractive index; and Λ= grating period of fiber.

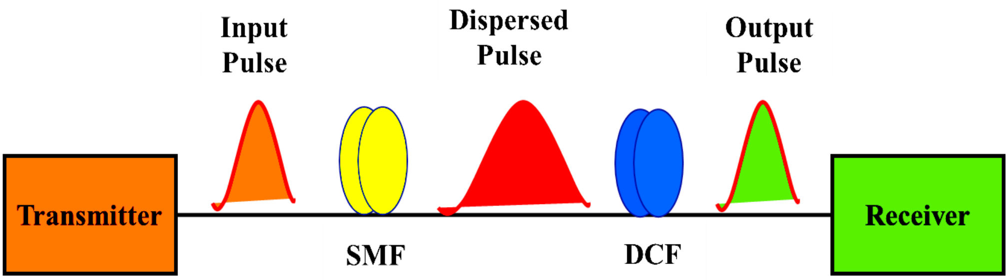

Fig.1: Basic principle of DCF techniques

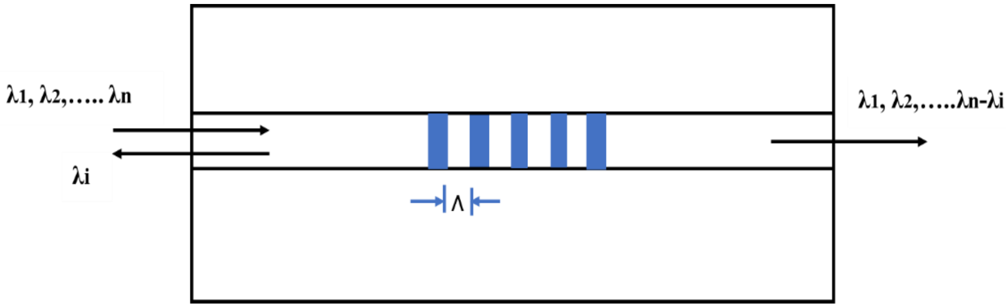

Fig.2: Schematic of Uniform Fiber Bragg Grating

2.3 Optical Phase Conjugation

Optical-Phase-Conjugation (OPC) is a nonlinear dispersion-managed technique, and it can compensate group-velocity-dispersion (GVD) and self-phase-modulation (SPM) simultaneously [14-16]. The basic concept of optical phase conjugation is shown in Figure 3 and it is shown that the optical phase conjugator is placed between SMF SPAN-1 and SMF SPAN-2. The nonlinear impairments generated in the first span of transmission link can be cancelled in the second span of transmission link. Therefore OPC technique improves the nonlinear performance for long-haul optical transmission systems [17, 20]. Hence, the optical phase conjugation technique is known as midway optical phase conjugation or mid-span spectral inversion technique [22-27]. Furthermore, the authors show mathematically how OPC can compensate for the problem of group-velocity dispersion. The pulse spectrum before the OPC is given by:

$$\tilde{A}\left(\frac{L}{2},\omega\right)=\tilde{A}(0,\omega)\exp\left(\frac{i}{4}\beta_2 L\omega^2\right) \quad (4)$$

The optical field after the OPC is given by equation (5)

$$A^*(L,t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\tilde{A}^*\left(\frac{L}{2},\omega\right)\exp\left(\frac{i}{4}\beta_2 L\omega^2-i\omega t\right)d\omega \quad (5)$$

Where, $\tilde{A}^*\left(\frac{L}{2},\omega\right)$ is the Fourier transform of $A^*\left(\frac{L}{2},t\right)$.

The pulse spectrum after the OPC is given by:

$$\tilde{A}^*\left(\frac{L}{2},\omega\right)=\tilde{A}^*\left(0,-\omega\right)\exp\left(\frac{-i}{4}\beta_2 L\omega^2\right) \tag{6}$$

Put the value of equation (6) in equation (5)

$$A\left(L,t\right)=A^*\left(0,t\right) \tag{7}$$

Hence, the equation (7) shows the input optical field is completely recovered except the phase reversal induced by the OPC.

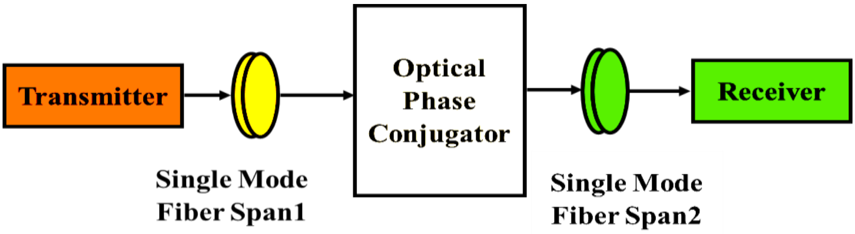

Fig.3: Basic principle of optical phase conjugation

3. Description of Proposed System

In the proposed model, 32×40Gbps optical transmission systems is designed through a hybrid module as dispersion compensator of DCF, DCF-FBG, OPC-DCF, and OPC-DCF-FBG using RZ pulse generators. Proposed model is simulated via Opti-system simulator for 300km length of SMF as shown in Figure 4. The proposed model is classified into three parts that are the transmitter, channel and receiver. The results related to the proposed model are discussed in the results Section.

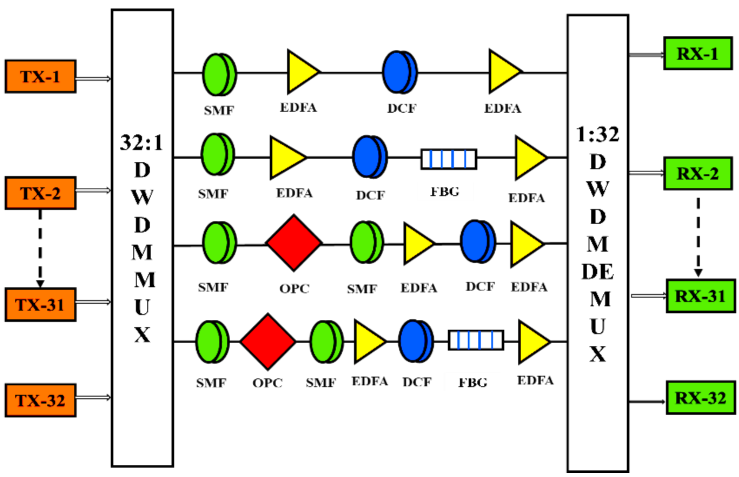

Fig.4: Proposed model for hybrid dispersion compensation techniques: DCF; DCF-FBG; OPC-DCF; and OPC-DCF-FBG

3.1 Transmitter

Optical transmitter contains four blocks which are Pseudo-Random Bit Sequence (PRBS), Return to Zero (RZ) pulse generator, continuous-wave laser (CWL) and Mach-Zehnder (MZ) modulator. Data rate for the proposed model is 40Gb/s. In this proposed model RZ pulse generator is used to convert binary data into electrical pulse. The CW laser and MZ modulator is used to modulate laser signal. MZ-modulator receives an electrical signal and provides an optical-signal at the output. Extinction-ratio of the MZ-modulator is to be chosen 30dB.

3.2 Channel

This section is known as the transmission link. In this section different dispersion compensation techniques are used i.e. SMF-DCF, DCF-FBG, OPC-DCF and OPC-DCF-FBG The length of SMF and DCF are 300 km and 51 km simultaneously.

3.3 Receiver

In the receiver section, the output of DWDM is connected to PIN photodetector and pass-through low pass electrical Bessel filter. Further, the data pulse is provided to the 3R-Regenerator circuit where reshaping, retiming, and re-amplification are to be accomplished. Then, to get the performance parameter, Eye analyzer is used. Furthermore, all parameters related to proposed model are discussed in Table 1.

Table 1: Components and simulated parameter values of the proposed model

Components	Parameters	Values
Data source	Data Rate	40Gbps
	Sample per bit	32
	Sequence length	256
	Total no. of channels	32
Pulse Generator	RZ	Exponential
CW Laser	Output power	-2 to 2dBm
	Central frequency	193.1-196.2THz
	Channel spacing	0.8nm (100GHz)
MZ-Modulator	Extinction ratio	30dB
	Insertion loss	5dB
SMF	Length	300km
	Dispersion	17ps/nm/km
	Attenuation loss	0.2dB/km
	Dispersion slop	0.075ps/nm^2/ km
	Differential Group delay	0.2ps/km
	Core effective area	70μm^2
	Reference wavelength	1550nm
DCF	Length	51 km

	Dispersion	-100ps/nm/km
	Attenuation loss	0.5dB/km
	Differential Group delay	0.2ps/km
	Core effective area	22μm^2
	Reference wavelength	1550nm
EDFA amplifier	Gain	60-120dB
	Amplifier length	10m
	Noise figure	4 dB
PIN Photo-detector	Gain	2
	Sensitivity	-100dBm
	Dark current	10nA
	Responsivity	1A/W
	Error probability	10-Sep
LPB Filter	Order	3
	Cut-off frequency	30GHz

4. Results and Analysis

In this section, we are investigating the performance of hybrid dispersion compensation for 32×40Gbps DWDM optical transmission systems using different DCF, DCF-FBG, OPC-DCF and OPC-DCF-FBG techniques. The performance of simulated model is calculated for 300km length of SMF with RZ pulse generator at different input power levels. The output results are measured in terms of quality-factor (Q-factor), bit-error-rate (BER) and eye-diagrams via BER analyzer. Q-factor and minimum BER for 300km length of SMF via proposed dispersion compensation techniques having RZ pulse generator at different input power levels are summarized in Table 2.

Table 2: Q-factor and BER for 300km length of SMF with RZ pulse generator at different input power

Techniques	DCF		DCF-FBG		OPC-DCF		OPC-DCF-FBG	
Power (dBm)	Q-Factor	BER	Q-Factor	BER	Q-Factor	BER	Q-Factor	BER
-2	12.85	2.31E-38	13.25	1.27E-40	17.09	5.45E-66	19.61	4.11E-86
-1	13.18	3.02E-40	13.02	2.58E-39	18.45	1.37E-76	21.25	9.14E-100
0	12.34	1.60E-35	12.63	4.16E-37	20.21	2.52E-91	22.71	1.15E-110
1	11.46	6.20E-31	11.61	1.12E-31	19.92	7.62E-89	23.85	3.02E-120
2	10.03	3.20E-24	10.17	8.28E-25	20.84	5.14E-97	25.1	1.53E-130

It is found from Table 2, Q-factor for DCF and DCF-FBG techniques are almost the same and the Q-factor decreases as power is increased. However, the Q-factor for OPC-DCF and OPC-

DCF-FBG techniques is increasing from 20.21-22.71 at 0dBm input power. Combined OPC-DCF-FBG technique gives the best result compared to other dispersion compensation techniques. It can be seen from Table 2 that the values of BERs are almost constant for both DCF and DCF-FBG techniques; however, BER is very less at optimized 0dBm input power for OPC-DCF and OPC-DCF-FBG techniques. Therefore, OPC-DCF-FBG dispersion technique gives batter Q-factor and minimum BER for 300km length of SMF at optimized 0dBm input power as compared to DCF, DCF-FBG and OPC-DCF techniques.

The effects of Q-factor vs. input power variations are shown in Fig.5 for the 300km length of SMF. It is observed that the Q-factor is decreased as power is increased for all the four dispersion compensation techniques and among all techniques OPC-DCF-FBG technique gives the best performance. Similarly, the effect of BER vs. input power variations for all four dispersion schemes having RZ pulse generators are shown in Fig.6. Therefore, it is observed that the OPC-DCF-FBG technique gives minimum BER among all four dispersion compensation techniques.

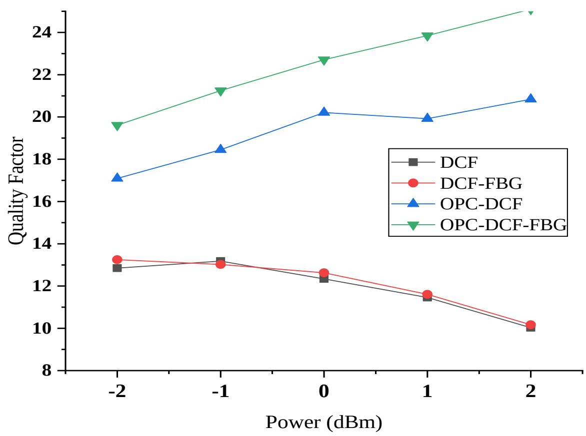

Fig.5: Variations of Q-factor vs. power for 300km length of SMF with RZ pulse generator

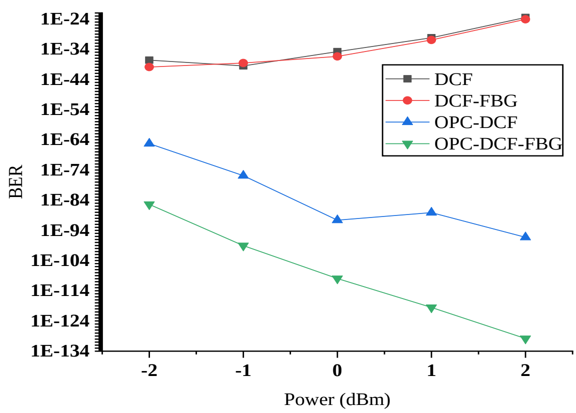

Fig.6: Variations of BER vs. power for 300km length of SMF with RZ pulse generator

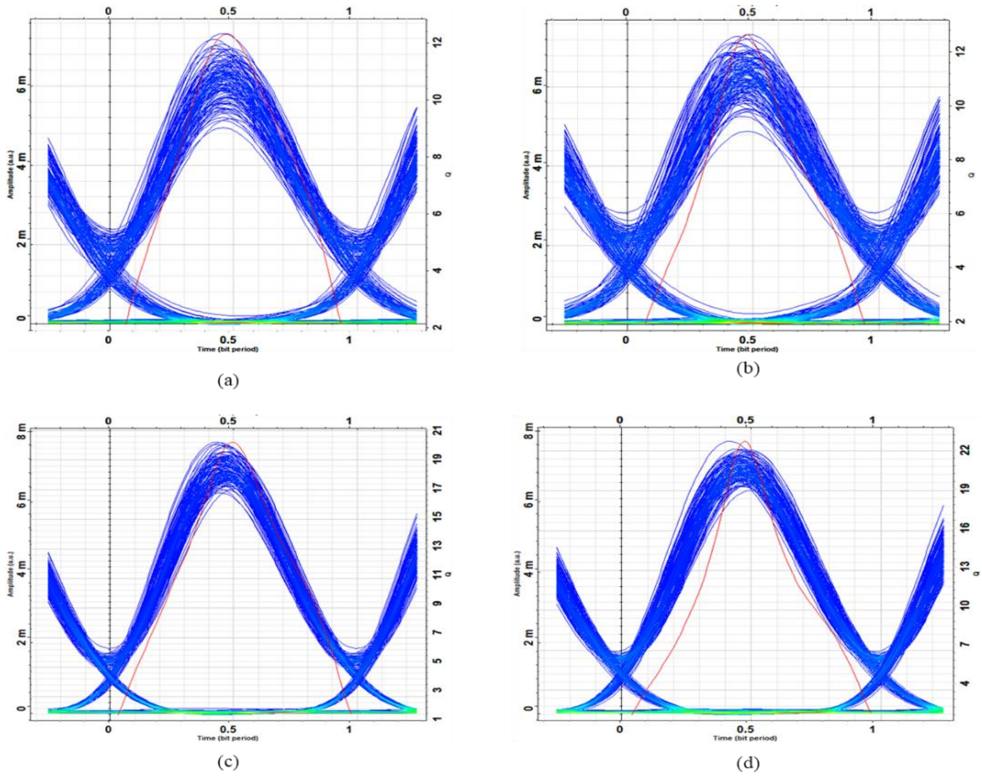

Fig.7: Eye-diagrams for different dispersion compensation techniques via RZ pulse generator at 300km length of SMF: (a) DCF only; (b) DCF-FBG; (c) OPC-DCF; (d) OPC-DCF-FBG.

Table 3: Comparison of proposed work with previous research work reported by researchers

References	Work done	Performance	Conclusion
Meena et al. 2018 [4]	A 4×8 Gbps system with 150km length of SMF is designed using pre, post and symmetric dispersion compensation techniques compensations	Maximum Q-factor is 33.77dB using symmetric with RZ	Low capacity, low bit rates, shorter reach.
Ajmani et al. 2019 [18]	A 8×2.5 Gbps system is designed for 180km length of optical fiber using different hybrid dispersion compensation techniques.	Maximum Q-factor for proposed system is 8.70dB using OPC-FBG dispersion compensation technique.	Very low data rate, low capacity, shorter reach
Bhattacharjee et al. 2020 [19]	A 8×120Gbps system is designed for 40km length of SMF using OPC-DCF technique.	Maximum Q-factor for proposed system is 26.2dB with OPC-DCF	Shorter reach, Low capacity.
Aggrawal et al. 2021[21]	A 32×10 Gbps system for 300km length of SMF is designed using different hybrid dispersion compensation techniques.	Maximum Q-factor for proposed system is 17.7dB with OPC-FBG-DCF technique.	Low data rate, shorter reach.
Proposed Work	A 32×40Gbps system for 300km length of SMF is designed using different hybrid dispersion compensation techniques.	Maximum Q-factor for proposed system is 22.71dB using OPC-DCF-FBG technique with RZ pulse generator.	High data rate, High capacity, longer reach.

From Figure 7 It is observed that the Eye-opening for DCF and DCF-FBG are not clear and eye opening for OPC-DCF and OPC-DCF-FBG techniques are very clear. Hence, the OPC-DCF-FBG technique gives the finest eye-opening when compared with DCF, DCF-FBG and OPC-DCF dispersion compensation techniques.

5. Conclusions

In this paper, the performance of proposed model 32×40Gbps optical transmission system is calculated using different hybrid dispersion compensation techniques i.e. DCF, DCF-FBG, OPC-DCF and OPC-DCF-FBG with RZ pulse generator. The proposed model is designed for 300km length of optical fiber with 51 km length of DCF. Performance of proposed system is calculated with respect to eye-diagrams, Q-factor and BER. It is found that maximum quality factor (Q-factor) and minimum BER (bit-error-rate) for 300km length of SMF are 22.71 and 1.15e-110 respectively at 0dB input power using OPC-DCF-FBG technique. Therefore, OPC-DCF-FBG hybrid dispersion compensation technique with RZ pulse generators gives the best performance compared to other dispersion compensation techniques.

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