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Investigation of long-haul optical transmission systems: diverse chirped FBGs with DCF for 300km length of SMF

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Abstract

Long-haul optical fiber transmission systems (OFTS) are essential to cover the remote areas, but the long distance OFTS systems are mostly affected by attenuation and dispersion issues. In an optical transmission system, attenuation and dispersion are considered as a linear effect. Therefore, to avoid the attenuation happening, erbium-doped-fiber-amplifier (EDFA) is used and dispersion or pulse width broadening (PWB) effects can be reduced by dispersion compensation fiber (DCF) /chirped fiber Bragg grating (CFBG) techniques. In this work, different CFBG, DCF and joint DCF+FBG techniques are proposed to mitigate the effects of dispersion as PWB. These techniques are implemented for a OFTS that has 300km length of optical fiber and 10Gbps data rate on the Opti-System simulator. Performance of suggested model is evaluated and compared by pulse width reduction percentage (PWRP), quality-factor (Q-Factor), bit error rate (BER), pulse amplitude and eye-diagrams. It is observed from the results that the joint DCF+FBG techniques achieved an improved pulse shape with 95.74% PWRP, Q-factor >29, minimum BER and better eye-opening of received signal.

Keywords

Dispersion compensation fiber, Erbium-doped-fiber-amplifier, Fiber bragg grating, Pulse width reduction percentage, Quality-factor.

1.Introduction

In recent scenario, a galloping increment in web or network applications is increased day by day and consumers require low-cost, high speed data rates for long distance optical signal transmission [1]. But it is very challenging to fulfil the user's desires of high speed and low-cost trade-off. However, optical fiber technology comes out with an eventual solution because it has high data rates/capacity and low-cost [2]. But the transmission performance through single mode fiber (SMF) has some limitations due to linear and non-linear properties of fiber [3]. The attenuation and dispersion or pulse width broadening (PWB) are occurring due to linear-effects [4–6]. Different optical amplifiers are also used to avoid the issue of attenuation such as Raman amplifier (RA), semiconductor optical amplifiers (SOA) and erbium doped fiber amplifier (EDFA) [7, 8]. Further, in order to avoid the delay or PWB effects in long-haul optical transmission systems, dispersion compensation techniques can be used. Fiber Bragg grating (FBG) and dispersion compensation fiber (DCF) are major techniques to bridle the dispersion or PWB phenomena [9, 10].

Further, DCF and FBG techniques are reported to conflict the dispersion or PWB in optical fiber transmission system (OFTS) by selecting the different location as pre, post, and symmetric compensation [11–13]. The comparative analysis for different long-haul optical transmission system has also been designed through DCF and FBGs techniques. It has been observed that the DCF and FBG give good performance [10]. Furthermore, comparative analysis of different hybridization-dispersion-compensation techniques like chirped fiber Bragg grating (CFBGs), DCF+FBG, optical phase conjugation (OPC) +DCF, FBG+DCF+OPC are available in the literature. These techniques overcome the dispersion phenomena, but the cost of system increases [1, 5, 14–20]. According to the literature [11–20], most of the investigations emphasize on DCF, FBG, OPC+DCF and DCF+FBG techniques as dispersion compensator, but the cost of implementation is still high and challengeable. It is also observed that the performance of OFTS system

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was described in detail, but slight exertion was carried out for calculation of pulse amplitude and pulse width reduction percentage (PWRP) using diverse chirped FBGs and hybrid dispersion compensation techniques. Hence, the main aim of this paper is evaluating the performance of diverse CFBGs and joint DCF+FBG as dispersion compensator to increases PWRP and reduce the cost of proposed optical transmission systems. Further, the proposed model is also compared with previously reported optical transmission systems as dispersion compensator [1, 5, 15–20].

This paper is organized as follows. Section 2 presents literature review, section 3 describes the methods used in this paper. Section 4 reviews the results. Section 5 presents the discussion with limitations. Conclusion and future work are described in section 6.

2.Literature review

Aggarwal et al. [1] explored the performance of 300km OFTS using hybrid dispersion compensation techniques. PWRP using hybrid FBG+DCF+OPC dispersion compensation technique was 70%. This technique gave the best result compared to FBG+DCF technique, but the overall performance of implemented system was less. Further, Dar and Jha [5] designed a 100km OFTS using different chirping profiles of Tan-apodized FBG and DCF. PWRP using DCF-FBG technique was 96.96%. The performance of the designed system was good, but it was designed for shorter reach. Mohammed et al. [15] explored the performance of different chirping functions and compared with DCF for 100km OFTS. PWRP using DCF-FBG technique was 96.36%. The performance of the proposed system was good but used for shorter reach and medium cost. Chakkour et al. [20] calculated the performance of wavelength division multiplexing (WDM) OFTS using a combination of EDFA and FBG techniques for 100km OFTS. Maximum gain achieved was 37.69 dB at 1558nm wavelength. But the system was designed with less capacity and low gain. Meena and Meena [21] performed 4×8 Gbps OFTS using pre, post and symmetrical dispersion compensation techniques with different pulse generators. Return to zero (RZ) pulse generator with a symmetrical approach gave the best quality factor (Q-factor) of 33.77, but the proposed system was designed for very less number of channels and data transmission rate. Rashed and Tabbour [14] designed and evaluated the Q-factor and bit error rate (BER) for 432km length of OFTS using DCF and FBG approach and Q-factor was improved by 82.45% but PWRP was not reported. Irawan et al. [22] investigated the performance of OFTS for 250km length of SMF having 90mm CFBG. The reported system achieved Q-factor of 20.7 but it's used for shorter reach. Aggrawal et al. [23] investigated the PWRP using different hybrid dispersion compensation techniques. It is found that DCF and two linearly chirped FBG with tanh apodized function gave the best PWRP of 97.9% with minimum cost compared to other dispersion techniques. But the proposed system is designed for shorter reach. Nsengiyumva et al. [24] compared two models with three stage and four stage DCF and FBG dispersion compensation techniques with different apodization functions. It is found that three stages DCF and FBG with tanh apodized function gave the better Q-factor of 18.58 compared to four stages DCF and FBG. But the system is designed for shorter reach with low performance. Gul and Ahmad [25] compared tanh and Gaussian apodized function with different chirping profile using DCF and FBG approach. It is observed that the combination of quadratic CFBG of 26.6mm grating length with Gaussian apodized function and DCF length of 11km gives better performance with low cost but the system is designed for shorter reach. Sayed et al. [26] proposed a four-uniform cascaded FBG system for 200km length of optical fiber. Q-factor of 7-14 was achieved for the proposed system with 10-6-10-10 BER. The proposed work is novel but not performed well. Sayed et al. [27] proposed a system of 110km length of optical fiber using CFBG with hamming apodization function. Q-factor using hamming apodization function is 8.27 which is best compared to other apodization functions. In this paper, a new apodization function is used by the author, but the performance of the system is not good with reference to the Q-factor. Sayed et al. [28] suggested a model using symmetrical and post dispersion compensation techniques. Performance is evaluated with reference to the Q-factor and BER and performance is increased by 21% for symmetrical dispersion compensation approach and 19% for post dispersion compensation approach compared to earlier done work. In this paper, the proposed system is designed for longer reach, but system is not suitable for a large number of channels. Yousif et al. [29] proposed a system of 100km length of optical fiber using CFBG with non-return to zero (NRZ) modulation format. Achieved Q-factor is 39.93dB at input power of 15dBm. The proposed system's performance is good with reference to the Q-factor, but at large input power. Nsengiyumva et al. [30] proposed a design using four cascaded uniform fiber

Bragg grating (UFBG) for different length of SMF with 10 Gbps and 40 Gbps data rates. The Q-factor obtained from the proposed system at 10 Gbps is 15.64dB for 150km length of SMF. The system is designed for longer reach, but the performance of the suggested model is not good with reference to the Q-factor. Mustafa et al. [31] suggested a new apodization function with CFBG technique to improve the system performance. In this paper author compared different apodization profiles for 100km length of optical fiber. The proposed model improves the Q-factor by 1.08% and decreases the BER by 52.8% with a reduction in power by 4%. This model gives good BER and power saving results, but no major improvement in Q-factor. Fathalla et al. [32] proposed a system for 100 km length of SMF using CFBG technique to overcome the problem of chromatic dispersion. Q-factor improved from 2.6dB to 27.14dB and BER is decreased from 0.0038 to 1.49e-162. The proposed model is implemented for shorter reach with low Q-factor. Zdravecký et al. [33] proposed a dense wavelength division multiplexing (DWDM) system with different types of amplifiers to increase transmission speed with low BER. The best result in terms of BER was achieved with EDFA amplifiers. All the BER values are in order of 1×10-14. The performance of the system is good, but it's designed for shorter reach. Qureshi et al. [34] proposed a model of the bi-directional DWDM system with 40 channels and 10 Gbps data rate. In this paper, pre, post and symmetric techniques with RZ and NRZ modulations are used. It is found that RZ modulation scheme gives the best performance compared to a NRZ modulation scheme. Achieved Q-factors are from 9.4 to 10.2 for all 40 channels. In the proposed model, numbers of channels are very high, but the system is designed for shorter reach with Q-factor. Bhattacharjee et al. [35] examined the performance of an OFTS using OPC-DCF approach. Q-factor of 26dB is achieved both high-cost system is designed for shorter reach. Hossian et al. [36] proposed different models using various dispersion compensation approach as pre, post, symmetrical DCF and FBG techniques. The post DCF technique gives the best result compared to FBG technique. Q-factor achieved for 10 Gbps system is 41.40dB. The system has good Q-factor, but data rate is low. Mustafa et al. [37] proposed a model using pre, post and symmetrical dispersion compensation methods with NRZ and modified duobinary (MDB) modulation schemes. It is realized that MDB modulation scheme gives better performance compared to NRZ modulation scheme. Q-factor of 8.96 is achieved using MDB scheme. Author used new modulation scheme but achieved Q-factor is very low. Palanichamy et al. [38] proposed a model using DCF, FBG and delay line filter (DLF) dispersion compensation methods. It is observed that the DLF gives best performance compared to DCF and FBG. Q-factor of 11.08 is achieved using DLF approach. In this work authors used a new approach, but less Q-factor is obtained. Bhattacharjee et al. [39] proposed a DWDM based radio over fiber (RoF) optical system using DCF and FBG techniques. Q-factor of 15.97 was obtained for 120km length of SMF. The system was designed for high data rates but low Q-factor. Mishra et al. [40] suggested a 16×40 Gbps DWDM system using DCF technique. The system was designed with different modulation formats: RZ, NRZ and carrier suppressed return to zero (CSRZ). Maximum Q-factor of 15.73 was achieved using CSRZ modulation format. Proposed system was designed with high data rates but low Q-factor.

In view of the above analysis as mentioned in introduction and literature is that the majority of researchers are interested only in DCF and FBG approaches. They were designed expensive OFTS systems for shorter reach and less capacity. In this paper, jointly DCF +FBG techniques has been designed, optimized and evaluated for longer reach and high Q-factor transmission systems.

3.Methods

3.1Uniform fiber Bragg grating

A FBG is an irregular pattern of refractive index along the length of an optical fiber, either periodic or aperiodic. In case of UFBG, refractive index along the length of optical fiber is uniform. When a light beam with a window of wavelengths is launched, only Bragg's wavelength is reflected as given by Equation 1[41, 42].

$$\lambda_{Bragg} = 2 \cdot n_{eff} \cdot \Lambda \qquad (1)$$

where λ_{Bragg} is Bragg's or reflecting wavelength, n_{eff} and Λ are effective refractive index of core and grating period of fiber, respectively.

3.2Non-uniform fiber bragg grating

An individual wavelength is returned through uniform FBGs, but for dispersion compensator, it must be chirping the grating period during the length of FBGs to return all wavelengths of occurrence pulse at different positions as reported [10]. Therefore, non-uniform grating periods are created in chirped FBG Hence, we establish a CFBGs series of gratings among various periods to reflect band or all wavelength components and generate separate time-delay for every wavelength [43, 44].

3.2.1Diverse chirped FBGs profiles

To compensate the dispersion, FBG structures need to chirp through different chirping profiles such as linear chirp (Lc), square root chirp (Sc), and cubic root chirp (Cc). These structures are apodized to improve the performance of OFTS [5, 15, 42, 45]. These chirping profiles are defined by Equation 2, 3 and 4.

Linear Chirp

$$\Lambda(z) = \Lambda_0 - \left[\frac{z-\frac{L_g}{2}}{\frac{L_g}{2}}\right]\Delta \qquad (2)$$

Square Root Chirp

$$\Lambda(z) = \Lambda_0 - \left[\sqrt{\frac{z}{L_g}} - \frac{1}{\sqrt{2}}\right]\Delta \qquad (3)$$

Cubic Root Chirp

$$\Lambda(z) = \Lambda_0 - \left[\sqrt[3]{\frac{z}{L_g}} - \frac{1}{\sqrt[3]{2}}\right]\Delta \qquad (4)$$

Where, Λ (z) indicates grating period at distance z, Λ_0 is grating period in center, Δ is overall chirp.

To sharpness these chirping profiles, tanh-apodization profile is generally used by the investigators for the best dispersion compensation [42, 45].

3.3Dispersion compensation fiber

Due to the non-linearity of the fiber, dispersion complications occur when an optical signal is sent over a long distance through SMF. Positive dispersion coefficient of SMF around 17 ps/nm-km and negative dispersion coefficient of DCF between -70 and-90 ps/nm-km have been improved and selected in the suggested model to combat dispersion. To minimize the effects of dispersion, the DCF and SMF are connected in an OFTS, as shown in *Figure 1*.

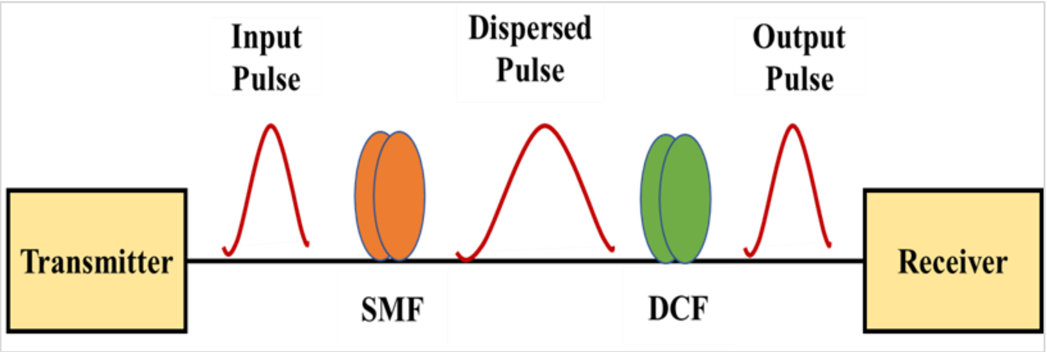

Figure 1 Basic principle of DCF technique

Therefore, the suggested model should satisfy Equations 5 and 6 for perfect dispersion compensation [43].

$$D_{SMF} \times L_{SMF} + D_{DCF} \times L_{DCF} = 0 \qquad (5)$$

$$L_{DCF} = -L_{SMF}\left(\frac{D_{SMF}}{D_{DCF}}\right) \qquad (6)$$

Where, D_{SMF} =Dispersion of SMF; D_{DCF} = Dispersion of DCF; L_{SMF} = Length of SMF; L_{DCF} = Length of DCF.

3.4Proposed model

The proposed model was designed using different chirped FBGs, DCF and joint DCF-FBG techniques for dispersion compensation. In FBG, different chirping functions are used as linear-chirp FBG (Lc-FBG), square root chirp FBG (Sc-FBG), and cubic root chirp FBG (Cc-FBG). The proposed model is shown in *Figure 2*. Designed system is allocated into three units which are transmitter unit, transmission link and receiver unit. In transmitter unit, 10Gbps bit data rate is generated in the form of binary data with the help of pseudo random bit sequence (PRBS). This binary data is transfigured into an electrical signal at the hand of the pulse generator. Continuous wave laser (CWL) generates the light continuously and Mach-Zehnder modulator (MZM) modulated these lights according to pulse generator signal. Extinction-ratio of MZM is to be choosing 30dB. *Figure 2* depicts the generated optical signals transmitted over SMF while considering various chirping FBG, DCF, and joint DCF+FBG. This is referred to as a transmission link. As a result, the transmission link unit is being investigated using various position falls of Lc-FBG/Sc-FBG/Cc-FBG, DCF, and joint DCF-FBG as dispersion compensators. As a result, the optimization is performed for the 300km length of the SMF transmission link. The proposed model was implemented on the Opti-system simulator. Further, all components and optimized parameters allied to the different chirping FBGs, SMF, DCF, and EDFA for the designed OFTS systems are organized in *Table 1* and *Table 2*. Furthermore, in *Figure 3* physical arrangement of different CFBGs, DCF and Joint DCF+FBG are shown. In receiver unit, positive-intrinsic-negative (PIN) photo detector is used for sensing optical signal and that optical signal is transmitted through the low pass Bessel filter (LPBF). Further, re-amplification, re-shaping and re-timing (3R-Regenerator) are used to recover the bit sequence. Then, the PWRP, BER, Q-factor, and eye-diagrams are calculated using the BER/Eye analyzer.

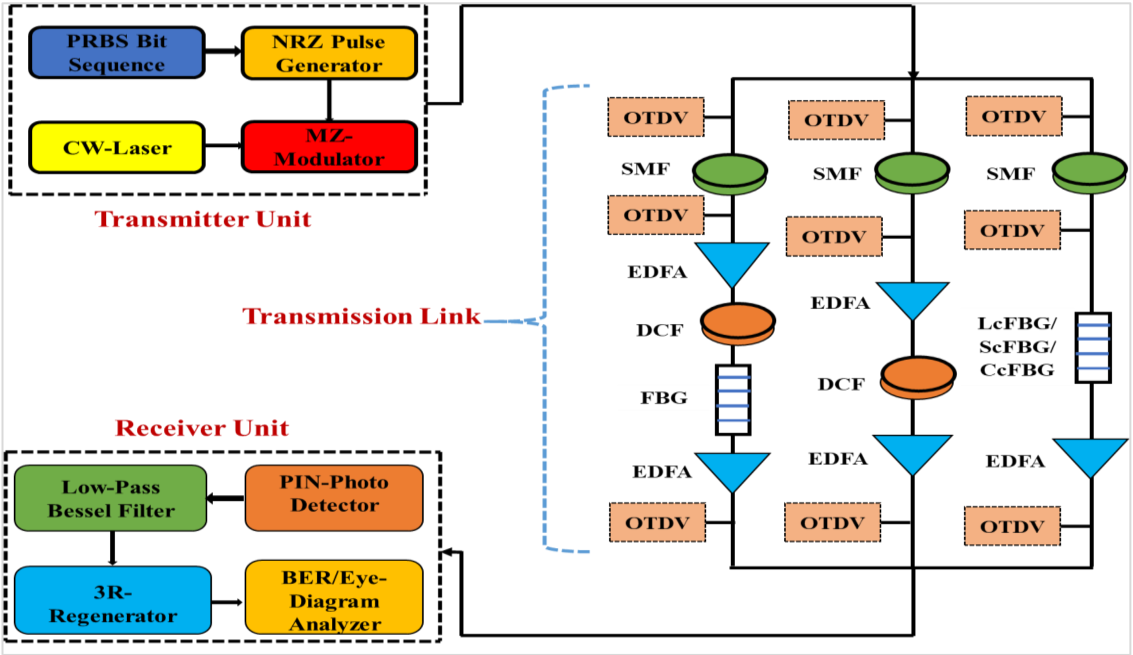

Figure 2 Proposed modal to evaluate the performance of different CFBGs, DCF, and joint DCF+FBG dispersion compensation techniques

Table 1 All parameters with optimized value of proposed optical transmission systems

Components	Parameters	Values
Data source	Data Rate	10 Gbps
	Sample per bit	64
	Sequence length	128
Pulse Generator	NRZ	Exponential
	Rise time	0.05 bits
	Fall time	0.05 bits
CW Laser	Output power	0dBm
	Central frequency	193.1THz
MZ-Modulator	Extinction ratio	30dB
	Insertion loss	5dB
Single Mode Fiber	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	80μm^2
	Reference wavelength	1550nm
DCF Fiber	Length	60km
	Dispersion	-85ps/nm/km
	Dispersion slope	-0.37(ps/nm2/km)
	Attenuation loss	0.4dB/km

Components	**Parameters**	**Values**
	Differential group delay	0.2ps/km
	Core-effective-area	$80\mu m^2$
	Reference wavelength	1550nm
EDFA amplifier	Gain	10-20dB
	Noise figure	4dB
PIN Photo-detector	Responsivity	1A/W
	Error probability	10^{-9}

Table 2 Optimized simulated parameters for different chirped FBGs

Parameters	**Values**
Length of chirped FBGs (mm)	49 for Lc-FBG 35 for Sc-FBG 28 for Cc-FBG
Chirp parameter	0.0001
Modulation AC	0.0001
Effective index	1.95
Apodization function	Tanh
Tanh parameter	4

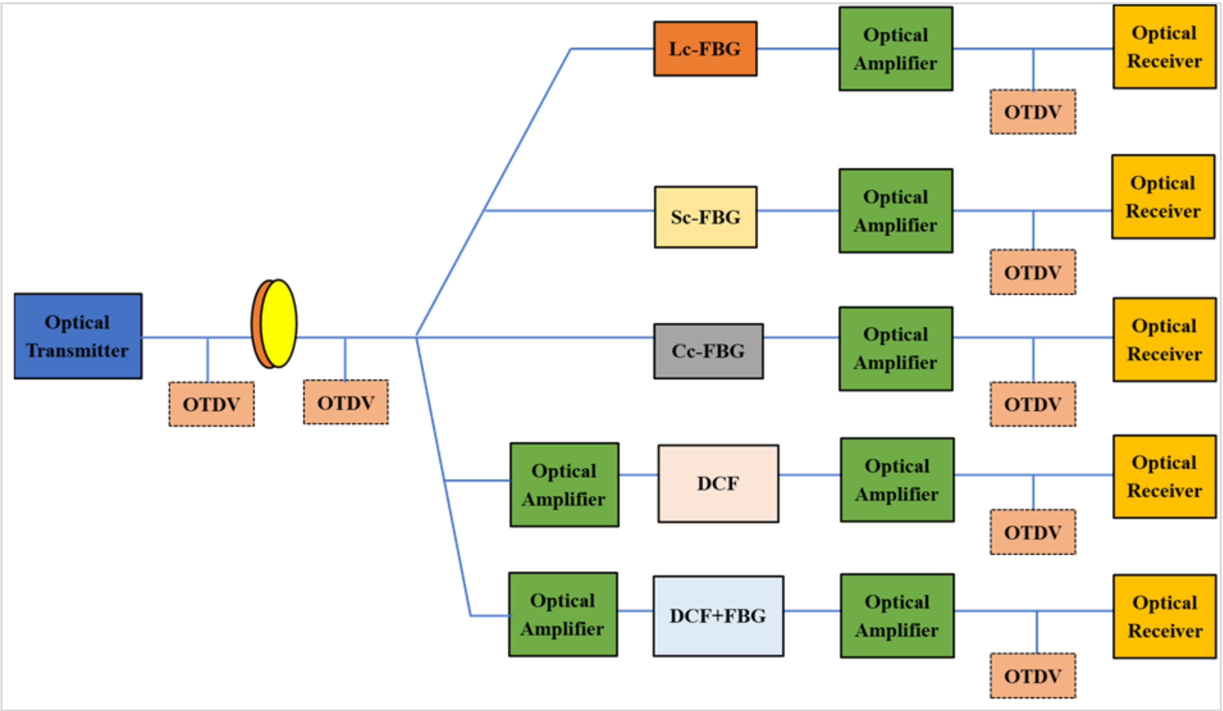

Figure 3 Physical arrangement of different CFBGs, DCF and joint DCF+FBG techniques for comparative performance evaluation of proposed model

4.Results

The proposed OFTS is investigated to carry out the optimum pulse-width-reduction-percentage for long-haul communication systems. For that purpose, PWRP is the effective parameter of estimating the level of modifying dispersion through each of our used dispersion compensation techniques. Thus, we assume that the width of the original transmitted pulse is W_{TX} and pulse width after transmitted through SMF will be expended having a pulse width of W_{SMF} is called dispersion. Then, after applying our proposed dispersion compensation techniques, the pulse width is given by W_{DCT}. Further, the PWRP can be calculated as given by Equation 7 [1, 5]:

$$\text{PWRP} = \frac{W_{SMF}-W_{DCT}}{W_{SMF}-W_{TX}} \qquad (7)$$

The transmitted optical pulse signals can be pictured through optical time domain visualizer (OTDV). The additional parameters like Q-factor, BER, pulse amplitude and shapes of eye-diagrams can be inferred directly from figures as well as BER/Eye analyzer.

4.1Transmitted Pulse before/after SMF

The optical pulse signal of the proposed system is visualized through OTDV before and after transmission over 300km length of SMF. Before transmission, the width of original pulse is around 104ps with 1mW amplitude as illustrated in *Figure 4*. Thereafter, when a pulse is transmitted over 300km length of SMF, the output of OTDV as pulse-width is 198ps and amplitude is 10µW. Therefore, we can get the expended pulse-width having a reduced pulse amplitude is visible in *Figure 5*.

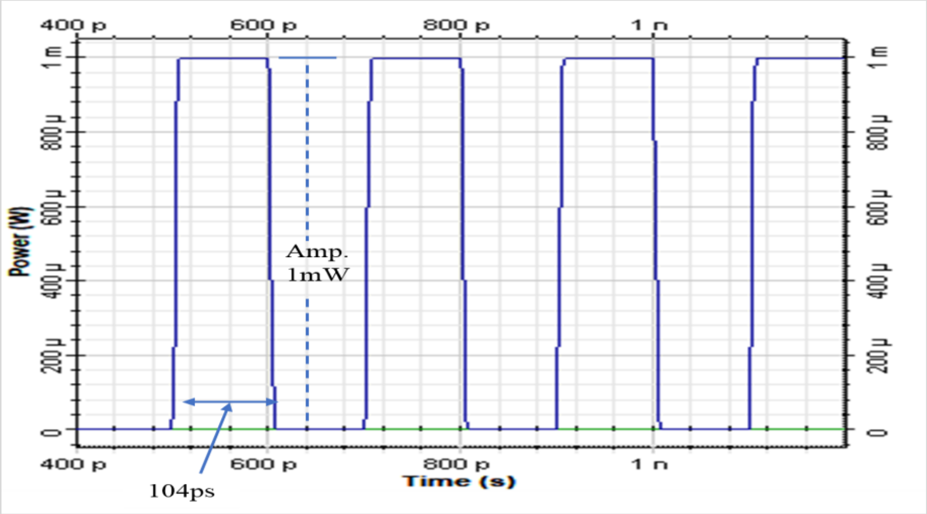

Figure 4 Transmitted optical signal pulse

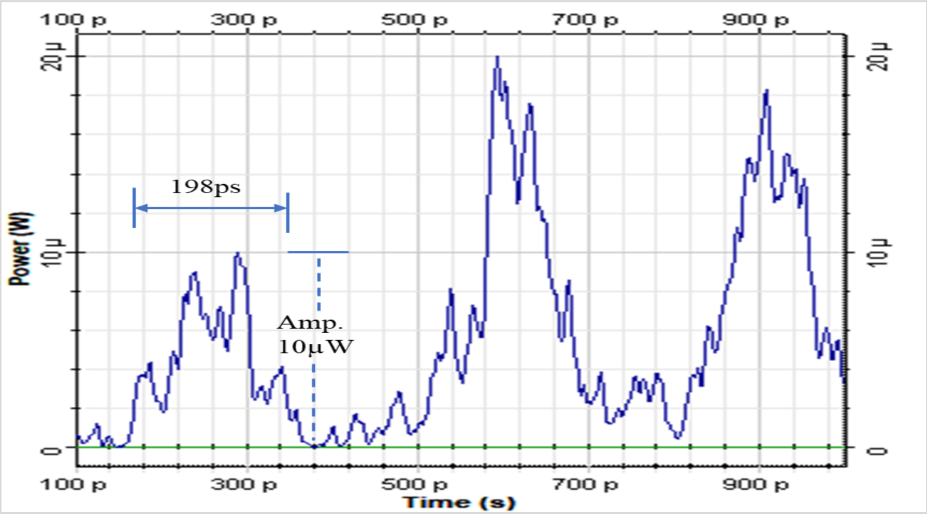

Figure 5 Transmitted optical signal pulse after 300km length of SMF

4.2Dispersion compensation with different chirped FBGs techniques

In this section the performance as PWRP for a different chirping profile of FBGs are evaluated and discussed to overcome the dispersion level. Using Lc-FBG, the width of pulse, amplitude are 124ps and 1.13mW, respectively is visible in *Figure 6*. Thus, the calculated PWRP of 78.72% is attained and good pulse-shape is attained using Lc-FBG. Further, when Sc-FBG is used, the width of the pulse, amplitude are 138ps and 1.33mW, respectively as can be seen in *Figure 7*. Thus, calculated PWRP of 63.82% is achieved with fair pulse-shape. Furthermore, when Cc-FBG is used, width of the pulse is 148ps and amplitude is 1.27mW as can be seen in *Figure 8*. Hence, the calculated PWRP of 53.19% is achieved with worst pulse-shape.

4.3Dispersion compensation with DCF technique

To overcome the dispersion phenomena, the best profitable DCF technique is used. In the proposed set-up with existing parameters, the optimized length and dispersion of DCF are 60km, -85ps/nm.km, respectively to produce an optimum performance. Therefore, the SMF dispersion coefficient approximately 17ps/nm-km has been optimized for 300km length of optical fiber. Therefore, the proposed system investigation through DCF technique revelations that the attained pulse-width, amplitude are 110ps and 1.55mW, respectively as can be seen in *Figure 9*. Hence, higher PWRP of 93.61% is achieved with better pulse-shape than all different chirping FBGs techniques.

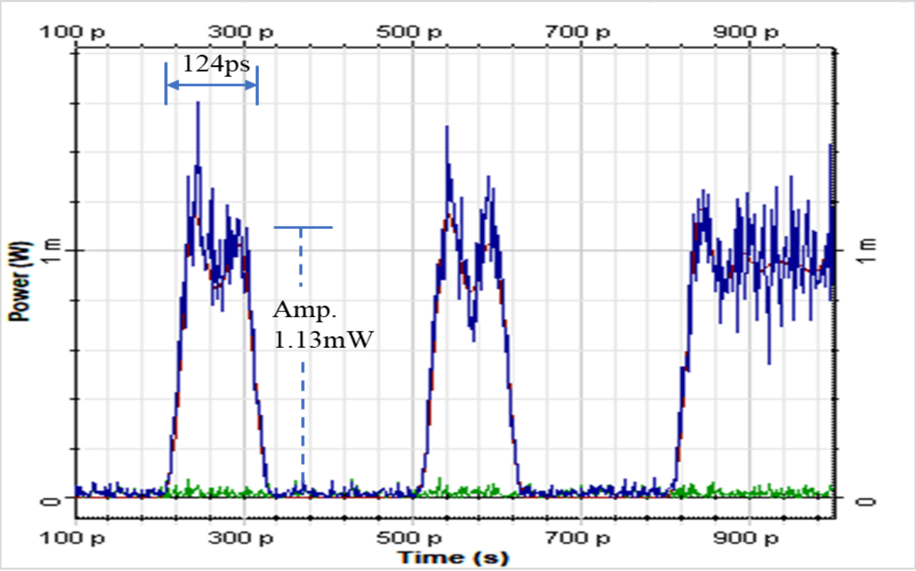

Figure 6 Transmitted optical signal pulse after Lc-FBG and EDFA optical amplifier

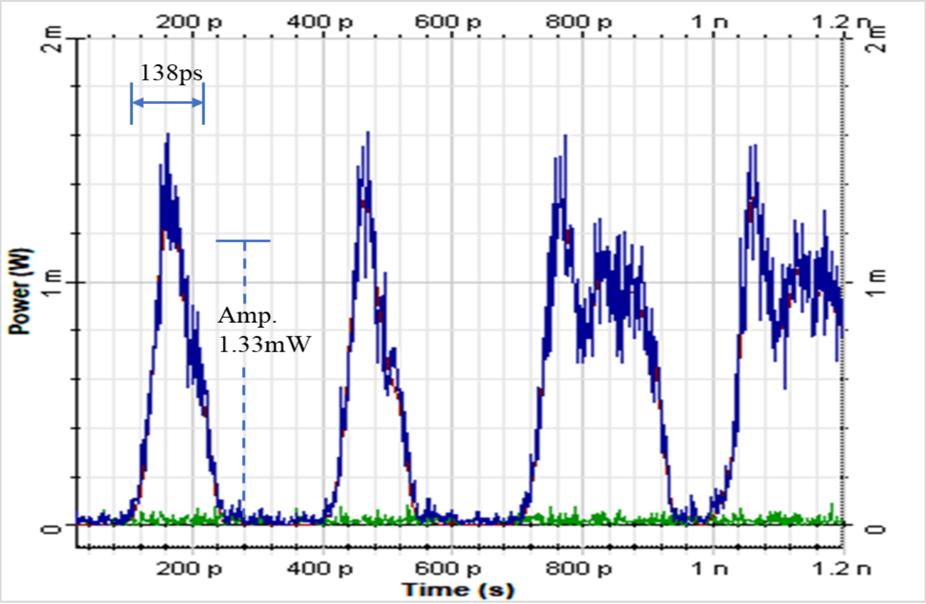

Figure 7 Transmitted optical signal pulse after Sc-FBG and EDFA optical amplifier

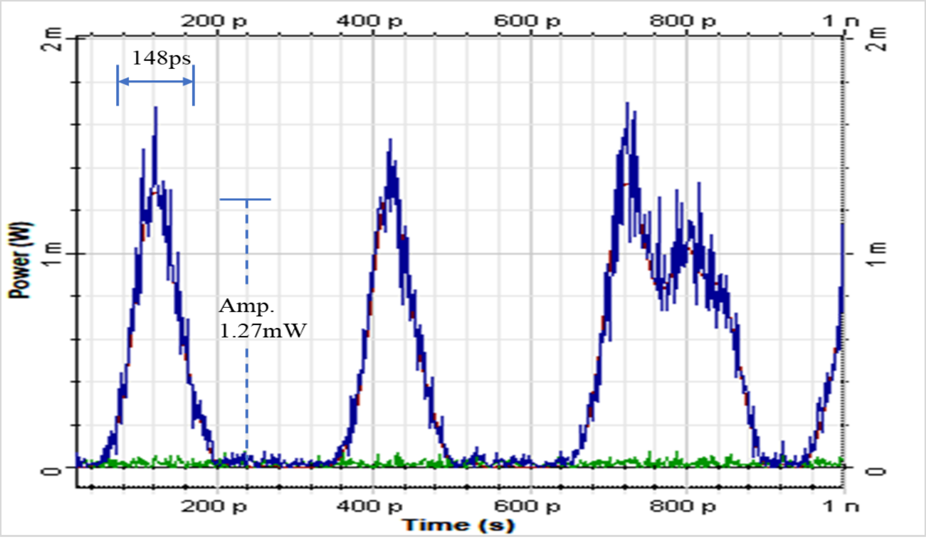

Figure 8 Transmitted optical signal pulse after Cc-FBG and EDFA optical amplifier

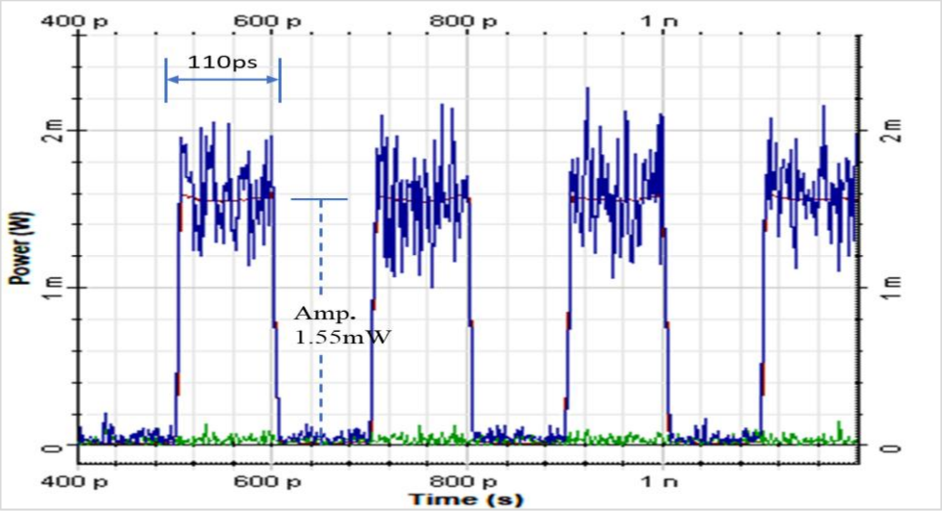

Figure 9 Transmitted optical signal pulse after DCF and EDFA optical amplifier

4.4Dispersion compensation with joint DCF+FBG technique

To mitigate the dispersion, DCF with uniform FBG technique is investigated jointly. The existing parameters of DCF and SMF are remains same, but uniform FBG are optimized through mathematical trials to attain improved performance. Using jointly DCF+FBG technique, attained pulse-width and amplitude is 108ps and 1.50mW, respectively as can be seen in *Figure 10*. Thus, the calculated PWRP of 95.74% is achieved through jointly DCF+ FBG technique.

5.Discussion

Table 3 provides a comparison of all mentioned dispersion compensation approaches. *Table 3* shows that Lc-FBG performed better as compared to other chirped FBG techniques. The attained Q-factor, PWRP using Lc-FBG is 22.98 and 78.72%, respectively. Further, the obtained Q-factor, PWRP using the DCF technique is 24.50 and 93.61%, respectively. Therefore, the DCF technique gives very good performance using an optimized length of 60km. Furthermore, the achieved Q-factor, PWRP via jointly DCF+FBG technique is 29.63 and 95.74%, respectively. In view of above analysis and discussions, among all the dispersion compensation techniques, the joint DCF+FBG technique gives the best performance. Furthermore, the simulated eye-patterns for various dispersion compensation techniques are shown in *Figure 11*. It can be observed from *Figure 11*, among all the chirped

FBG, Lc-FBG gives the clear eye-opening diagram and very clear eye-shape is obtained for joint DCF+FBG techniques as compared to different chirped FBG and DCF techniques.

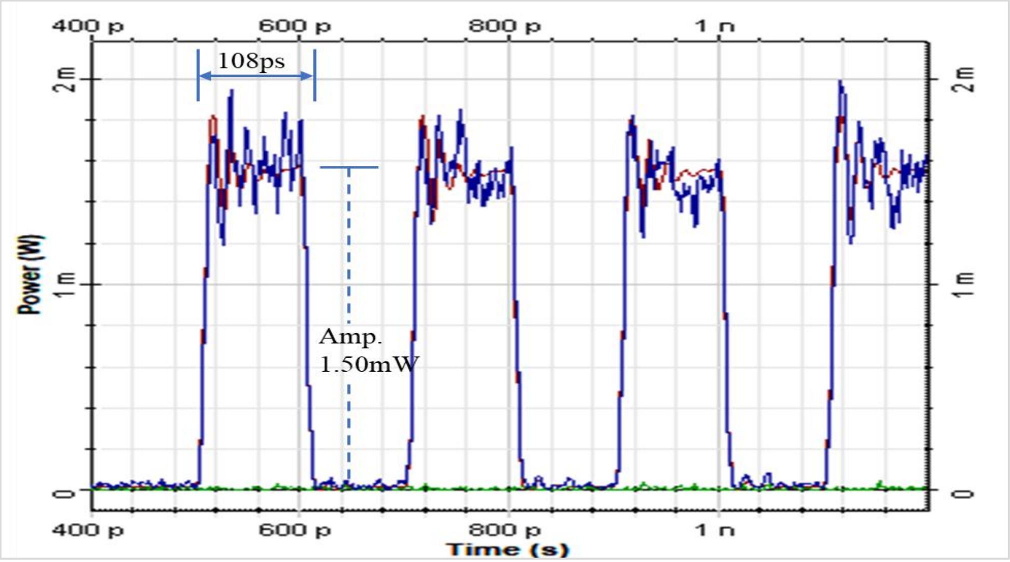

Figure 10 Transmitted optical signal pulse after DCF+FBG and EDFA optical amplifier

Table 3 Comparative analysis of different dispersion compensation techniques

Parameters	Lc-FBG	Sc-FBG	Cc-FBG	DCF	DCF+FBG
Q-Factor	22.98	14.22	9.35	24.50	29.63
BER	2.22e-11	3.24e-04	3.75e-02	5.67e-13	1.72e-19
PWRP	78.72%	63.82%	53.19%	93.61%	95.74%
Amplitude	1.13mW	1.33mW	1.27mW	1.55mW	1.50mW

Further, a comparative analysis between quality factors versus different dispersion compensation techniques is shown in *Figure 12*. It can be observed from *Figure 12* that the jointly DCF+FBG technique gives the highest quality factor which is around 29.63 as compared to different chirped FBG and DCF techniques.

Moreover, a comparative analysis between PWRP versus different dispersion compensation techniques is shown in *Figure 13*. It can be observed from *Figure 13* that the joint DCF+FBG technique gives best pulse-width-reduction-percentage about 95.74% when we compared to all other dispersion compensation techniques.

Furthermore, *Table 4* shows the Q-factor at various input power levels for various dispersion compensation techniques. It is clear from the *Table 4* the Q-factor increases along with an increase in input power. Only in case of DCF and joint DCF+FBG, Q-factor is reduced when more power is applied. Furthermore, Q-factor of different chirping profile with different apodization functions are shown in *Table 5*. It is clear from the *Table 5*, Lc-FBG gives the best Q-factor among all chirping profiles. It has 3.80 for uniform, 14.77 for Gaussian and 22.98 for Tanh apodization functions. Furthermore, the proposed model is also compared with previously reported optical transmission systems as dispersion compensator by the researchers in literature as shown in *Table 6*.

5.1Limitations

In this paper, different dispersion compensation methods such as: DCF, chirped FBG and joint DCF+FBG are used to improve the PWRP of the received signal. The joint DCF+FBG technique gives the best PWRP compared to DCF and chirped FBG approaches. However, the DCF is a costly entity, hence, the length of DCF is a limiting factor to keep the overall cost under control.

A complete list of abbreviations is shown in *Appendix I.*

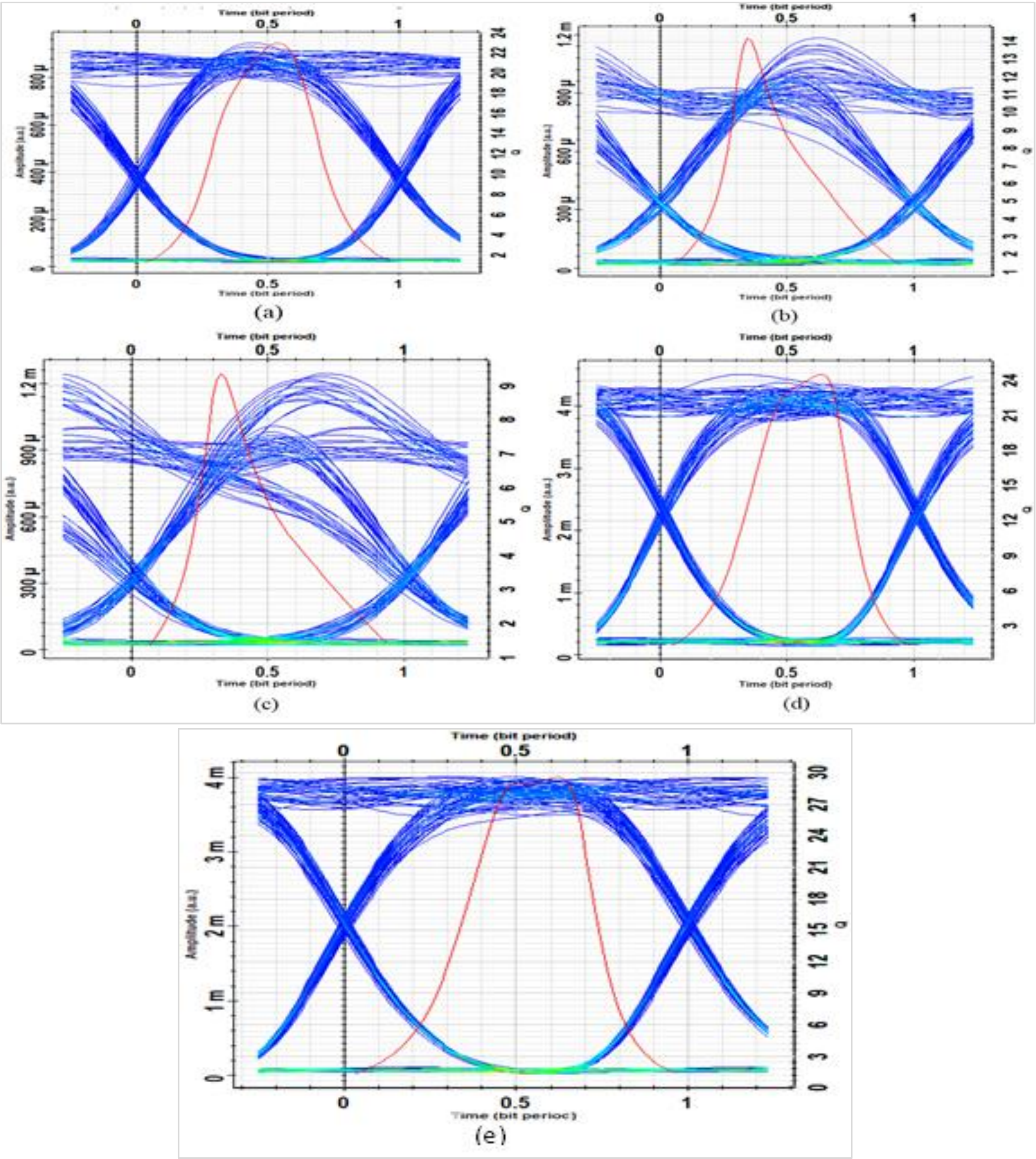

Figure 11 Simulated Eye-diagrams using different dispersion compensation techniques (a) Lc-FBG; (b) Sc-FBG; (c) Cc-FBG; (d) DCF; (e) DCF+FBG

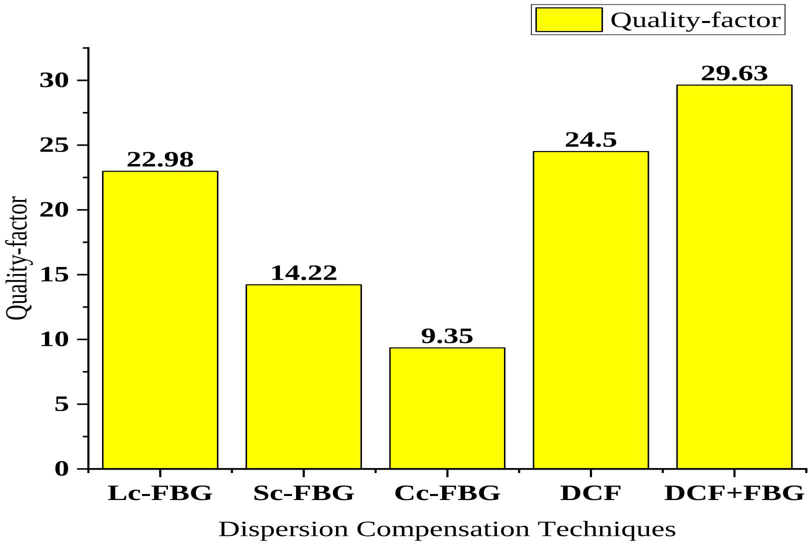

Figure 12 Comparative analysis of quality factors vs. different dispersion compensation techniques

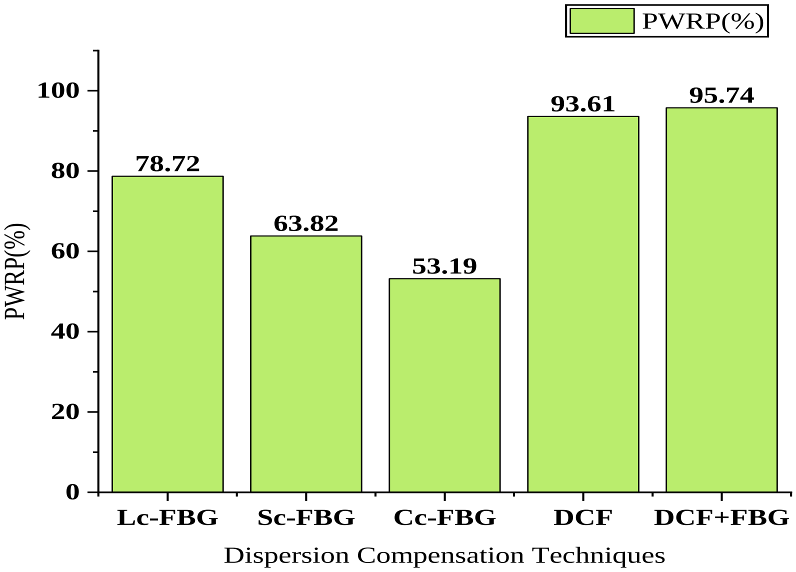

Figure 13 Comparative analysis of PWRP vs. different dispersion compensation techniques

Table 4 Q-factor of different dispersion compensation techniques at different input power levels

Input power (dBm)	Lc-FBG	Sc-FBG	Cc-FBG	DCF	DCF+FBG
-2	18.57	12.98	8.88	20.51	24.63
-1	20.71	13.64	9.13	22.74	27.31
0	22.98	14.22	9.35	24.50	29.63
1	25.40	14.70	9.52	25.23	30.74
2	27.87	15.07	9.65	24.43	29.59

Table 5 Q-factor of different chirping profile with different apodization function

Chirp profile	Uniform	Gaussian	Tanh
Lc-FBG	3.80	14.77	22.98
Sc-FBG	3.17	8.58	14.22
Cc-FBG	3.49	5.16	9.35

Table 6 Overall comparative investigation of suggested work with previously done work in literature

References	Investigation/Accomplishment	Performance	Conclusion
Aggarwal et al. [1], 2021	Explored the performance of hybrid dispersion compensation techniques for 300km OFTS	PWRP via FBG+DCF technique is 55% and FBG+DCF+OPC is 70%	Longer-haul, medium performance, moderate cost
Dar et al. [5], 2016	Explored the performance of different chirping profiles of Tan-apodized FBG and DCF for 100km OFTS	PWRP via DCF technique is 94.45% and DCF-FBG technique is 96.96%	Shorter reach, high performance, cost effective
Mohammed et al. [15], 2014	Explored the performance of different chirping functions for 100km OFTS	PWRP via DCF technique is 93.34% and DCF-FBG technique is 96.36%	Shorter reach, good performance, medium cost
Badar and Anisha [16], 2015	Investigated the performance of the 120km OFTS using FBG+DCF, FBG+OPC, and OPC+DCF approaches.	Q-factor = 35.4, PWRP= NA	Shorter reach, less capacity, high cost
Neheeda et al. [17], 2016	Investigated the 320km OFTS performance evaluation using pre, post, and symmetric DCF approaches.	Q-factor = 6.96, PWRP= NA	Long-haul, medium performance, high cost
Kaur and Singh [18], 2017	Investigated the performance of pre, post, and symmetric DCF approaches for 150km OFTS.	Q-factor = 36.3, PWRP= NA	Shorter reach, less capacity, high cost
Tahhan et al. [19], 2017	Explored the performance of FBG & FBG-EDFA techniques for 120km OFTS	Q-factor = 6, PWRP= NA	Shorter reach, medium performance, medium cost
Chakkour et al. [20], 2020	Explored the performance of DCF & FBG techniques for 500km OFTS	Q-factor = 11.5, PWRP= NA	Long-haul, less capacity, low cost
Irawan et al. [22], 2022	Investigate CFBG technique for 250km length of SMF with 90mm length of CFBG	Q-factor 20.7, PWRP=NA	Shorter reach, less capacity
Proposed Work	Explored the performance analysis of diverse chirped FBG, DCF and Joint DCF+FBG technique for 300km OFTS	PWRP via DCF technique is 93.61% and DCF+FBG technique is 95.74%	Longer reach, high performance, medium cost

6.Conclusion and future work

This paper investigates the performance of 300km OFTS having 10Gbps data-rate through different CFBGs, DCF and joint DCF+FBG techniques. Performance is evaluated, deliberated and compared with reference to PWRP, Q-Factor, BER, pulse amplitude and eye-diagrams. Among different chirping FBG, the Lc-FBG gives good performance with 78.72% PWRP and 22.98 Q-factor. Using DCF the attained PWRP, Q-factor is 93.61% and 24.50, respectively. Joint DCF+FBG technique were obtained the PWRP of 95.74% and Q-factor of 29.63. It is observed from the analyzed and discussed results, the joint DCF+FBG techniques give better pulse-shape having 95.74% PWRP, Q-factor >29, minimum BER and better eye-opening of received signal. Furthermore, the comparative analysis of the proposed work is also carried out with earlier reported OFTS as dispersion compensator [1, 5, 15–20, 22]. In future, the proposed system can be designed through OPC-DCF-FBG techniques as a hybrid dispersion compensator for DWDM, OFTS.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Author’s contribution statement

Raj Kumar Gupta: Methodology, data investigation, data collection, manuscript draft preparation, interpretation of results. **Dr. M. L. Meena:** Study conceptualization, design supervision, interpretation of results, manuscript review and editing.

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Appendix I

S. No.	Abbreviation	Description
1	BER	Bit Error Rate
2	Cc	Cubic Root Chirp
3	Cc-FBG	Cubic Root Chirp Fiber Bragg Grating
4	CFBG	Chirped Fiber Bragg Grating
5	CSRZ	Carrier Suppressed Return to Zero
6	CWL	Continuous Wave Laser
7	DCF	Dispersion Compensation Fiber
8	DLF	Delay Line Filter
9	DWDM	Dense Wavelength Division Multiplexing
10	EDFA	Erbium Doped Fiber Amplifier
11	FBG	Fiber Bragg Grating
12	Lc	Linear Chirp
13	Lc-FBG	Linear Chirp Fiber Bragg Grating
14	LPBF	Low Pass Bessel Filter
15	MDB	Modified Duobinary
16	MZM	Mach-Zehnder Modulator
17	NA	Not Available
18	NRZ	Non-Return to Zero
19	OFTS	Optical Fiber Transmission Systems
20	OPC	Optical Phase Conjugation
21	OTDV	Optical Time Domain Visualizer
22	PIN	Positive-Intrinsic-Negative
23	PRBS	Pseudo Random Bit Sequence
24	PWB	Pulse Width Broadening
25	PWRP	Pulse Width Reduction Percentage
26	Q-Factor	Quality Factor
27	RA	Raman Amplifier
28	RoF	Radio Over Fiber
29	RZ	Return to Zero
30	Sc	Square Root Chirp
31	Sc-FBG	Square Root Chirp Fiber Bragg Grating
32	SMF	Single Mode Fiber
33	SOA	Semiconductor Optical Amplifiers
34	UFBG	Uniform Fiber Bragg Grating
35	WDM	Wavelength Division Multiplexing