Journal of Indian Research (ISSN: 2321-4155)
Vol.9, No.3&4, July-December-2021, 45-65

COMPARATIVE ANALYSIS OF OPTICAL TRANSMISSION SYSTEM USING DCF-UNIFORM FBG BASED TECHNIQUES WITH NRZ AND RZ MODULATION

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Archana Agarwal**

ABSTRACT

In this paper, we propose a single-channel optical transmission system using hybrid dispersion compensation techniques in three different (pre-, post-, and symmetrical) configurations. Dispersion compensation techniques reduced the pulse broadening effects of the transmitted signal that is known as Inter Symbol Interference (ISI). To overcome ISI, Uniform FBG and Dispersion Compensation Fiber (DCF) schemes are modeled, analyzed, and compared to investigate the performance of the optical transmission system. The proposed system is designed for 10 Gbps using non-return-to-zero (NRZ), and return-to-zero (RZ) modulation format with an optical amplifier over a channel length of 100 km single-mode fiber (SMF) and 20 km dispersion compensation fiber with a loop span of two, so that the overall channel length is 240 km. At the transmitter side, different input sequences as PN, FCC, and Walsh codes are used as data sequences in the data generator. Performance of the designed system is analyzed and compared using Optisystem 17.0 simulator in terms of bit error rate (BER), quality factor (Q-factor) and eye-diagram by varying input power (mW), modulation formats (NRZ/RZ), and input sequence like PN, FCC, and Walsh code. It is observed during analysis that Walsh codes provide a higher value of Q factor and a low value of BER for the proposed system models.

Keywords: Amplifier, Attenuation, BER, Dispersion Compensation Fiber (DCF), dispersion, modulation, Inter Symbol Interference (ISI), non-linear effect, Non-Return to Zero (NRZ), Optisystem, optical fibre, Q-factor, refractive index, telecommunication, transmitter, Uniform FBG.

INTRODUCTION

Recently, in the telecommunication sector, the demand for optical fiber technology is increasing day by day due to large bandwidth, high data rate, reliable and low-cost optical

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communication links[1].

Normally the transmission in an optical system is mainly affected when different wavelength signals are transmitted over an optical fiber. Due to the variations in the core and cladding refractive index, these optical signals travel at different speeds. Therefore, optical signals overlap after traveling a long distance through fiber. Hence the broadening of pulse that is also known as Inter Symbol Interference (ISI) effect causes dispersion and losses in transmitted signals which lead to an error signal at the receiver end [2]. Therefore, attenuation, non-linearity, and dispersion are the major factor that affects optical transmission networks. To overcome the attenuation problem, an erbium-doped fiber amplifier (EDFA) is introduced as shown in Figure 1. EDFA is the most frequently used optical amplifier. It works on a low loss 1550 nm wavelength window of silica-based fiber[3]-[5]. The non-linear effect can also be avoided using appropriate power levels.

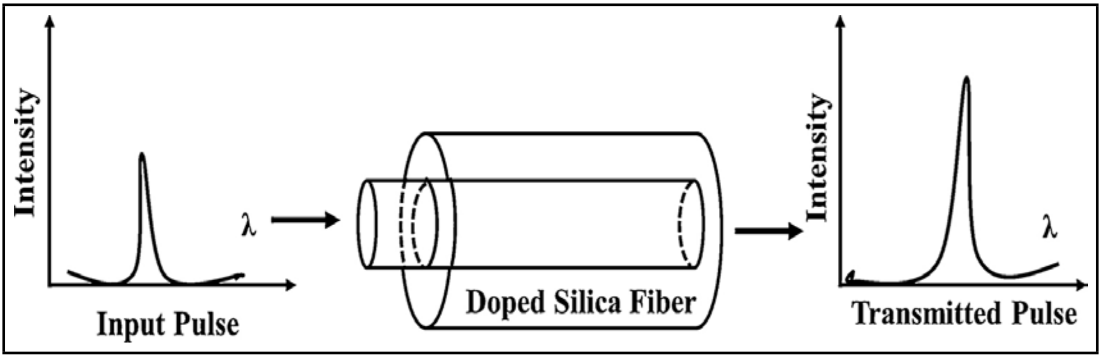


Figure 1: Basic Principle of EDFA

In optical transmission system, dispersion is the key issue that limits the long distance and high speed optical fiber communication[6]-[8].Out of the other problems, dispersion affect the system most and difficult to overcome[9].

To overcome the dispersion issues, various techniques are suggested such as Dispersion Compensation Fiber (DCF)[10], Dispersion Compensating Filter[11]-[12] and Fiber Bragg Grating (FBG)[13]. Out of these, the DCF and FBG are most efficient dispersion compensation techniques. In DCF, a negative dispersion coefficient special fiber is introduced to compensate the effect of positive dispersion in an optical fiber communication link[14]. Various authors have investigated the detailed design characteristics, applications, choice of optimum length and operating conditions of DCF as an effective dispersion compensator[15]-[19]. It is concluded from literature that DCF technique is simple, reliable and easy to upgrade installed fiber links, but it increases non-linear effects as well as cost of fiber communication systems[20].

To overcome the challenges of the DCF techniques, FBG is suggested to compensate dispersion in fiber networks. The FBG significant importance for design, testing and estimation of dispersion compensator. Therefore, FBG is characterized with insignificant non-linear effects, low loss, cost competence and high competence for working in optical transmission systems[21]. The dispersion compensation using FBG is proposed by Qullette[22], and Williams[23]. An FBG is a distributed Bragg reflector developed in a short fragment of optical fiber that reflects specific wavelengths of light and transmits all others. This is accomplished by making an intermittent variety within the refractive profile of the fiber core, which creates reflection for a selected wavelength[24]. By changing the refractive index profile and grating period, Fiber Bragg grating can be divided into uniform FBG and ideal dispersion compensation FBG. In uniform Fiber Bragg grating, unvarying grating periods are used [25]. Uniform means the grating period and index of refraction is constant throughout the length of the grating. The basic principle of uniform FBG is shown in the Figure 2.

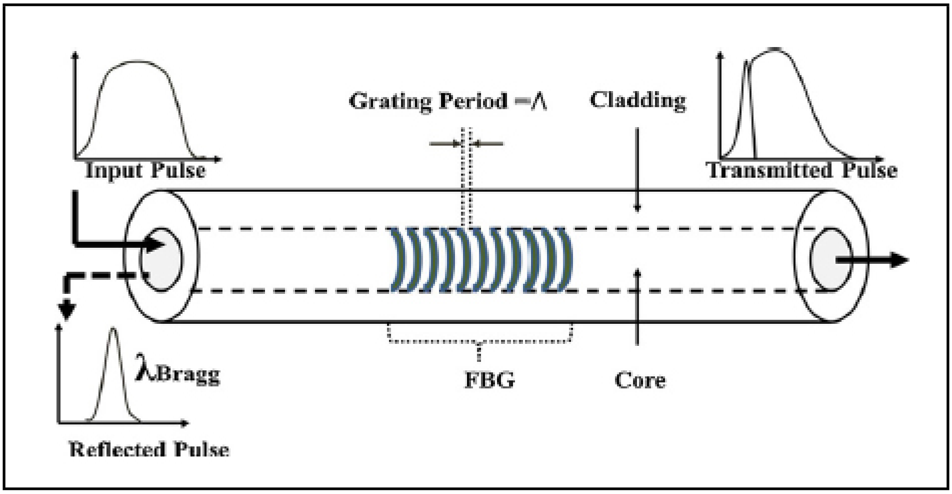


Figure 2: Basic Principle of Uniform FBGs

The data transmission format must be a factor when analyzing the performance of optical communication systems, because it deals directly with the system output. Non-return to zero (NRZ) and Return to zero (RZ) are two very common modulation techniques, which are used to modulate optical pulses in optical networks[26]. In optical fiber communication, basically, PN Code sequences generated by Pseudo-Random Bit Sequence generator are used to generate a digital sequence. For the analysis in this paper, the other two codes FCC and Walsh codes are used. The FCC codes are often designed by using tridiagonal matrix property, at any given number of users and weights. Walsh-Hadamard (WH) codes[27] are binary orthogonal and might easily be generated from Hadamard matrices. The orthogonal sequences generated from Hadamard matrices are called Walsh-Hadamard matrices[28]-[29].

The proposed work presents the performance analysis of an optical transmission system with Uniform FBG and DCF techniques for 10 Gbps optical link with 240 km of single-mode fiber. DCF and Uniform FBG are used in three configurations pre-, post-, and symmetrical along with the optical fiber i.e. SMF.

The optimized parameters of SMF, as well as uniform FBG, are identified and after simulation, performance parameters of the proposed models are analyzed and compared with previously reported works with DCF-Ideal Dispersion Compensation FBG (IDCFBG) as a dispersion compensation technique. Finally, it can be observed that the presented work improves the performance of the proposed model by reducing dispersion through the Uniform

FBG-DCF technique. The designed optical configurations are modeled and simulated using the Optisystem 17.0 simulator.

In this paper, the whole analysis of dispersion compensation is based on comparing the value of the Q factor and BER using NRZ and RZ modulation techniques with PN, FCC, and Walsh input sequence code at the transmitter side by varying CW laser input power from 1 mW to 10 mW.

PROPOSED SYSTEM MODEL

A single channel optical transmission system is designed to evaluate and compare the performance based on DCF-Uniform FBG dispersion compensation techniques. The proposed model is simulated by Optisystem 17.0 software through using NRZ and RZ modulations, different input sequence, and different input power in three different configurations to investigate how dispersion affected the performance of optical transmission system at 10 Gbps data rate. The fundamental block diagram of proposed system model is shown in Figure 3.

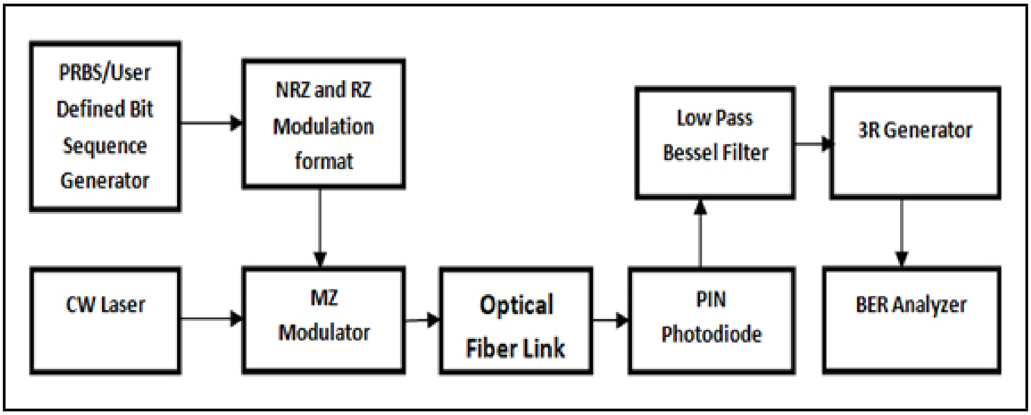


Figure 3: Experimental setup of the proposed system model

At the transmitter side, to produce the pseudo-random bit sequences and user-defined bit sequences, both pseudo-random and user-defined bit sequence generators are used at data rate of 10 Gbps. To convert binary data into electrical pulse, non-return to zero (NRZ) and return to zero (RZ) pulse generator are used. Continuous Wave (CW) laser and Mach-Zehnder (MZ) modulator having 30 dB extinction ratios are used to modulate the CW laser signal. Central frequency of 193.1 THz is selected for CW laser according to recommendation of ITU-TG.694.1.

The optical input signal is spread over a single optical fiber consisting of SMF, DCF with Uniform FBG and optical amplifiers. The parameters of SMF, DCF and Uniform FBG are preferred in such a way to produce best possible performance. The length of SMF and DCF are 100 km and 20 km respectively with a span of two loops. Therefore, total transmission length of channel is 240 km. The position of DCF and SMF with Uniform FBG are preferred according to the dispersion compensation techniques used and relocated at the time of simulations to analyze value of Q factor and BER of the optical link. This can be achieved in pre-, post-, and symmetrical compensation configuration as shown in the Figure 4.

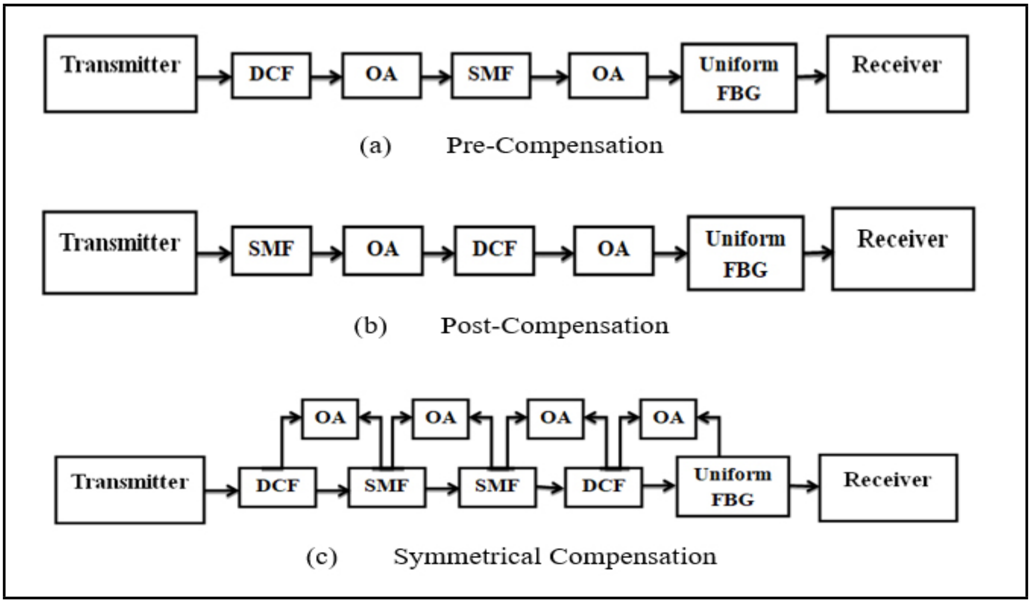


Figure 4: Optical fiber link configurations for the proposed system model

- Pre-compensation: In the pre-compensation scheme, DCF is placed before the SMF along with optical amplifier and Uniform FBG.
- Post-compensation: In the post-compensation scheme, DCF is placed after SMF along with optical amplifier a Uniform FBG.
- Symmetrical-compensation: In the symmetrical compensation scheme, DCF is placed before and after the SMF along with optical amplifier, a Uniform FBG.

For DCF based systems, additional amplifier is required to reduce the loss of DCF itself. At the receiver side to detect the optical signal, a PIN detector is used along with a low pass electrical Bessel filter and Eye/BER analyzer along with 3R generator. The all component parameters related to SMF, DCF and Uniform FBG are tabulated in Table 1, 2 and 3 respectively.

Table 1: Single Channel Optical System Parameters

Parameters	Value
Bit Rate(Gb/s)	10
Sequence Length	1024
Samples/bit	32
Sample Rate (Hz)	3.2e+011
Number of Samples	32768
CW Laser frequency (THz)	193.1
CW Laser Power (mW)	1 to 10
Reference Wavelength (nm)	1550

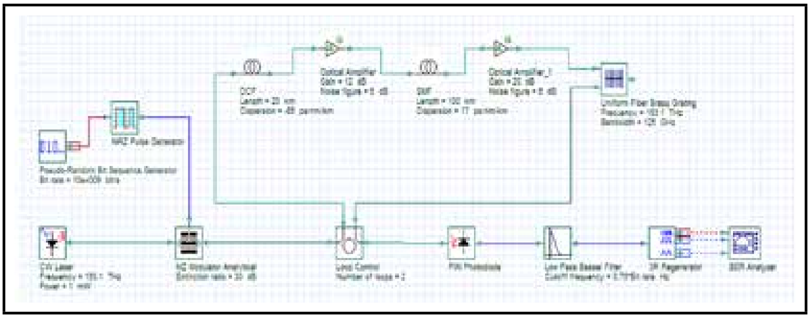
Table 2: Fiber parameters

PARAMETERS	SMF	DCF
Length (km)	100	20
Dispersion (ps/nm/km)	17	-85
Dispersion Slope	0.075	-0.3
Attenuation	0.2	0.6
First Order Dispersion coefficient(ps2/km)	-20	-20
Differential Group Delay(ps/nm)	0.5	0.5
Nonlinear refractive index(m2/w)	2.6e-20	2.6e-20

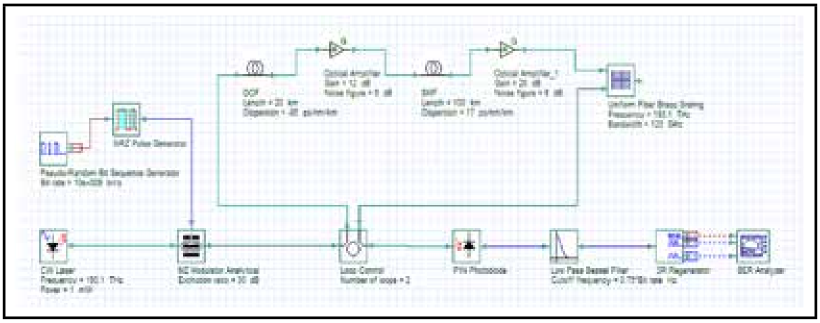
Table 3: Uniform FBG parameters

PARAMETERS	VALUE
Frequency (THz)	193.1
Bandwidth (GHz)	125

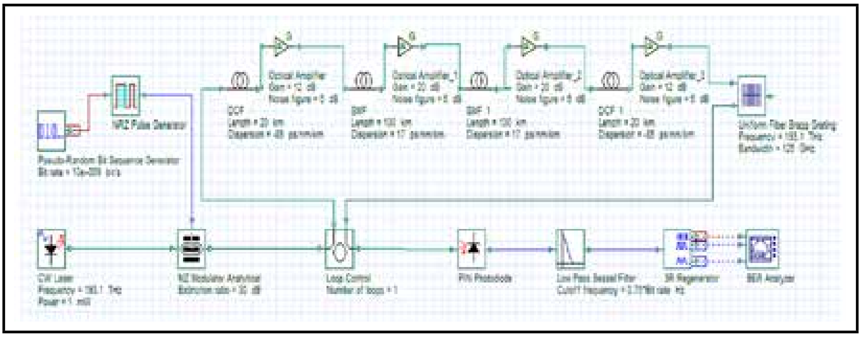
In this paper, DCF with Uniform FBG-based dispersion compensation techniques for three configurations using NRZ and RZ modulations with three different types of input sequences are implemented. Figure 5 and Figure 6 shows the experimental setup for the Pre-, Post-, and Symmetrical DCF with Uniform FBG techniques for NRZ and RZ modulations respectively using PN code generated by PRBS generator.



(a) Pre-DCF with Uniform FBG

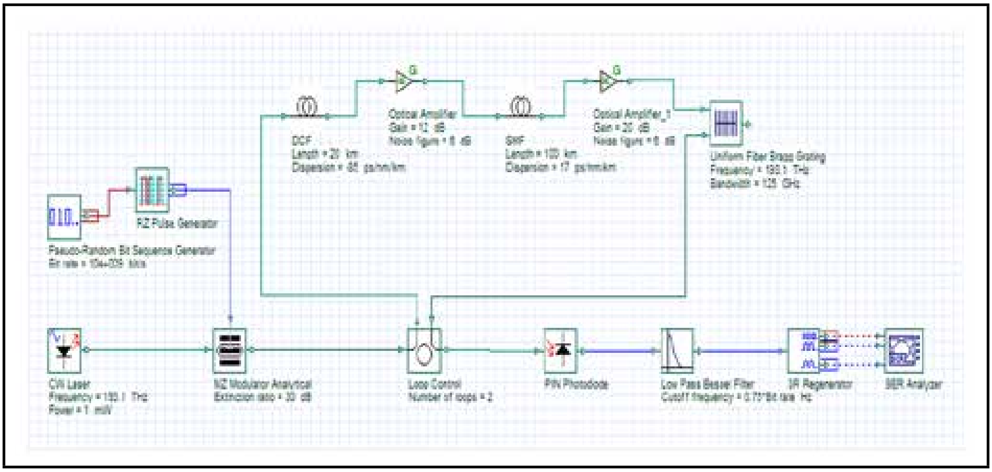


(b) Post- DCF with Uniform FBG

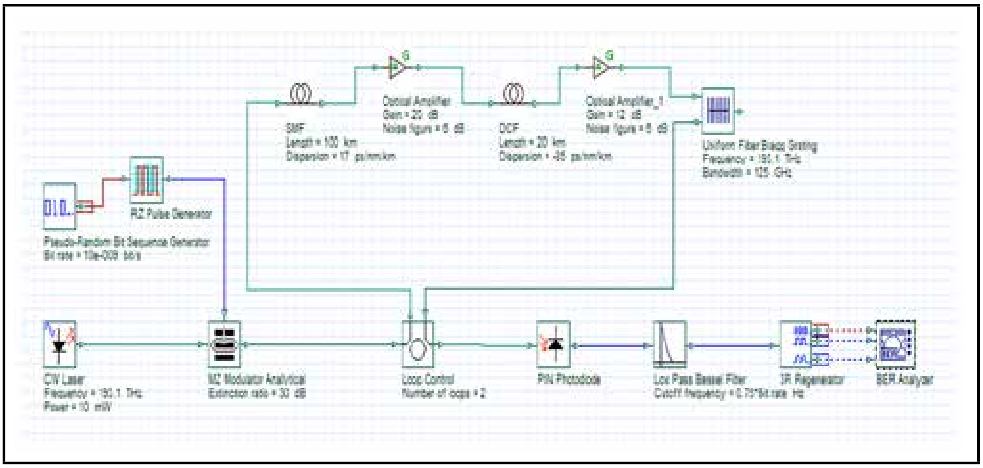


(c) Symmetrical DCF with IDCFBG

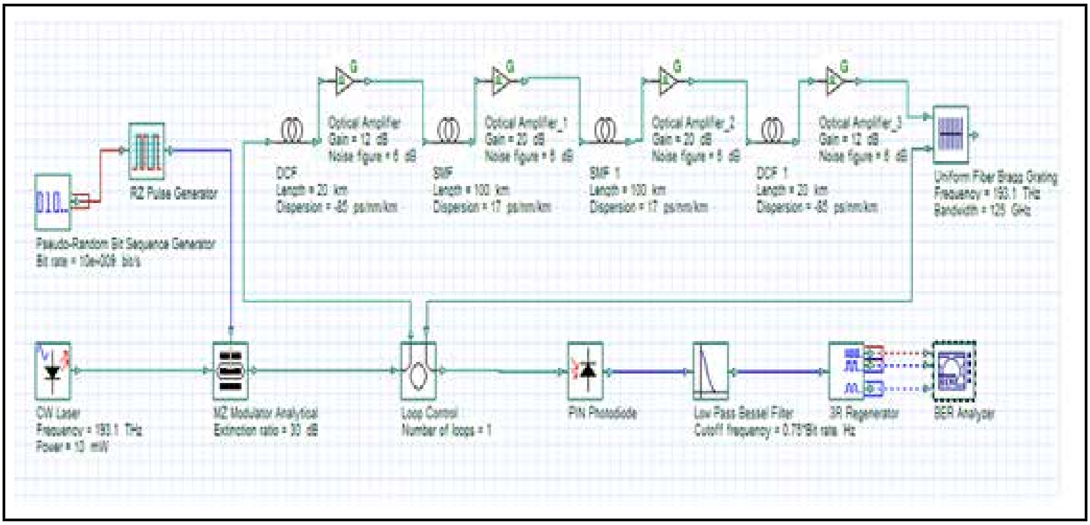
Figure 5 Simulation setup for (a) Pre (b) Post and (c) Symmetrical DCF with Uniform FBG compensation using NRZ modulation



(a) Pre-DCF with Uniform FBG



(b) Post-DCF with Uniform FBG



(c) Symmetrical DCF with Uniform FBG

Figure 6: Simulation setup for (a) Pre- (b) Post- and (c) Symmetrical DCF with Uniform FBG compensation using RZ modulation.

For the next simulation setup to apply FCC and Walsh code, PRBS generator is replaced by the user defined bit sequence generator in the entire Figure 5 and 6, where 16 bits of FCC Codes (0110111001010001) and Walsh codes (0110011001100110) are used for the simulation.

RESULTS AND DISCUSSIONS

Before discussion on results, it is necessary to point out that our key concern is to analyze and compares the performance of single channel optical transmission system using DCF-Uniform FBG technique for pre-, post-, and symmetrical configuration using NRZ and RZ modulations with different input sequence applied to the data generator by varying input power. The performance of the proposed models is simulated on Optisystem 17.0 simulator. Quality factor (Q-factor) and bit error rate (BER) are measured using BER Analyzer. For enhanced optical fiber communication system, $Q>6$ and $BER \leq 10^{-9}$ are the acceptable values. Therefore, higher value of Q-factor and lower value of BER authenticate the low dispersion and better performance of optical transmission system.

Effect on Q-factor by varying input power

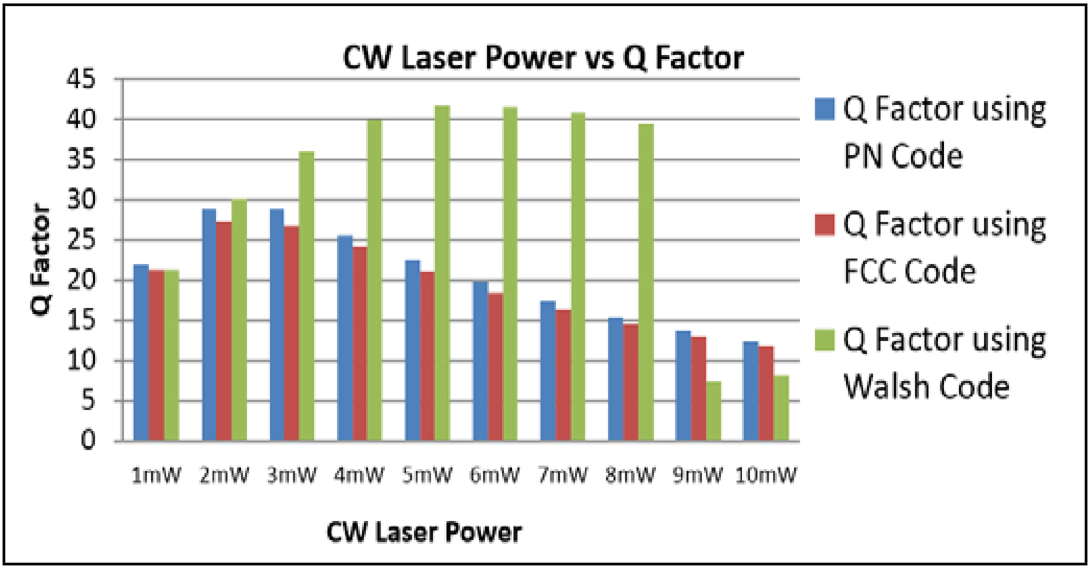
This section provides the performance of proposed optical transmission system model by obtaining value of Q-factor with varying input power from 1 mW to 10 mW for three configurations of the proposed model using NRZ and RZ modulations with different input sequence like PN, FCC and Walsh codes.

The value of Q-factor for the proposed model using NRZ modulation is shown in the Table 4. Highest value of Q-factor was 41.6897 at 5 mW for pre-configuration, Q-factor of 51.7953 at 8 mW for post-configuration and Q-factor of 63.4228 at 10 mW for symmetrical configuration with Walsh code.

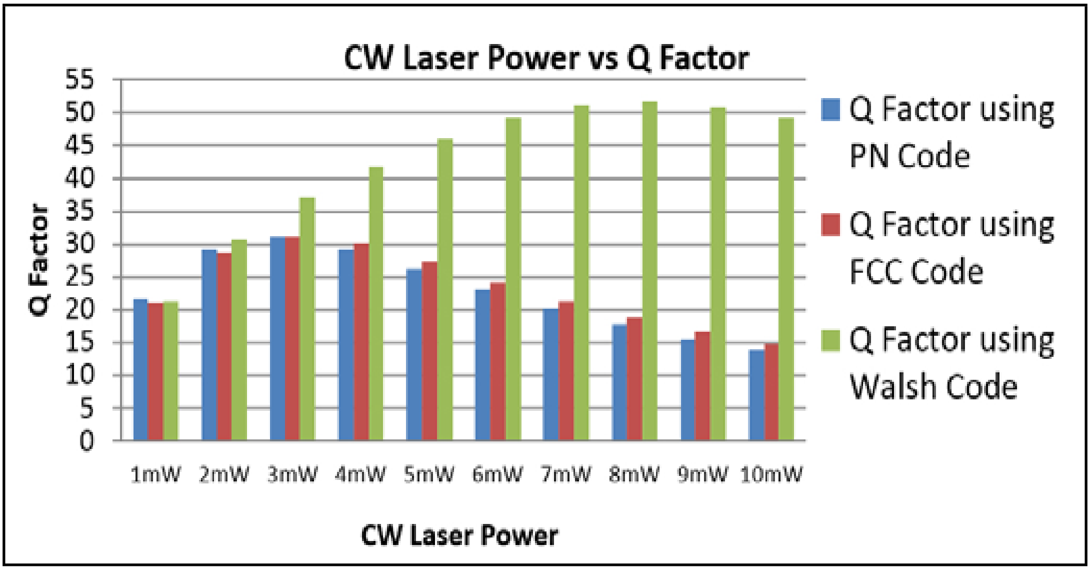
Table 4: Q factor versus Input Power for NRZ modulation

Power	Pre-DCF with Uniform FBG			Post-DCF with Uniform FBG			Symmetrical DCF with Uniform FBG		
	Q Factor using PN Code	Q Factor using FCC Code	Q Factor using Walsh Code	Q Factor using PN Code	Q Factor using FCC Code	Q Factor using Walsh Code	Q Factor using PN Code	Q Factor using FCC Code	Q Factor using Walsh Code
1mW	21.9479	21.3501	21.3038	21.6118	21.1728	21.3286	20.1938	19.9787	20.0312
2mW	28.9038	27.3941	30.0188	29.1894	28.5976	30.609	29.1652	28.6638	28.8147
3mW	28.8197	26.8417	36.0527	31.0576	31.0744	37.1928	35.7248	34.8648	35.2207
4mW	25.6111	24.2009	39.9049	29.2866	30.0837	41.7537	40.5011	39.2999	40.4048
5mW	22.5649	21.1743	41.6897	26.2668	27.388	45.9345	43.5304	42.0587	45.2892
6mW	19.7678	18.5152	41.602	23.0588	24.2815	49.1384	44.8959	44.5204	49.7507
7mW	17.3786	16.383	40.7455	20.1771	21.3464	51.2463	45.9734	46.216	53.837
8mW	15.3979	14.5649	39.4055	17.7062	18.8053	51.7953	46.4464	46.9881	57.5565
9mW	13.7495	13.0424	7.46676	15.6365	16.622	50.8798	46.0155	46.823	60.7897
10mW	12.3707	11.7574	8.22286	13.8958	14.7796	49.0689	44.8115	45.8425	63.4228

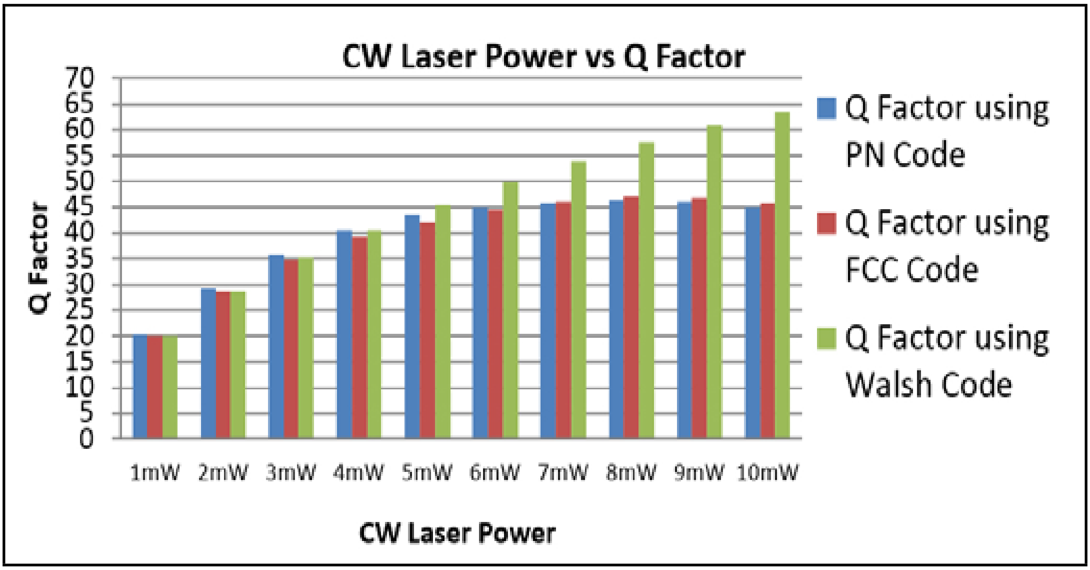
A comparative graph between Q-factor and CW laser power ranges from 1 mW to 10 mW is drawn as shown in the Figure 7 for the pre-, post- and symmetrical configuration of the proposed model using NRZ modulation.



(a) Pre-DCF with Uniform FBG Configuration



(b) Post-DCF with Uniform FBG Configuration



(c) Symmetrical DCF with Uniform FBG Configuration

Figure 7: Q factor versus Transmitted Power for (a) Pre-, (b) Post-, and (c) Symmetrical DCF with Uniform FBG configuration using NRZ modulation

From the graph, it can be concluded that when the Walsh code is used as input sequence, it gives the higher values of Q-factor as compared to PN and FCC codes at particular value of input power.

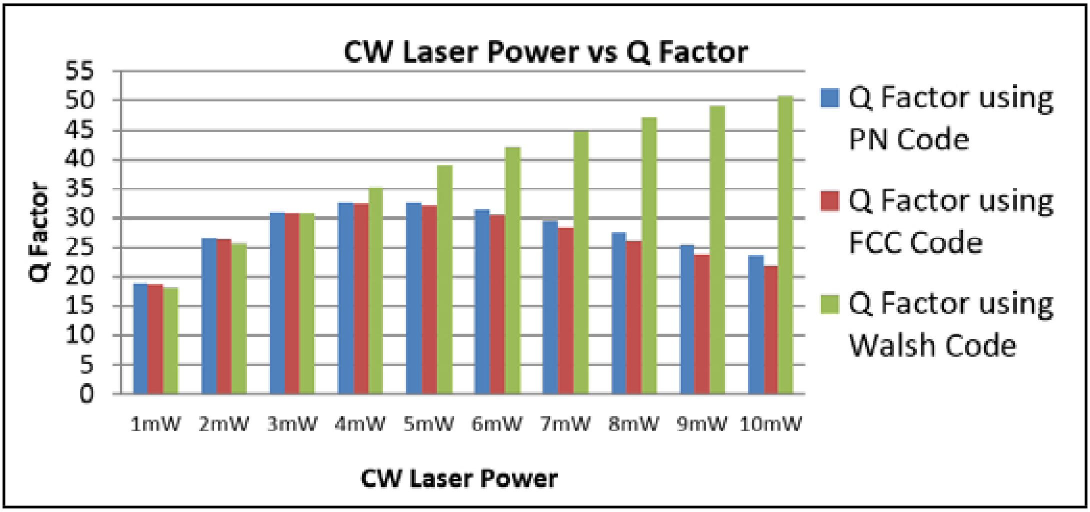
The value of Q-factor for the proposed model using RZ modulation is shown in the Table 5. It provides the highest value of Q-factor of 50.8243 for pre-configuration, Q- factor of

54.3489 for post-configuration and Q-factor of 52.8758 for Symmetrical at 10 mW input power with Walsh code.

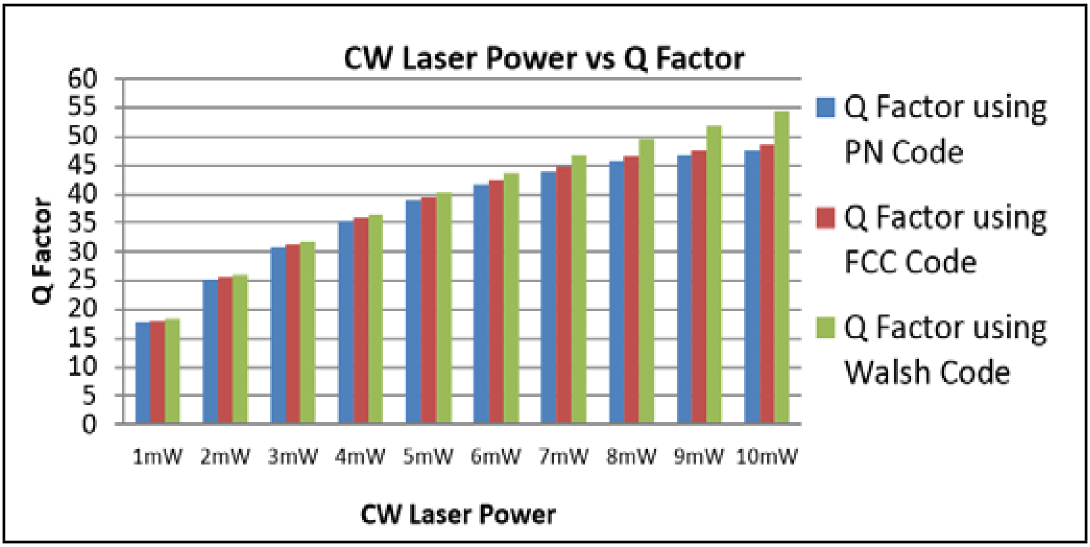
Table 5: Q factor versus Input Power for RZ modulation

Power	Pre-DCF with Uniform FBG			Post-DCF with Uniform FBG			Symmetrical DCF with FBG		
	Q Factor using PN Code	Q Factor using FCC Code	Q Factor using Walsh Code	Q Factor using PN Code	Q Factor using FCC Code	Q Factor using Walsh Code	Q Factor using PN Code	Q Factor using FCC Code	Q Factor using Walsh Code
1mW	18.9399	18.6472	18.2279	17.6815	18.0131	18.3778	17.7362	17.4959	17.5906
2mW	26.6446	26.4153	25.6932	25.291	25.6586	26.1156	25.3242	24.9246	25.1722
3mW	31.0811	30.8809	30.9403	30.884	31.3426	31.8621	30.8424	30.2528	30.8574
4mW	32.8222	32.5618	35.2987	35.3318	35.8804	36.462	35.038	34.2997	35.4936
5mW	32.7433	32.2512	38.9581	38.9291	39.5423	40.2671	38.0958	37.2782	39.3558
6mW	31.4866	30.5752	42.102	41.7849	42.4824	43.7065	40.1849	39.2858	42.6475
7mW	29.6669	28.4008	44.815	44.0447	44.7283	46.7632	41.3525	40.4041	45.5679
8mW	27.6137	26.0034	47.1753	45.6997	46.5296	49.5204	41.7993	40.8365	48.1236
9mW	25.5693	23.808	49.1736	46.7896	47.6622	52.0314	41.7583	40.605	50.5366
10mW	23.659	21.851	50.8243	47.4969	48.5224	54.3489	41.1854	40.1008	52.8758

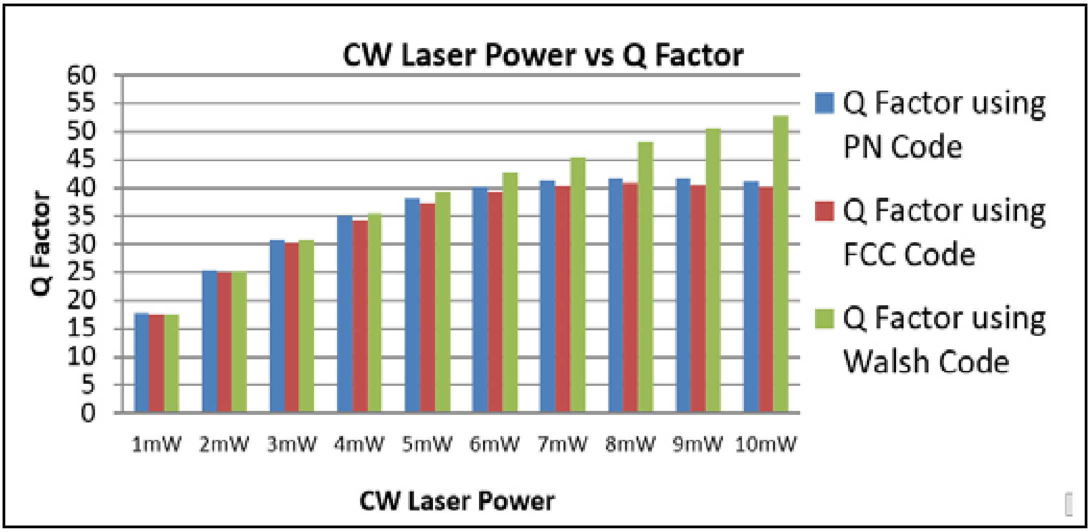
A comparative graph is also drawn for the same proposed model using RZ modulation as shown in Figure 8. From this graph, it is concluded that Walsh code provides the higher value of Q-factor as compared to PN and FCC codes.



(a) Pre-DCF with Uniform FBG Configuration



(b) Post-DCF with Uniform FBG Configuration



(c) Symmetrical DCF with Uniform FBG Configuration

Figure 8: Q-factor versus Transmitted Power for (a) Pre-, (b) Post-, and (c) Symmetrical DCF with Uniform FBG Configuration using RZ modulation

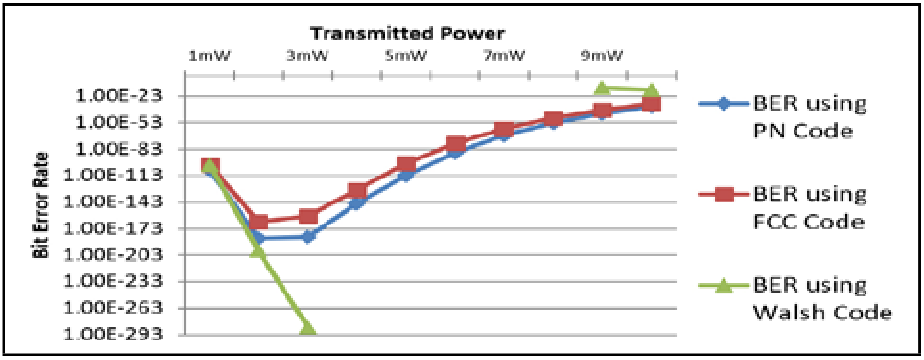
Effect on BER by varying input power

This section provides the performance of proposed optical transmission system model by obtaining value of BER with varying input power. The obtained value of BER by varying the input power for the proposed model using NRZ modulation is given in Table 6. It provides the lowest value of BER of 0 from 4 mW to 8 mW for pre-, and post -configuration and from 4 mW to 10 mW for symmetrical configuration with Walsh code.

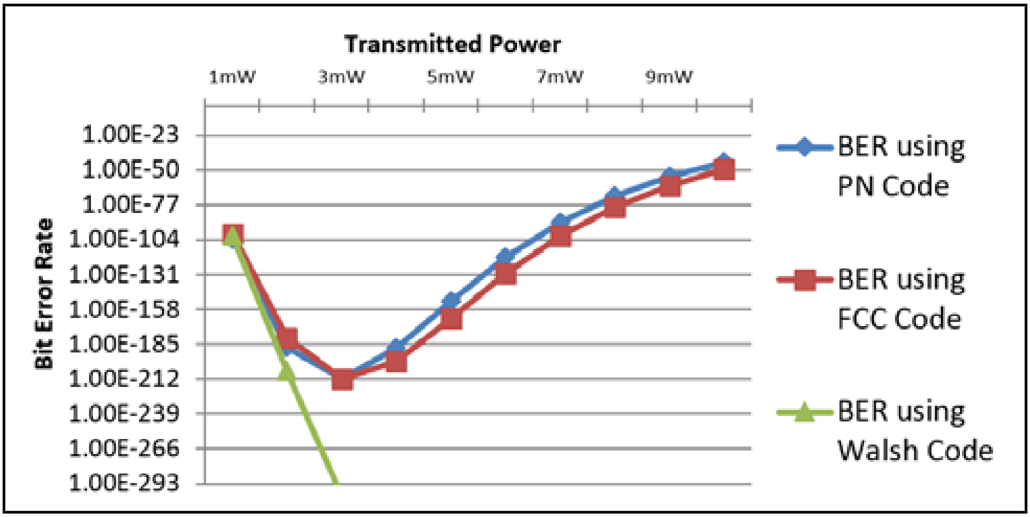
Table 6: BER versus Input Power for NRZ modulation

	Pre- DCF with Uniform FBG			Post- DCF with Uniform FBG			Symmetrical DCF with Uniform FBG		
Power	**BER using PN Code**	**BER using FCC Code**	**BER using Walsh Code**	**BER using PN Code**	**BER using FCC Code**	**BER using Walsh Code**	**BER using PN Code**	**BER using FCC Code**	**BER using Walsh Code**
1mW	2.82E-107	1.20E-101	3.24E-101	4.38E-104	5.62E-100	1.90E-101	3.41E-91	2.61E-89	9.00E-90
2mW	3.15E-184	9.40E-166	1.74E-198	8.10E-188	2.20E-180	2.74E-206	1.58E-187	3.19E-181	4.14E-183
3mW	3.45E-183	3.13E-159	3.90E-285	2.67E-212	1.59E-212	2.63E-303	4.72E-280	7.36E-267	2.80E-272
4mW	3.31E-145	6.26E-130	0	5.42E-189	2.81E-199	0	0	0	0
5mW	2.71E-113	4.65E-100	0	1.61E-152	1.34E-165	0	0	0	0
6mW	1.59E-87	4.43E-77	0	4.16E-118	1.08E-130	0	0	0	0
7mW	3.42E-68	7.16E-61	0	5.36E-91	1.47E-101	0	0	0	0
8mW	4.90E-54	1.34E-48	0	1.30E-70	2.38E-79	0	0	0	0
9mW	1.52E-43	2.04E-39	4.02E-14	1.42E-55	1.68E-62	0	0	0	0
10mW	1.14E-35	1.92E-32	9.79E-17	2.34E-44	6.97E-50	0	0	0	0

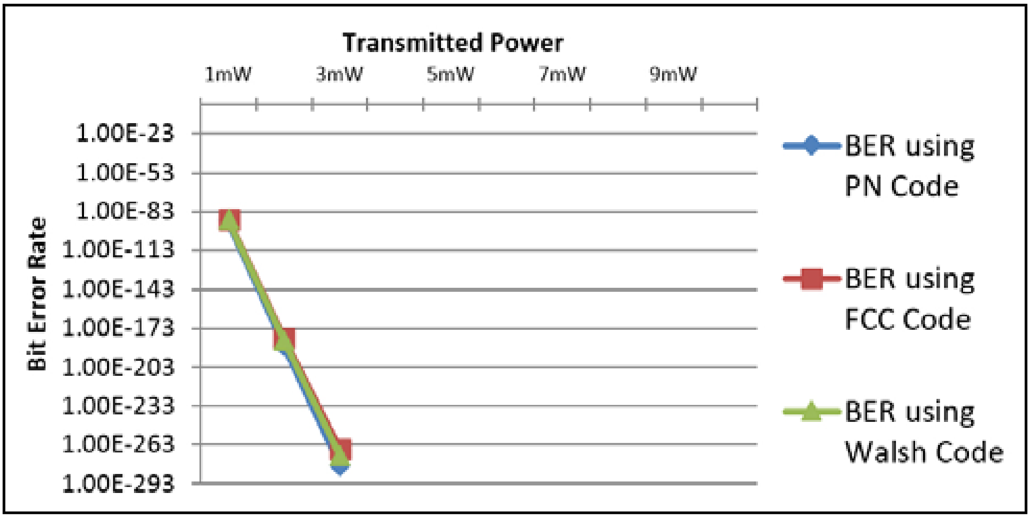
A comparative graph is drawn between BER and CW laser power that ranges from 1 mW to 10 mW as shown in the Figure 9 for the pre-, post-, and symmetrical configuration.



(a) Pre- DCF with Uniform FBG Configuration



(b) Post- DCF with Uniform FBG Configuration



(c) Symmetrical DCF with Uniform FBG Configuration

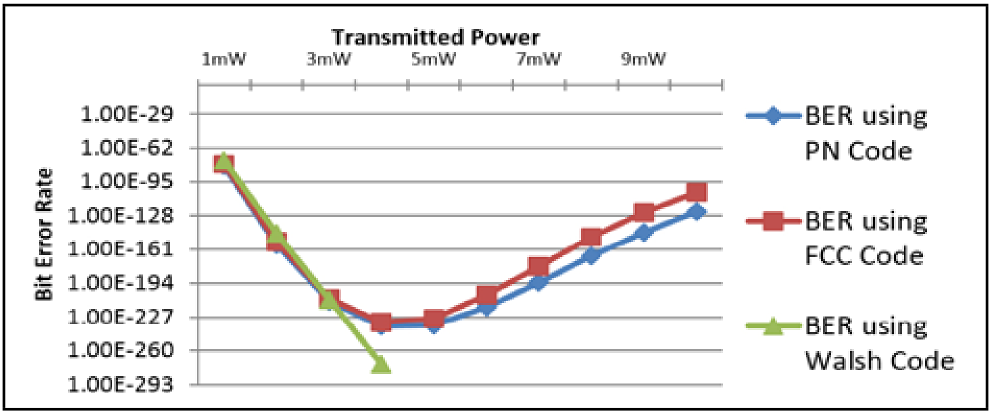
Figure 9: BER versus Transmitted Power for (a) Pre-, (b) Post-, and (c) Symmetrical DCF with Uniform FBG configuration using NRZ modulation

From the graph, it is concluded that when the Walsh code is used as input sequence, it gives the lower values of BER as compared to PN and FCC codes at particular value of input power.

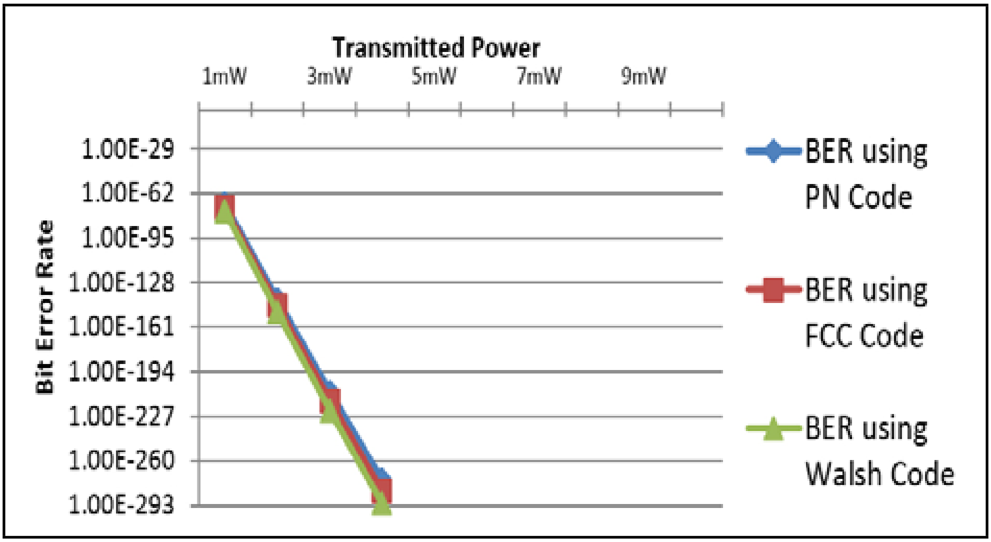
The value of BER obtained by varying the input power for the proposed model using RZ modulation is given in Table 7. It provides the lowest value of BER of 0 from 5 mW to 10 mW for pre-configuration with Walsh code, from 5 mW to 10 mW for post-configuration with PN,FCC and Walsh codes and from 6 mW to 10 mW with PN, FCC codes and from 5 mW to 10 mW with Walsh code for symmetrical configuration.

Table 7: BER versus Input Power for RZ modulation

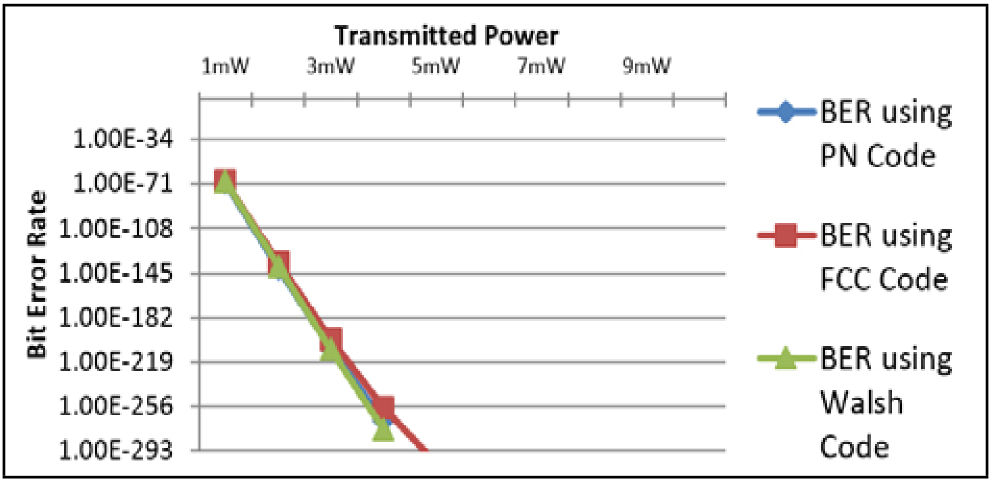
Power	Pre-DCF with Uniform FBG			Post-DCF with Uniform FBG			Symmetrical DCF with Uniform FBG		
	BER using PN Code	BER using FCC Code	BER using Walsh Code	BER using PN Code	BER using FCC Code	BER using Walsh Code	BER using PN Code	BER using FCC Code	BER using Walsh Code
1mW	1.69E-80	4.19E-78	9.80E-75	1.81E-70	4.88E-73	6.42E-76	6.99E-71	4.86E-69	9.24E-70
2mW	6.38E-157	2.79E-154	4.32E-146	1.22E-141	1.04E-145	7.59E-151	5.25E-142	1.24E-137	2.51E-140
3mW	1.33E-212	6.45E-210	1.10E-210	6.00E-210	3.78E-216	2.82E-223	2.13E-209	1.44E-201	1.35E-209
4mW	8.65E-237	4.33E-233	1.99E-273	5.92E-274	1.93E-282	1.42E-291	1.78E-269	2.37E-258	1.88E-276
5mW	1.19E-235	1.02E-228	0	0	0	0	4.50e-318	1.11E-304	0
6mW	4.11E-218	7.76E-206	0	0	0	0	0	0	0
7mW	6.28E-194	5.81E-178	0	0	0	0	0	0	0
8mW	2.31E-168	1.33E-149	0	0	0	0	0	0	0
9mW	1.01E-144	8.25E-126	0	0	0	0	0	0	0
10mW	2.85E-124	2.28E-106	0	0	0	0	0	0	0



(a) A comparative graph for the same proposed model using RZ modulation is drawn as shown in Figure 10. Pre-DCF with Uniform FBG Configuration



(b) Post-DCF with Uniform FBG Configuration

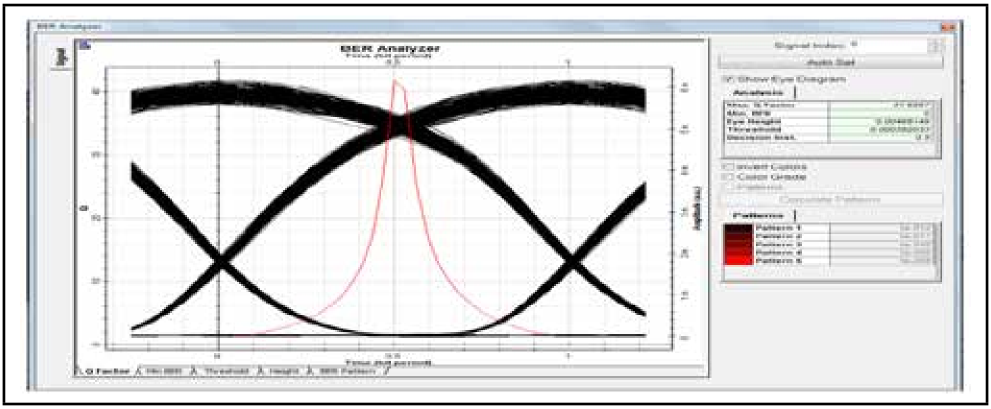


(c) Symmetrical DCF with Uniform FBG Configuration

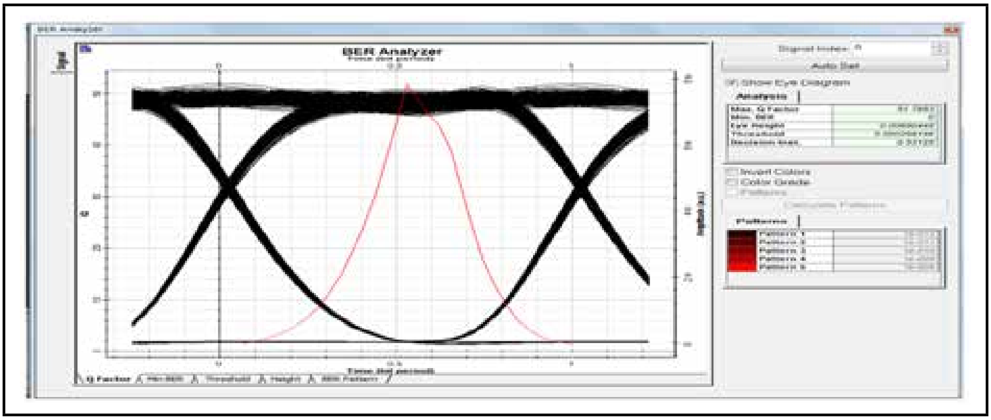
Figure 10: BER versus Transmitted Power for (a) Pre-, (b) Post-, and (c) Symmetrical Uniform FBG compensation technique using RZ modulation

BER Diagram

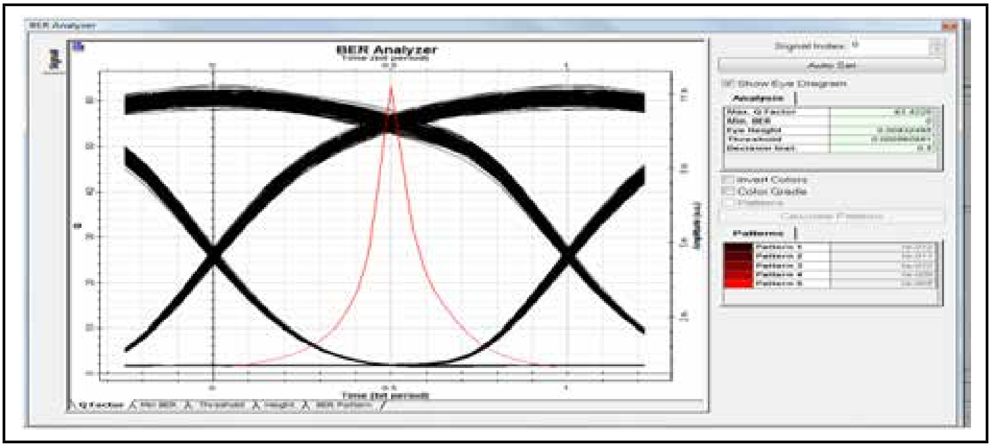
In this section, different eye diagrams are evaluated from the BER analyzer for the proposed model with different values of input power for NRZ and RZ modulations with different input sequence. The higher opening of eye or eye height in eye diagram is the parameter for the better performance of optical fiber link. Figure 11 and 12 shows the Eye diagram or BER diagram for pre-, post- and Symmetrical DCF with IDCFBG configurations using NRZ and RZ modulation for those values of input power and input sequence code in which we are getting the higher value of Q factor and minimum value of BER.



(a) Q-factor= 41.6897 and BER= 0 at 5 mw

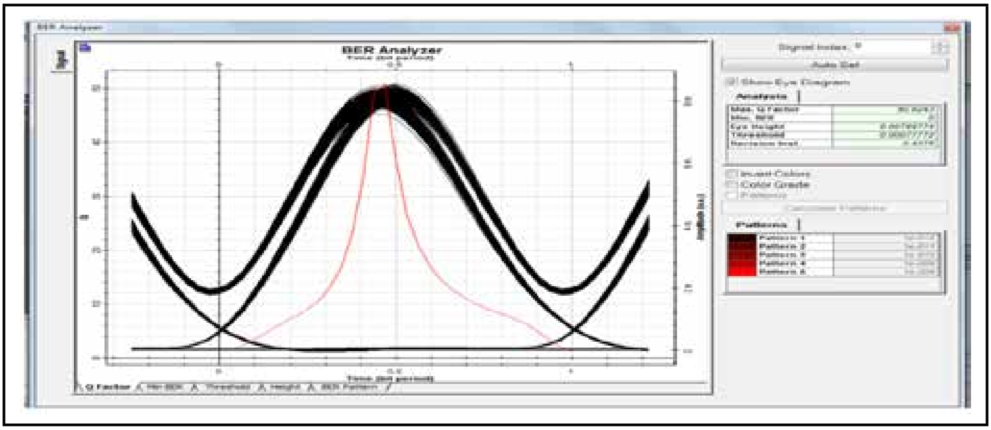


(b) Q-factor= 51.7953 and BER= 0 at 8 mw

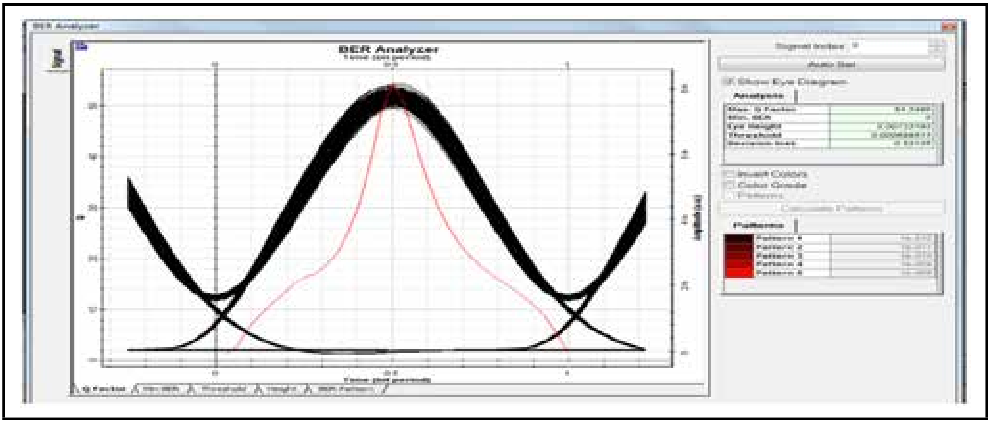


(c) Q-factor= 63.4228 and BER= 0 at 10 mw

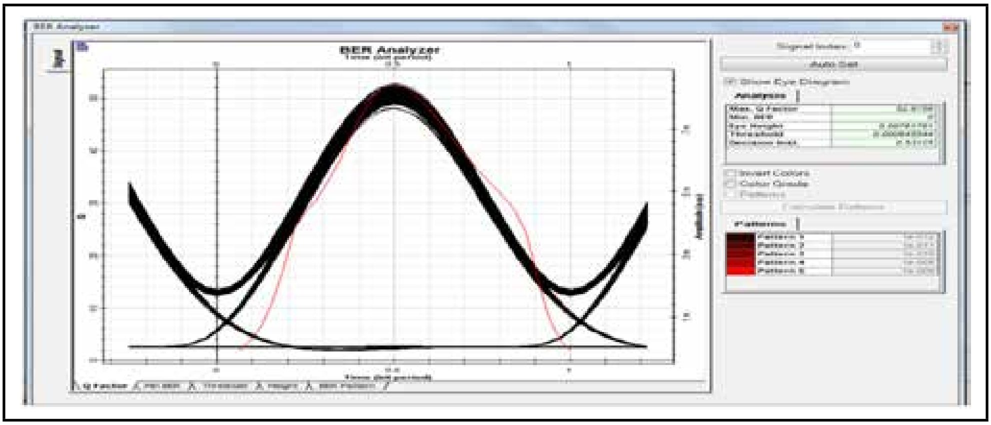
Figure 11: BER analyzer diagram for (a) Pre-, (b) Post-, and (c) Symmetrical DCF with Uniform FBG configuration using NRZ modulation with Walsh code



(a) Q-factor= 50.8243 and BER= 0 at 10 mW



(b) Q-factor= 54.3489 and BER= 0 at 10 mW



(c) Q-factor= 52.8758 and BER= 0 at 10 mW

Figure 12: BER analyzer diagram for (a) Pre-, (b) Post-, and (c) Symmetrical DCF with Uniform FBG configuration using RZ modulation for Walsh code

From the above eye diagrams, it can be concluded that the quality of eye opening of received signal is much clear by using the proposed model with Walsh code and provides the better performance for the dispersion compensation.

CONCLUSION AND FUTURE SCOPE

This work is completely focused on performance analysis of optical transmission system using DCF-Uniform FBG techniques having optical amplifier in order to compensate the dispersion phenomena. The performance parameters of 240 km optical link is investigated in terms of Q factor, BER and eye diagram for NRZ and RZ modulation formats with PN, FC and Walsh codes by varying the input CW laser power. From the analysis, it is concluded that when Walsh codes are used as user-defined input data sequence it gives the highest value of Q factor at 63.4228 and BER at 0 when the proposed model is used in symmetrical configuration with NRZ modulation at 10 mW. It is also concluded from the result analysis that when Walsh codes are used, it gives the highest value of Q factor and BER as compared to PN and FCC codes. In future, the proposed techniques can be applied by replacing uniform FBG by other dispersion compensator with DCF to compensate dispersion effects.

ACKNOWLEDGEMENT

We wish to thanks Optiwave Systems Inc., Canada for providing the Optisystem 17.0 software to complete this experimental work. We would like to thanks our colleagues from Sangam University, Bhilwara for sharing their views and comments with us in preparation and editing of the paper.

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