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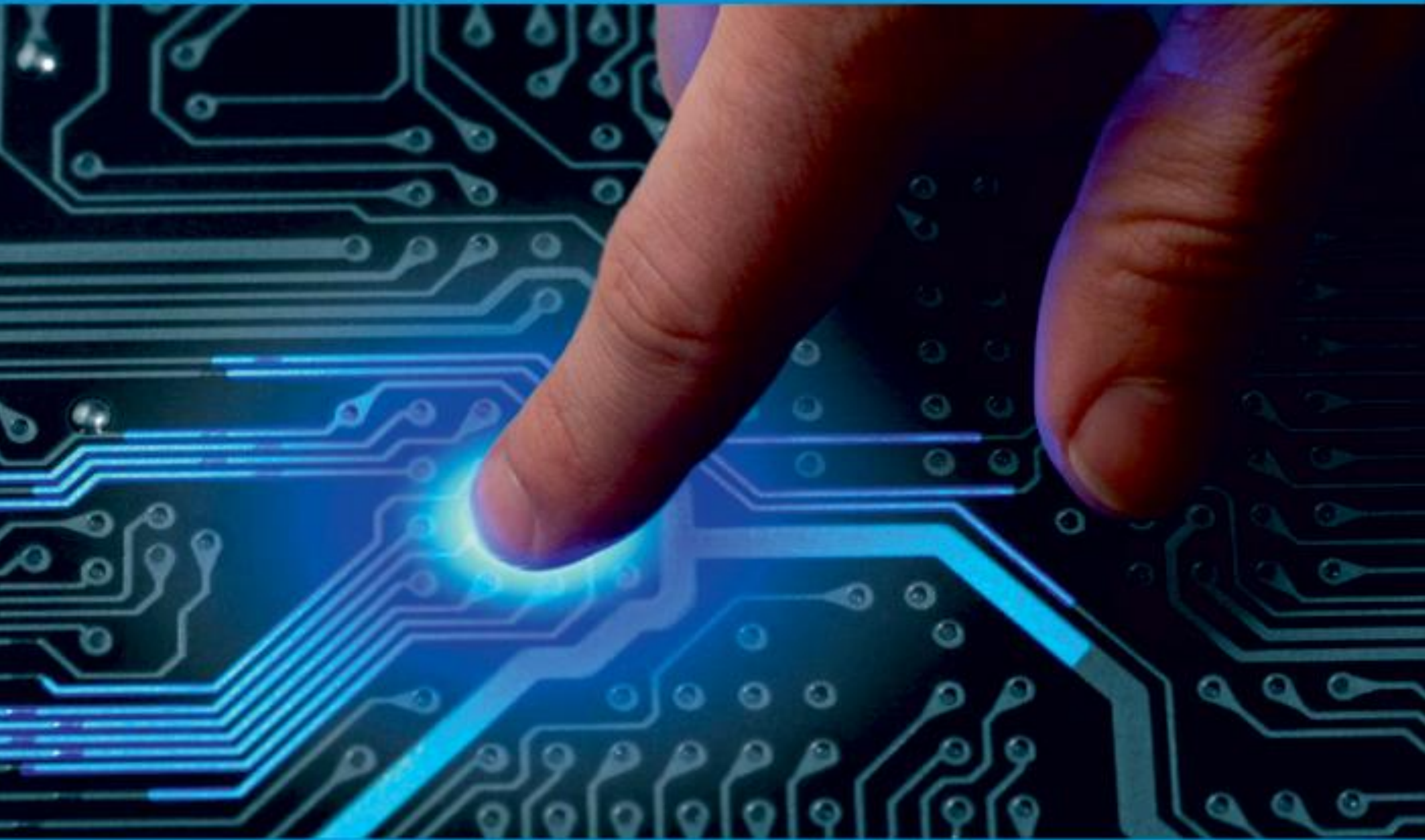

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Differential Quadrature Phase Shift Keying (DQPSK) Incorporated Chromatic Dispersion Compensation Using Hybrid DCF-FBG Module

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ABSTRACT: Long reach high speed optical networks are among the prime necessities of current generation internet services nowadays. Chromatic dispersion is one of the major constraints that optical fiber networks are facing for delivering data at distant optical network units. In this research work, a 10 Gbps chromatic dispersion compensated optical communication system is presented by employing differential quadrature phase shift keying (DQPSK) and hybrid dispersion compensation fiber (DCF) and fiber bragg grating (FBG) module. A cost effective, less complex and high performance based hybrid DCF-FBG module is introduced in three different configurations such as pre, post and symmetrical. Results revealed that hybrid DCF-FBG module provide excellent performance in post configuration and offered Q factor 23.22 and bit error rate (BER) 10^{-119}. Further, the presented system is compared with four-stage FBG dispersion compensation system employing duo-binary return to zero (DRZ), modified duo binary return to zero (MDRZ) and non return to zero (NRZ) system. It is observed that proposed system has 100% more performance efficiency than NRZ in post configuration, 37.94% than DRZ and 82.34% than DRZ.

KEYWORDS: DQPSK, DCF, FBG, DRZ, MDRZ

I. INTRODUCTION

Optical fiber transmission systems have the great potential to transmit data over long distances at high speeds with least losses that has revolutionised the worlds of telecommunications and medicine [1]. The signal degradation due to attenuation and pulse width broadening are the two major limitations in optical fiber that limit the overall reach of the system [2]. Erbium doped fiber amplifier (EDFA) is widely adopted optical amplifier for attenuation eradication and preferred in conventional band wavelength window [3]. The performance of optical communication systems can be greatly impacted by the group velocity dispersion (GVD). Different light wavelengths propagate at different speeds in a dispersive medium, such an optical fibre, which leads to GVD [4]. As a result of this phenomenon, optical pulses expand as they pass through the fibre, which has a number of detrimental impacts. As the pulses go through the fibre, their temporal spread widens and they start to overlap with one another. Intersymbol interference (ISI), in which signals from one pulse interfere with those from adjacent pulses, can result from this overlapping [5]. Dispersion compensating fibers (DCFs) are a practical solution to mitigate the effects of group velocity dispersion (GVD) in optical communication systems. DCFs are specially designed fibers with a negative dispersion coefficient, typically used in combination with standard single-mode fibers (SMF) that have positive dispersion. Proper design and placement are crucial to effectively compensate for dispersion without introducing other impairments. Efficient compensation reduces the need for multiple components and lowers overall system cost [6]. Fiber bragg gratings (FBGs) are designed to reflect light at specific wavelengths that experience dispersion, effectively compressing the broadened pulse. FBGs are periodic variations in the refractive index of a fiber core, reflecting specific wavelengths [7]. There are different types of FBGs models such as uniform, chirped, tilted, phase shifted and apodized. The apodization function in FBGs derive the performance and basic principle of narrowing the full width at half maximum (FWHM) with a suitable degree of reflectivity is the basis for employing FBG as a dispersion compensator. Multiple stages of apodized FBGs are deployed in [8] for reducing the FWHM but comes at the cost of high complexity.

A dispersion compensated pre, post and symmetrical configurations of DCF was deployed in [9] and used 21.25 km DCF for 100 km SMF and offered 14.9536 Q factor. Further in [10], FBG was cascaded with the DCF for improving the system performance. The system was investigated for different duty cycles and modulation methods. The outcomes revealed that with the incorporation of FBG cascaded with FBG can provide enhanced performance. Chirped FBG in eight channels and 150 km SMF based system was presented utilizing RZ, 45 mm FBG and 30 km DCF [11]. In [8], the 4-stage tan apodized and linear chirped FBG were deployed for chromatic dispersion compensation over 100 km SMF link in pre, post and symmetrical configuration. Moreover, they compared DRZ, MDRZ and NRZ for performance analysis and revealed that DRZ offered highest Q factor 14.41 in post configuration. However, there are several issues such as 4-stage FBG introduce high complexity and fault emerging risks, less performance and more BER.

In this work, a 10 Gbps chromatic dispersion compensated optical communication system is presented by employing DQPSK and hybrid DCF-FBG module. A cost effective, less complex and high performance based hybrid DCF-FBG module is introduced in three different configurations such as pre, post and symmetrical. Results revealed that hybrid DCF-FBG module provide excellent performance in post configuration and offered Q factor 23.22 and bit error rate (BER) 10^{-119}. Further, the presented system is compared with four-stage FBG dispersion compensation system employing DRZ, MDRZ and NRZ system. It is observed that proposed system has 100% more performance efficiency than NRZ in post configuration, 37.94% than DRZ and 82.34% than DRZ.

The presented research paper is organized as: Section 1 elaborated the background and literature in the context of dispersion compensation and component used. Section 2 discusses about the system setup of the proposed work and Section 3 shows the performance investigation. Conclusion and future scope are given in Section 4.

II. SYSTEM SETUP

For the simulation of proposed DQPSK based dispersion eradicated system, an optisystem software is employed. First and foremost, the global parameters of the simulation are fixed such as data rate is fixed to 10 Gbps and total 16384 numbers of samples are used. A DQPSK transmitter consisting of 1553.6 nm laser with launched power 0 dBm, three mach zehndar modulators (MZMs) having different operating points, NRZ pulse generators, 4-dpsk precoder, and sine generator as shown in Figure 1.

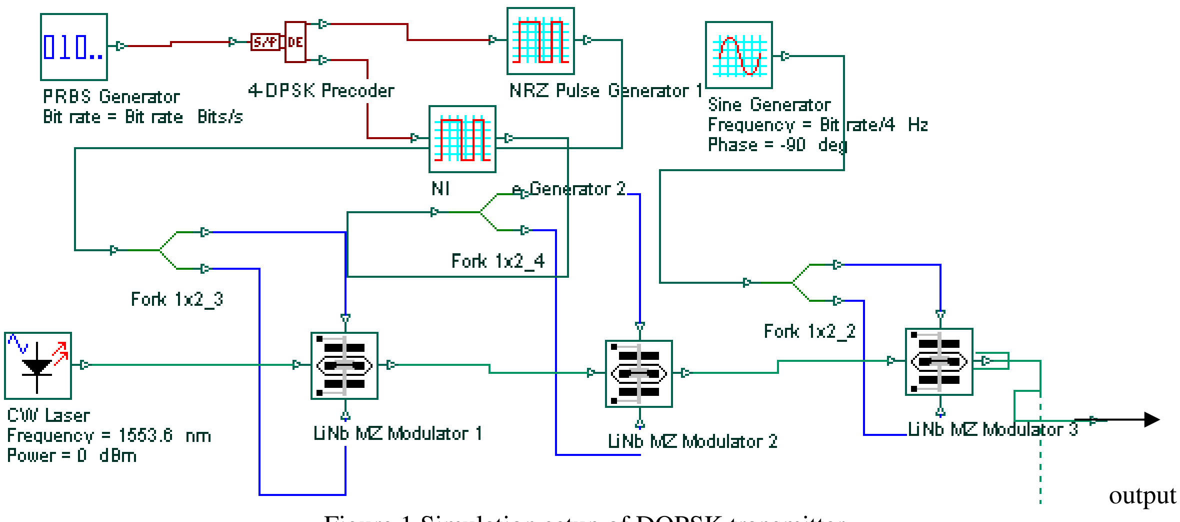

Figure 1 Simulation setup of DQPSK transmitter

There are three different arrangements of dispersion compensation hybrid DCF-FBG module as shown in Figure 2 for (a) pre (b) post and (c) symmetrical arrangement.

(a) Pre Configuration

In pre compensation, the hybrid DCF-FBG unit is placed prior to the 100 km SMF. The presented hybrid DCF-FBG module has 3 km DCF link, 1mm tan apodized linear chirped FBG. The value of tanh parameter is fixed to 0.5 and linear parameter 0.0001 µm. After the SMF, for the eradication of signal degradations, an EDFA with 40 dB gain and 4 dB noise figure was utilized. Optical spectrum analyzers, and optical time domain signal analyzers are placed after regular intervals for the monitoring. In this configuration, output pulse from transmitter is passed through hybrid DCF-FBG unit and it reduces the pulse width. The FWHM reduced pulse then fed to 100 km SMF and pulse broadening happened here at the rate of the 17 ps/nm/km. Signal amplified with EDFA and at the receiver, these signals are divided

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into two parts for phase demodulation at the DQPSK receiver. DQPSK receiver consists of PIN photo-detection based balanced detection, couplers, time delay, a phase shifter, substractor, low pass Bessel filter, regenerator and BER analyzer as shown in Figure 3.

(b) Post Configuration

In post compensation, the hybrid DCF-FBG unit is placed after the 100 km SMF. The presented hybrid DCF-FBG module has 3 km DCF link, 1mm tan apodized linear chirped FBG. In this configuration, signal gets broadened in 100 km SMF prior to the dispersion compensation unit. After the SMF, for the eradication of signal degradations, an EDFA with 40 dB gain and 4 dB noise figure was utilized. Signal amplified with EDFA and at the receiver, these signals are divided into two parts for phase demodulation at the DQPSK receiver. DQPSK receiver consists of PIN photo-detection based balanced detection, couplers, time delay, a phase shifter, substractor, low pass Bessel filter, regenerator and BER analyzer.

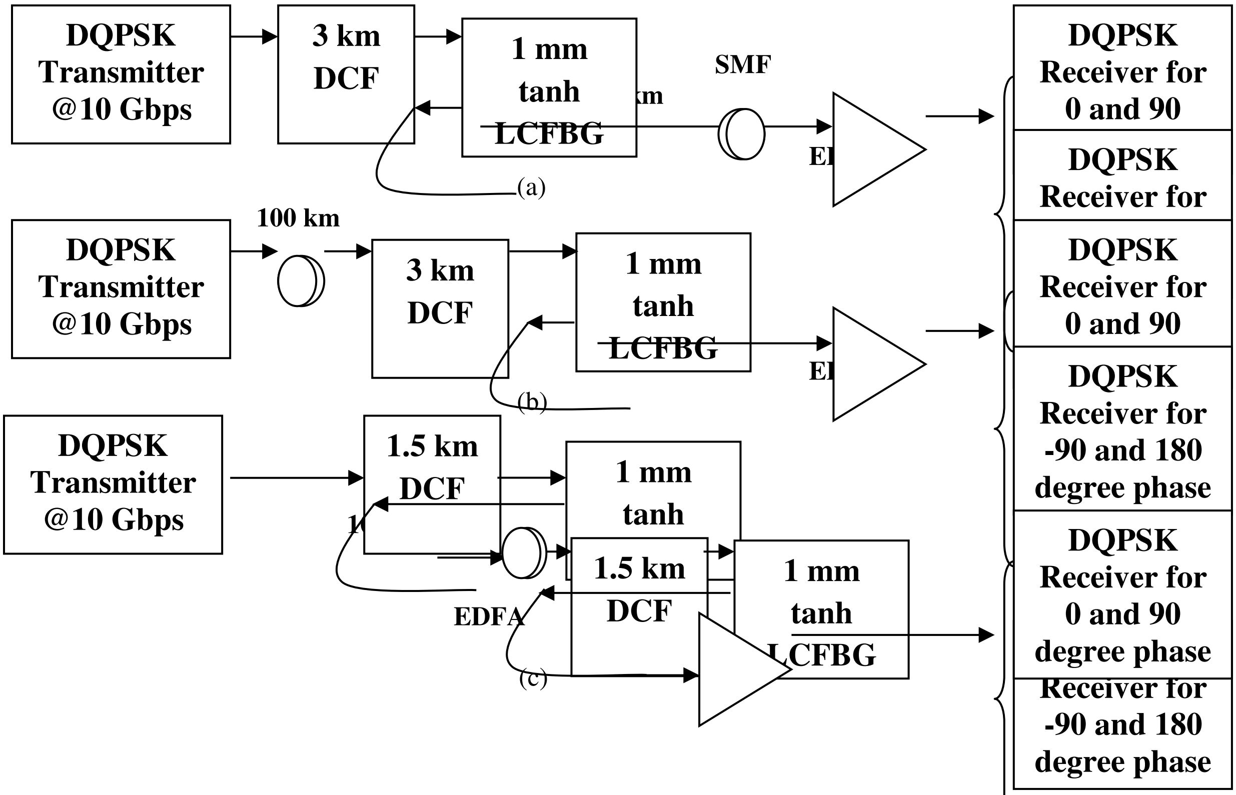

Figure 2 Hybrid DCF-FBG arrangements in (a) pre (b) post and (c) symmetrical configurations

(c) Symmetrical Configuration

In symmetrical compensation, the hybrid DCF-FBG unit with 1.5 km DCF and 0.5 mm FBG are placed prior to the 100 km SMF and also after the SMF. The presented hybrid DCF-FBG module has 3 km DCF link, 1mm tan apodized linear chirped FBG. In this configuration, signal first passed through first dispersion compensation unit and then 100 km. Further, one more stage of hybrid DCF-FBG with half length is placed to compensate the effects. After the second stage of hybrid SMF-DCF unit, for the eradication of signal degradations, an EDFA with 40 dB gain and 4 dB noise figure was utilized. Signal amplified with EDFA and at the receiver, these signals are divided into two parts for phase demodulation at the DQPSK receiver. DQPSK receiver consists of PIN photo-detection based balanced detection, couplers, time delay, a phase shifter, substractor, low pass Bessel filter, regenerator and BER analyzer.

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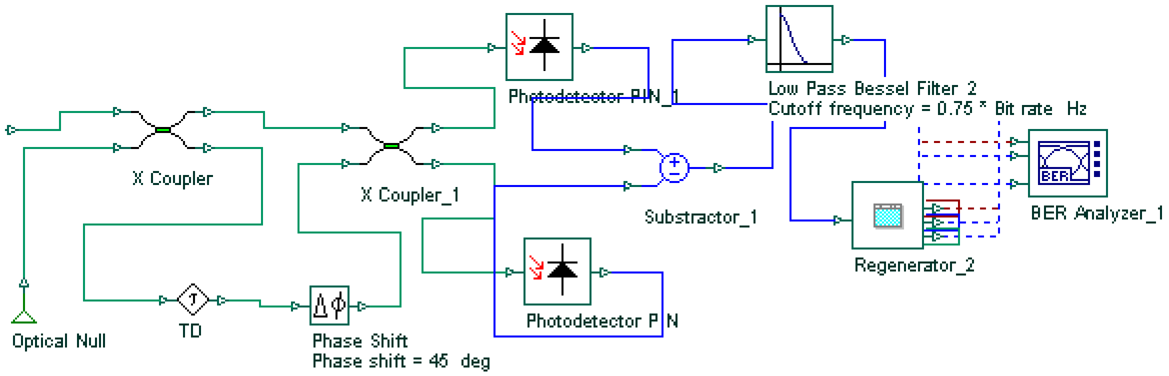
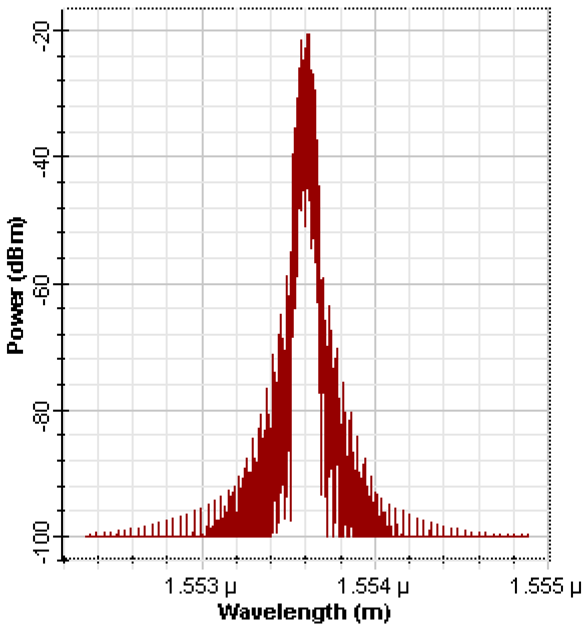


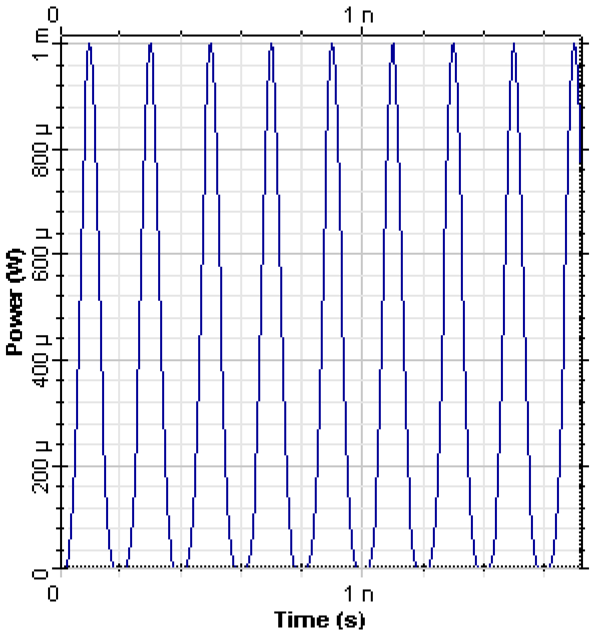
Figure 3 Internal structure of DQPSK receiver

3. Results and Discussions

The presented system is investigated for different arrangement of hybrid DCF-FBG unit and results are calculated in terms of Q factor and BER. In pre configuration, Figure 4 (a) depicts the optical spectrum of employed wavelength carrier and Figure 4 (b) shows the optical bits after the transmitter.



(a)



(b)

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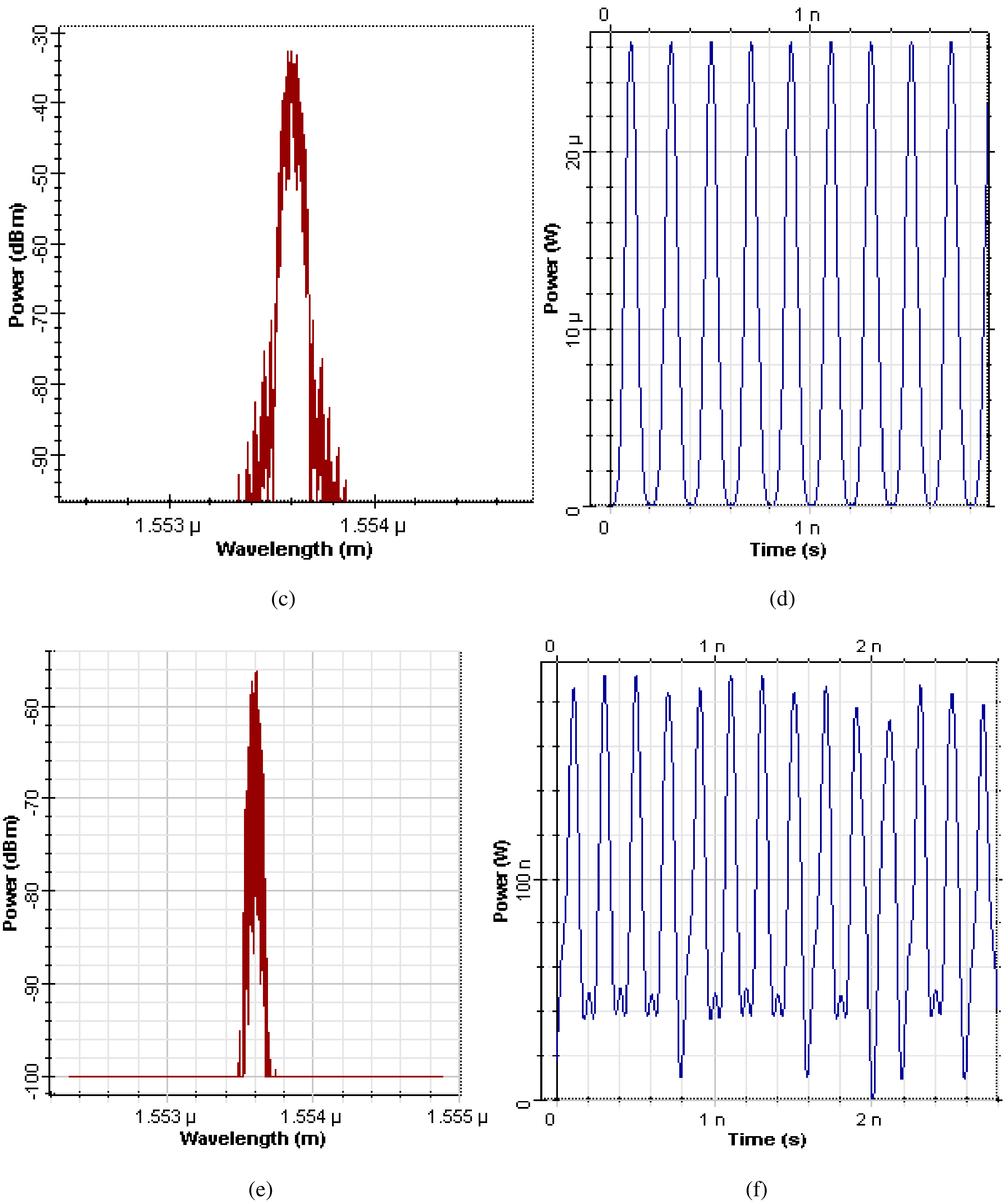

Figure 4 Representation of (a) optical carrier spectrum and (b) optical bits after transmitter, (c) optical carrier and (d) optical bits after DCF-FBG, (e) optical carrier and (f) after 100 km SMF

It is observed that transmitter carrier has -20 dB power and bits are perfectly shaped. Further, carrier spectrum is analyzed after the hybrid DCF-FBG configuration in Figure 4 (c) and data bits in Figure 4 (d). It is perceived that carrier has power loss after dispersion compensation unit and bits have also reduced amplitude. Figure 4 (e) and (f) represents the carrier spectrum and optical bits after 100 km SMF. Therefore, results showed the high carrier power and bits amplitude loss despite the EDFA.

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Eye diagram is the final evaluation of the signal and it is a decision making component. Eye diagram in pre configuration is well opened as shown in Figure 5 and has highest Q factor 13.16 and BER 6.8×10^{-40} for DQPSK while NRZ has 3.23, DRZ 8.96 an MDRZ 4.59 Q factor values.

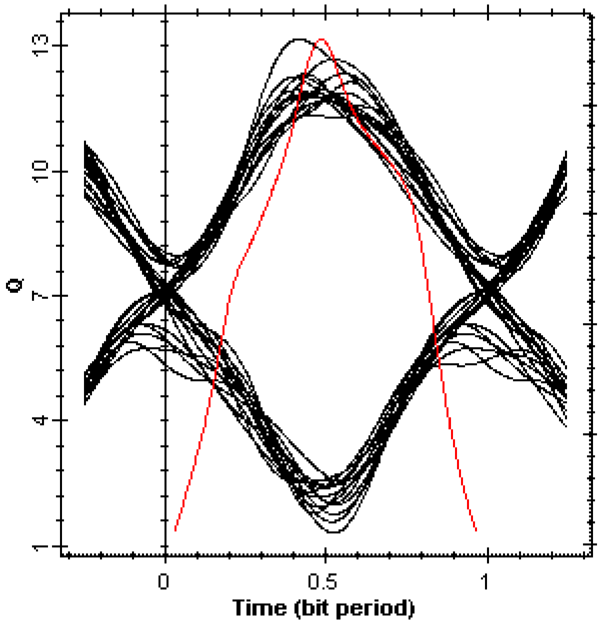
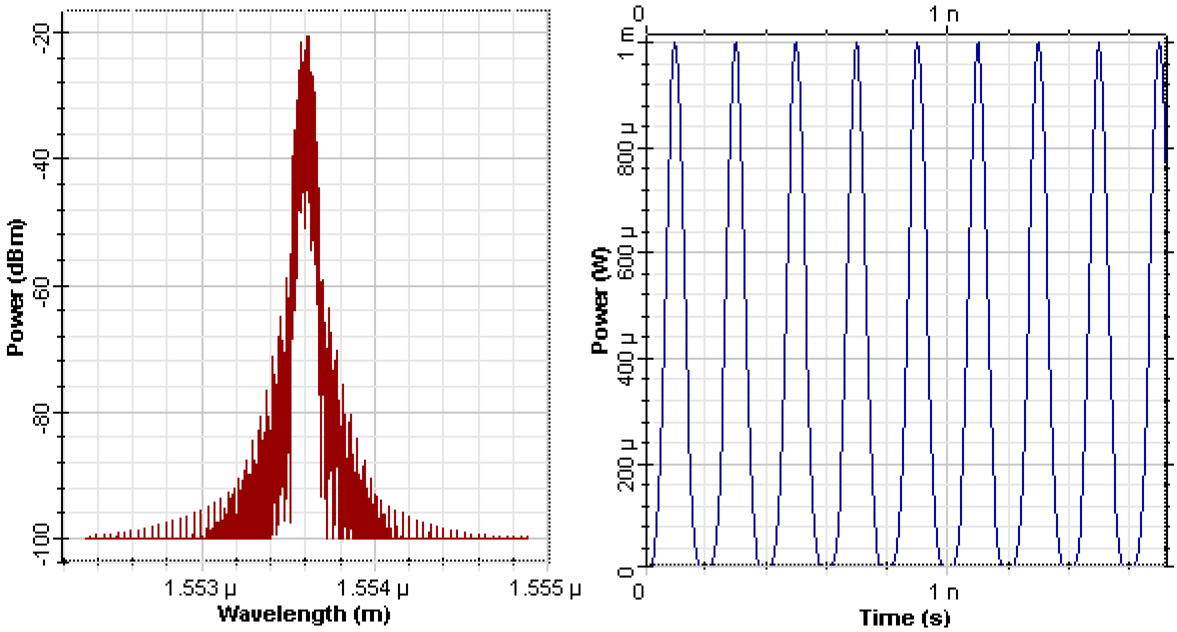


Figure 5 EYE diagram at 100 km SMF showing Q factor 13.16 and BER 6.8×10^{-40} for pre compensation

Similarly, in post dispersion compensation arrangement, Figure 6 (a), (b), (c), and (d) provide the optical spectrum after transmitter, data bits after transmitter, carrier spectrum after 100 km SMF and DCF-FBG, bits after 100 km SMF and DCF-FBG. It is observed that in post configuration, the dispersion compensation is better than pre configuration. In aforementioned pre dispersion compensation, pulse first gets reduced and then after passing through SMF, it gets broadened but overall the size of pulse is near to the original pulse. However, SMF has some nonlinear issues also and therefore any kind of noises, nonlinear effects etc are also gets amplified from EDFA placed. But in post configuration, emergences of noises are lower due to dispersion compensation after the pulse broadening.



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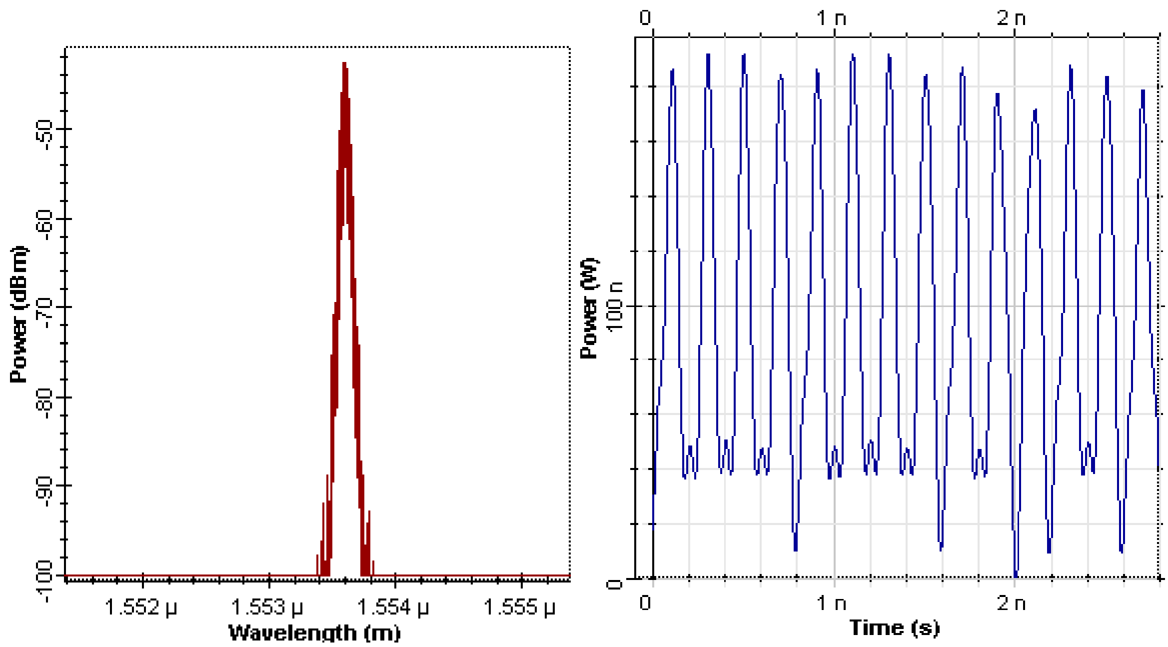

(c) (d)

Figure 6 Representation of (a) optical carrier spectrum after transmitter (b) optical bits after transmitter and (c) carrier spectrum after 100 km followed by DCF-FBG (d) optical bits after 100 km followed by DCF-FBG

Figure 7 depicts the Eye diagram in post configuration is more open than pre arrangement. This configuration has highest Q factor 23.22 and BER 10^{-119} for DQPSK while NRZ has 0, DRZ 14.41 an MDRZ 4.01 Q factor values.

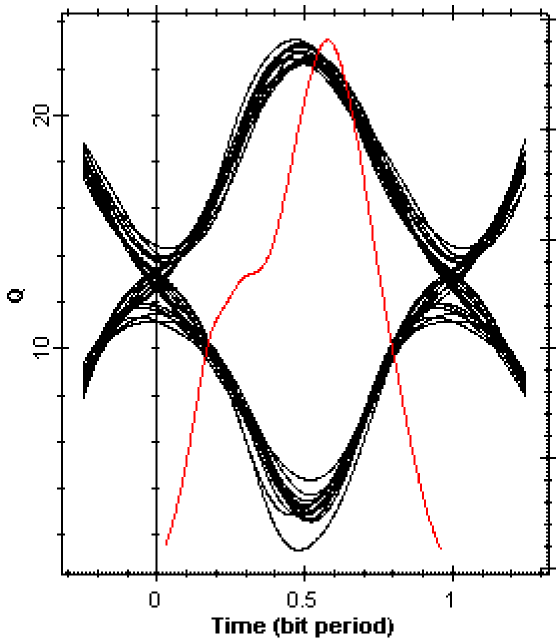

Figure 7 EYE diagram at 100 km SMF and DCF-FBG in post configuration showing Q factor 23.22 and BER 1.13×10^{-119}

In symmetrical configuration, the transmitted pulse gets narrowed using half length DCF and FBG. Further, signal is fed to 100 km SMF and followed by half length DCF-FBG. Figure 8 show transmitted carrier spectrum and optical bits

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in (a) and (b) respectively. Further, carrier spectrum and bits after 100 km SMF and second stage DCF-FBG are shown in Figure 8 (c) and (d) respectively.

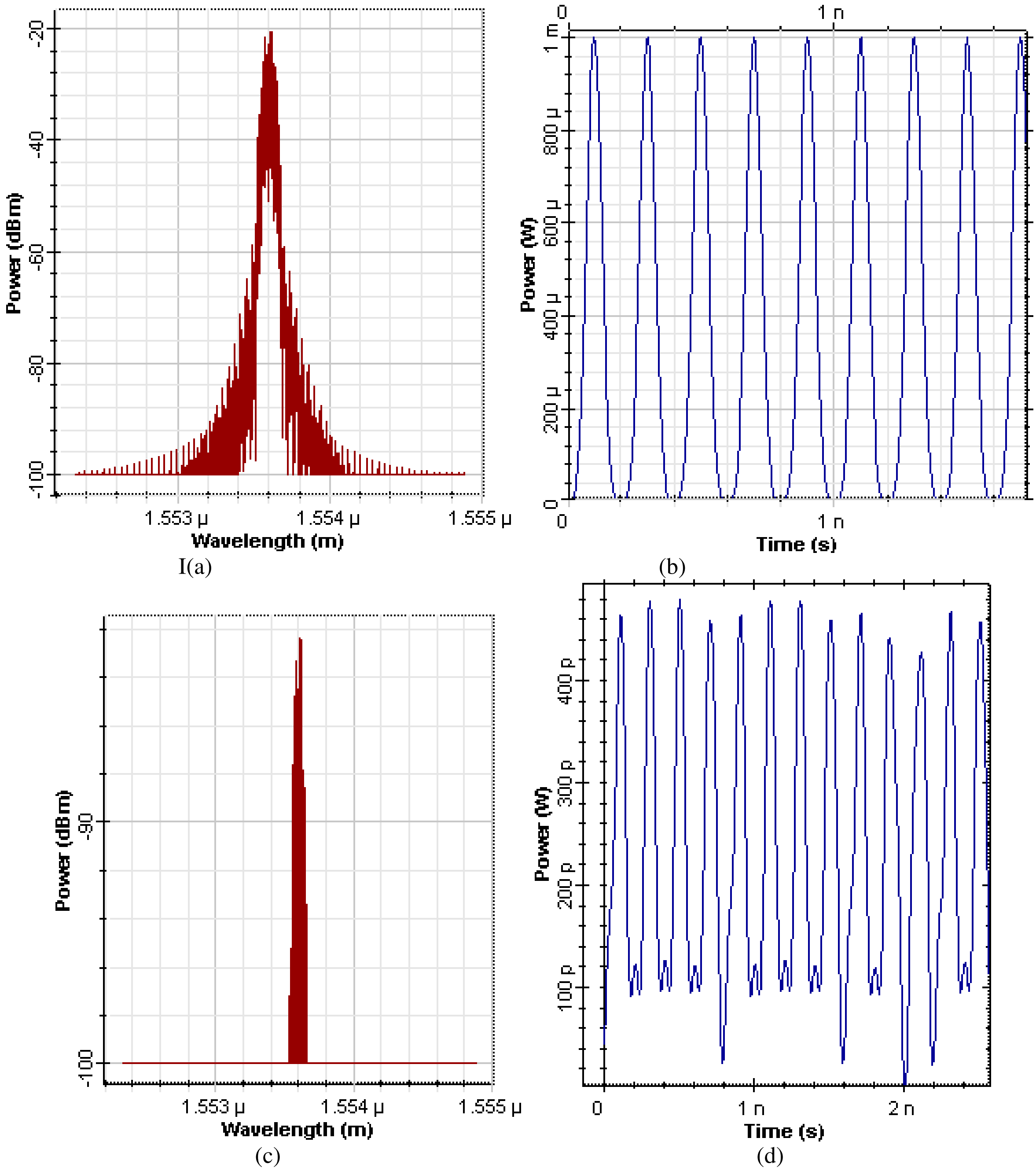

Figure 8 Representation of (a) optical spectrum after transmitter (b) optical bits after transmitter and (c) optical bits after 100 SMF and L/2DCF-L/2FBG

Figure 9 depicts the Eye diagram in symmetrical configuration is acceptable. This configuration has Q factor 13.12 and BER 10^{-39} for DQPSK while NRZ has 3.75, DRZ 12.06 an MDRZ 6.38 Q factor values.

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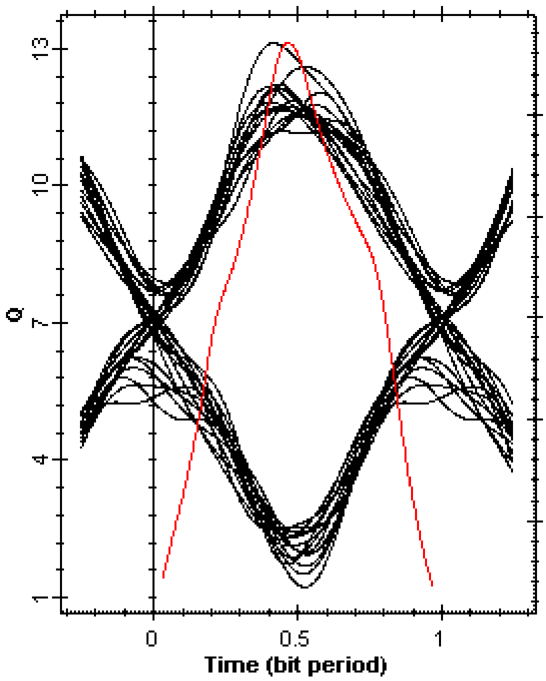

Figure 9 EYE diagram at 100 km SMF and DCF-FBG in symmetrical configuration showing Q factor 13.12 and BER 1.15×10^{-39}

Figure 10 represents the comparison of four different modulation formats modulations in pre, pos and symmetrical configuration in terms of Q factor. It is observed that DQPSK with four phase shifts has maximum Q factor in all the three configurations due to high efficiency in dispersion compensation. Further, the presented system is compared with four-stage FBG [6] dispersion compensation system employing DRZ, MDRZ and NRZ system. It is observed that proposed system has 100% more performance efficiency than NRZ in post configuration, 37.94% than DRZ and 82.34% than DRZ.

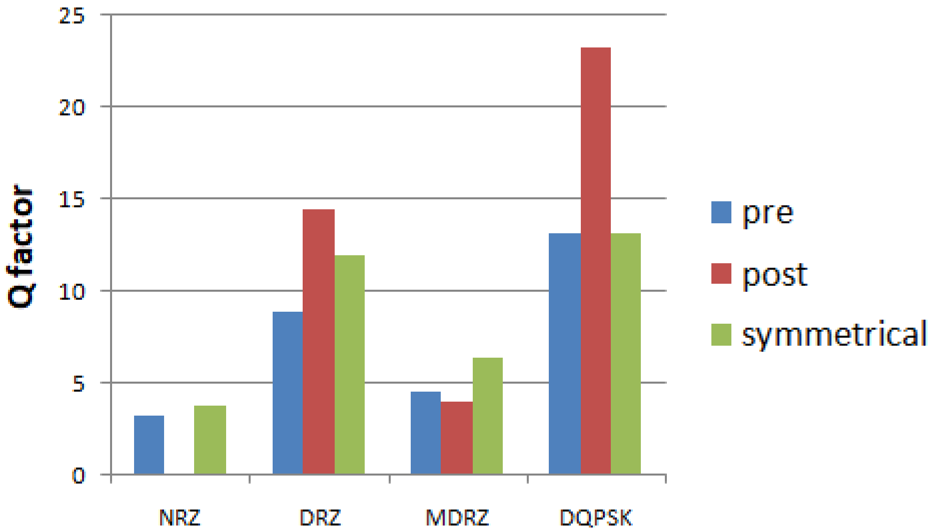

Figure 10 Performance of different modulation formats in terms of Q factor

The values of Q factor and BER obtained in presented work and in existing work are shown in Table 1. It is evident that proposed system using same input parameters has best performance.

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Table 1 Comparison of proposed work and existing work

Parameter	Existing work			Proposed Work
Data rate	10 Gbps			10 Gbps
Channel	Single			Single
SMF length	100 km			100 km
Modulation	NRZ/DRZ/MDRZ			DQPSK
Dispersion compensation	4-stage FBGs			DCF-single stage FBG
Dispersion compensation unit length	1.5 mm			3 km DCF+1mm FBG
EDFA Gain and Noise figure	40 dB and 4 dB			40 dB and 4 dB
Laser input power	0 dBm			0 dBm
Q factor in pre configuration	NRZ=3.23	DRZ=8.96	MDRZ=4.59	DQPSK=13.16
BER in pre configuration	NRZ=10^{-4}	DRZ=10^{-19}	MDRZ=10^{-5}	DQPSK=10^{-40}
Q factor in post configuration	NRZ=0	DRZ=14.41	MDRZ=4.01	DQPSK=23.22
BER in post configuration	NRZ=1	DRZ=10^{-47}	MDRZ=10^{-5}	DQPSK=10^{-119}
Q factor symm configuration	NRZ=3.75	DRZ=12.069	MDRZ=6.38	DQPSK=13.12
BER symm configuration	NRZ=10^{-5}	DRZ=10^{-34}	MDRZ=10^{-11}	DQPSK=10^{-39}

V. CONCLUSION

In this research work, a highly performance efficient 10 Gbps chromatic dispersion compensated optical communication system is presented by employing DQPSK and hybrid DCF-FBG module. A cost effective, less complex and high performance based hybrid DCF-FBG module is introduced in three different configurations such as pre, post and symmetrical. Results revealed that hybrid DCF-FBG module provide excellent performance in post configuration and offered Q factor 23.22 and BER 10^{-119}. In pre dispersion compensation, pulse first gets reduced and then after passing through SMF, it gets broadened but overall the size of pulse is near to the original pulse. However, SMF has some nonlinear issues also and therefore any kind of noises, nonlinear effects etc are also gets amplified from EDFA placed. But in post configuration, emergences of noises are lower due to dispersion compensation after the pulse broadening. Further, the presented system is compared with four-stage FBG dispersion compensation system employing DRZ, MDRZ and NRZ system. It is observed that proposed system has 100% more performance efficiency than NRZ in post configuration, 37.94% than DRZ and 82.34% than DRZ. In future, multi-channel system can be realized using DQPSK and presented dispersion compensation module.

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