DCF WITH IDEAL DISPERSION COMPENSATION FBG BASED DISPERSION COMPENSATION TECHNIQUE FOR SINGLE CHANNEL OPTICAL FIBER LINK USING NRZ AND RZ MODULATIONS WITH DIFFERENT INPUT SEQUENCES

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ABSTRACT

In this paper, a single-channel optical fiber link is proposed with a hybrid dispersion compensation technique to investigate chromatic dispersion. Chromatic dispersion is one of the limiting factors that are responsible for the performance limitation in the optical fiber link. In this proposed model, DCF with Ideal Dispersion Compensation FBG (IDCFBG) and optical amplifiers are implemented in three different (pre, post, and symmetrical) configurations using non-return-to-zero (NRZ), and return-to-zero (RZ) modulations with PN, FCC, and Walsh code input sequence. The proposed model is designed for a 10 Gbps data rate over the transmission distance of 240 km. The comparative analysis of the proposed model is analyzed in terms of Q factor, Bit Error Rate (BER), and Eye Diagram by varying the input laser power in mW using NRZ and RZ modulation. The simulation is carried out using Optisystem Version 17.0 software. The comparative analysis concludes that when the proposed model is used with Walsh code, it gives the higher value of Q factor in all the three different configurations as compared to other input sequences.

Keywords: *DCF, IDCFBG, NRZ, RZ, BER, Q factor*

1. Introduction

In the world of communication systems, optical fiber communication is one of the most important topics of research nowadays. In optical fiber communication, optical fibers are used to transfer information. It has many merits like low loss, high bandwidth, low weight, and immunity to electromagnetic interference over conventional transmission lines(Seeds & Williams, 2006). When an information-carrying signal is transmitted over the fiber some losses occur due to the distortions, attenuations, dispersions, absorptions, etc.(Singh, 2015). Out of these, dispersion is one of the foremost limiting factors that degrade the performance of the optical fiber(Kahlon & Kaur, 2014). Chromatic dispersion (CD) is one of the types of dispersion due to which Inter Symbol Interference (ISI) of the output pulse occurs(Keiser, 2011). Due to ISI, the receiver may not be able to differentiate between 0 and 1. The dispersion also reduces the data capacity at high transmission speeds and effective bandwidth. As a result, dispersion is a limiting factor on the data rate of fiber optic communication links(Keiser, 2000). So, it is important to develop an efficient dispersion compensation technique in optical communication systems to reduce the CD(MA et al., 2012).

There are several techniques to reduce the problem of dispersion; two widely used techniques are Dispersion Compensating Fiber (DCF) and Fiber Bragg Grating (FBG)(Pei et al., 2009),(Landolsi & El-Tarhuni, 2008) and (Hu et al., 2010). The CD can be reduced by DCF and dispersion compensators(V. M & WA, n.d.),(LG & SN, 2000). A DCF is often used to compensate for the dispersion effects of the fiber. In this technique, a fiber having a large negative dispersion coefficient is employed together with a Single-Mode Fiber (SMF) having positive. Therefore the dispersion of the fiber link is zero. The length of the DCF is shorter as compared to SMF. The placement of dispersion compensating fiber in the medium plays a crucial role, which decides the signal quality at the receiver end(Mishra et al., 2017). But a DCF may increase the optical loss, nonlinear effects, and cost of the optical transmission system(GP, 1997). The FBG is proposed to reduce the CD instead of DCF. The FBG can reduce the nonlinear effects and have a low cost. The dispersion compensation using FBG is proposed by Qullette(F, 1987), and Williams et al. (JAR et al., 1994). 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(KO & G, 1997). The light which enters into the grating depends upon the wavelength of light got reflecting by the grating. More distance will be traveled by the signal having a larger wavelength in grating before getting reflected; on the other hand, less distance will be traveled by the signal having a small wavelength in the grating before getting reflected. Hence the signal which is spread by CD during a single-mode fiber got reduced by traveling in FBG(T et al., 2014),(S. M & Rajveer, 2015). The FBGs are widely used in optical communication systems(SO et al., 2011) and optical sensors(C, 1999). 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(Pastor et al., 1996). Uniform means the grating period and index of refraction is constant throughout the length of the grating. Ideal dispersion compensation (IDCFBG) is additionally known as chirped grating. In this type of FBG, there is additive fluctuation within the grating period. It has the advantage of large chip parameters which causes a decrease in reflection power. Due to the higher optical characteristics of chirped FBG, it's more convenient for WDM systems(Swati et al., 2018).

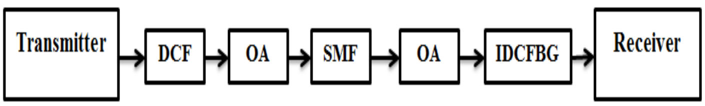
In (Gaurav & Archana, 2021b) and (Gaurav & Archana, 2021a), a DCF and IDCFBG based dispersion compensation technique was proposed with different modulations like NRZ, RZ, CSRZ and Duo Binary with different input sequence.

Now in this paper, a hybrid model in which DCF along with IDCFBG is proposed as dispersion compensators to analyze the performance of single-channel optical fiber link. DCF and Ideal Dispersion Compensation (IDCFBG) is used in three configurations pre, post, and symmetrical along with the optical fiber i.e. SMF. When analyzing the performance of optical communication systems, the data transmission format must be analyzed 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(U et al., 2016). In optical fiber communication, basically, PN Code sequences generated by Pseudo-Random Bit Sequence generator are used to generate a digital sequence. In this paper, the other two codes FCC and Walsh codes are used for the analysis. The FCC codes are often designed by using tridiagonal matrix property, at any given number of users and weights. Walsh-Hadamard (WH) codes(JL, 1923) are binary orthogonal and might easily be generated from Hadamard matrices. The orthogonal sequences generated from Hadamard matrices are called Walsh-Hadamard matrices(V et al., 1997),(Tai-Kuo, 2002).

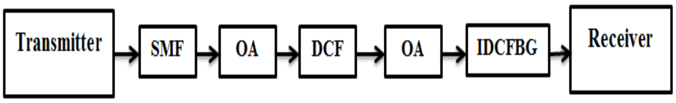
In this paper, the whole analysis of dispersion compensation is based on comparing the value of the Q factor and BER using NRZ and RZ modulation techniques with PN, FCC, and Walsh input sequence code at the transmitter side by varying CW laser power from 1 mW to 10 mW.

2. Experimental Setup

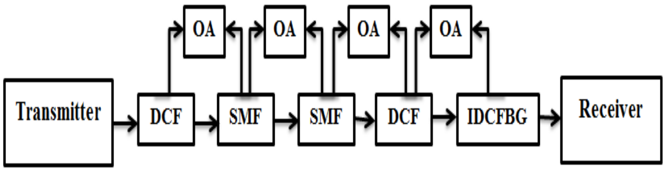
A single channel optical link is designed for 10 Gbps data rate based on hybrid DCF-IDCFBG dispersion compensation techniques. The proposed model shown in Figure 1 is simulated by Optisystem 17.0 software using NRZ and RZ modulations and different input sequence in three different configurations to perform the comparative analysis to investigate the performance of optical fiber link.



(a) Pre Compensation



(b) Post Compensation



(c) Symmetrical Compensation

Figure 1 Experimental setup of the proposed model

At the transmitter side, for all the three configurations continuous wave (CW) laser is used as a source of light at the single frequency of 193.1 THz according to recommendation of ITU-TG.694.1. Both pseudo random and user defined bit sequence generators are used to generate the pseudo random bit sequences and user defined bit sequences respectively. Non Return to Zero (NRZ), Return to Zero (RZ) and Mach-Zehnder (MZ) modulators are used to modulate the CW laser signal.

The optical input signal is spread over a single optical fiber consisting of SMF, DCF, IDCFBG and optical amplifiers. 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 IDCFBG is 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.

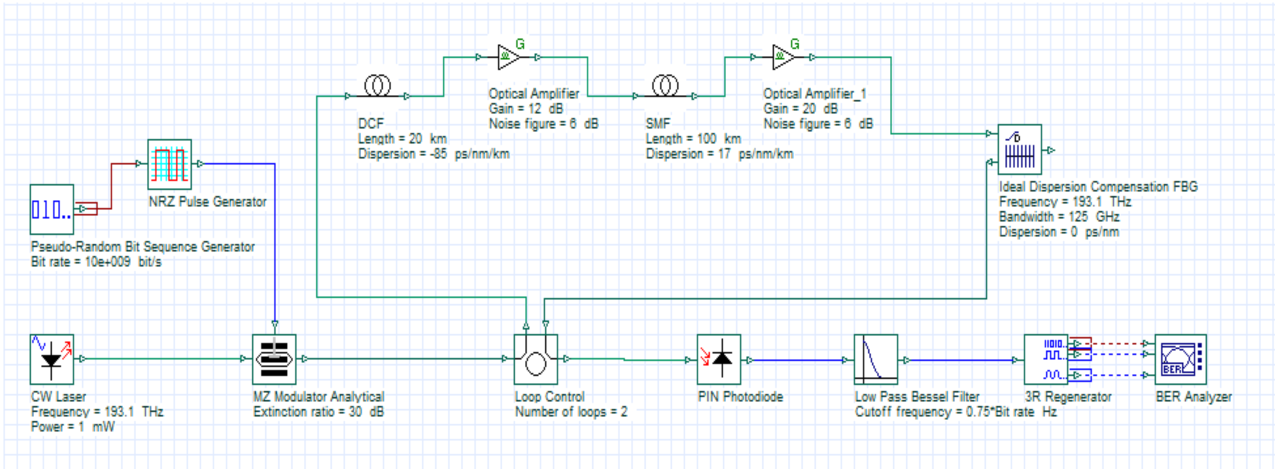
- Pre-compensation: In the pre compensation scheme, DCF is placed before the SMF along with optical amplifier and IDCFBG.
- Post-compensation: In the post compensation scheme, DCF is placed after SMF along with optical amplifier and IDCFBG.
- Symmetrical-compensation: In the symmetrical compensation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

At the receiver side to detect the optical signal, a PIN detector is used along with a low pass electrical Bessel filter and BER analyzer along with 3R generator. Different simulation parameters of single-mode fiber and DCF are tabulated in Table 1.

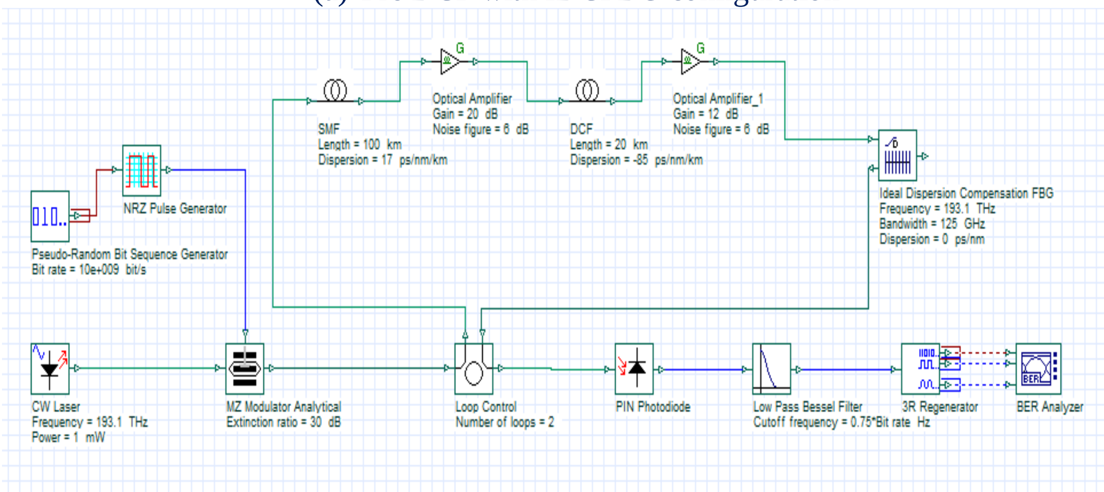
Table 1 Fiber Parameters

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(ps^2/km)	-20	-20
Differential Group Delay(ps/nm)	0.5	0.5
Nonlinear refractive index(m^2/w)	2.60E-20	2.60E-20

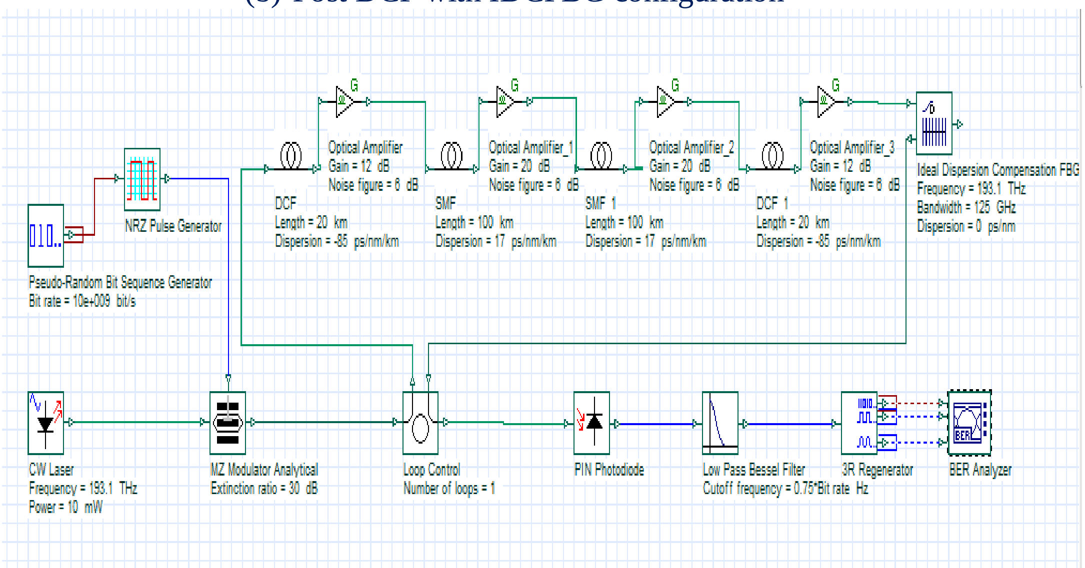
In this paper, DCF with IDCFBG based dispersion compensation techniques for three configurations using NRZ and RZ modulations with three different types of input sequences are implemented. Figure 2 and Figure 3 shows the experimental setup for the pre, post, and symmetrical DCF with IDCFBG techniques for NRZ and RZ modulations respectively using PN code generated by PRBS generator.



(a) Pre DCF with IDCFBG configuration

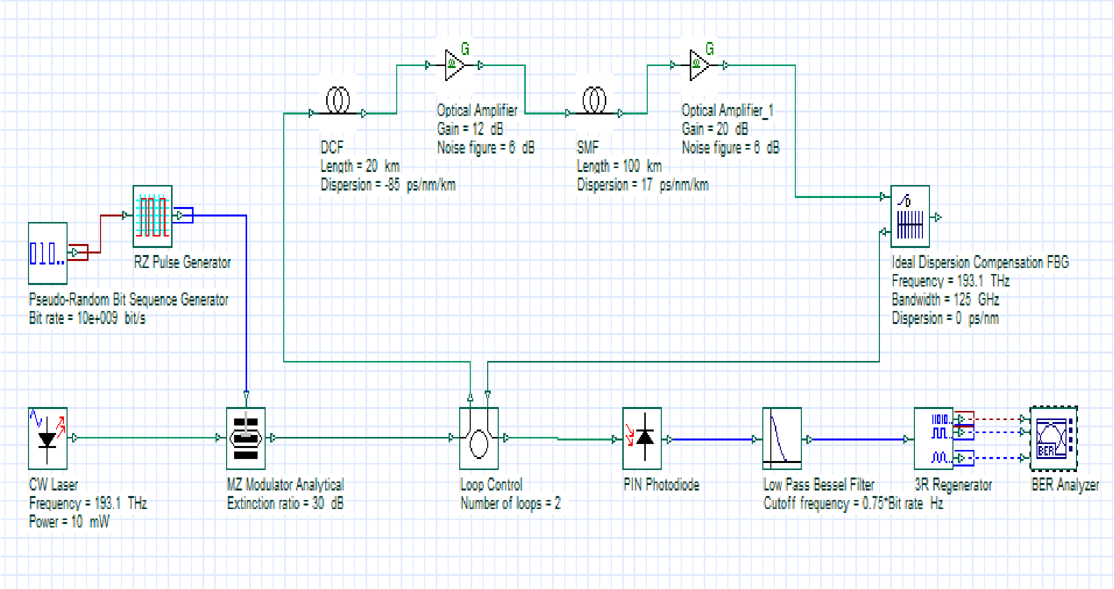


(b) Post DCF with IDCFBG configuration

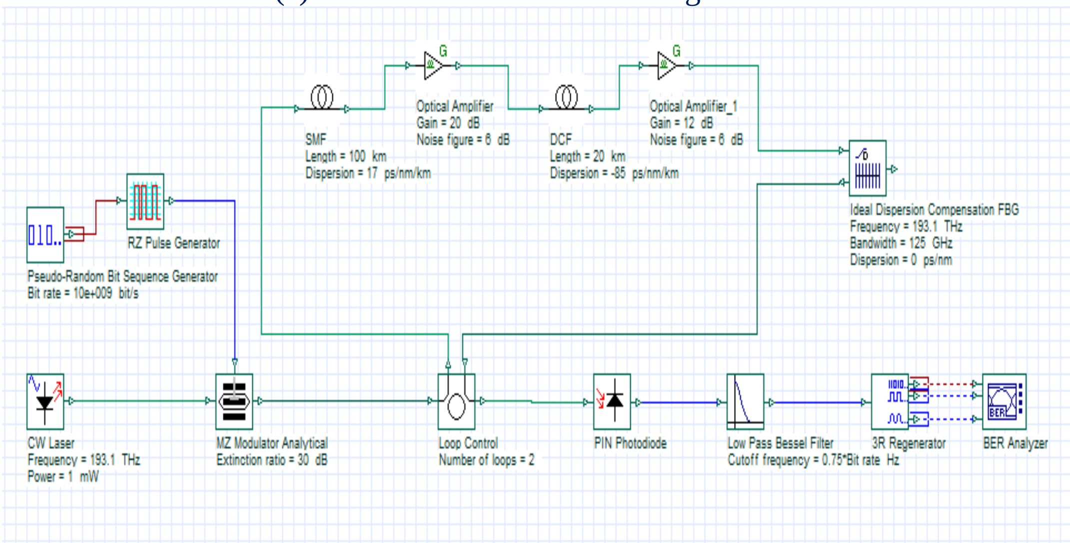


(c) Symmetrical DCF with IDCFBG configuration

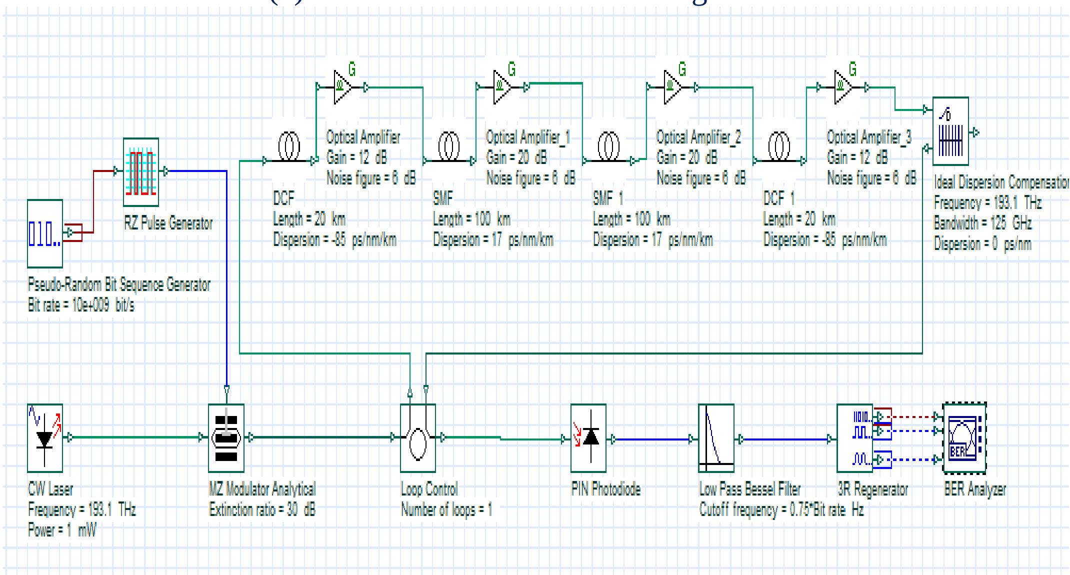
Figure 2 Simulation setup for (a) Pre (b) Post and (c) Symmetrical DCF with IDCFBG compensation using NRZ modulation.



(a) Pre DCF with IDCFBG configuration



(b) Post DCF with IDCFBG configuration



(c) Symmetrical DCF with IDCFBG configuration

Figure 3 Simulation setup for (a) Pre (b) Post and (c) Symmetrical DCF with IDCFBG 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 2 and 3, where 16 bit FCC and Walsh codes are used for the simulation.

3. Experimental Results and Discussion

The performance of the proposed models is simulated on Optisystem 17.0 simulator and quality factor (Q-factor), bit error rate (BER) are measured using BER Analyzer. For enhanced optical fiber communication system, Q>6 and BER≤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 fiber link. Performance of optical fiber link is investigate by varying the input power from 1 mW to 10mW for pre, post and symmetrical configuration of the proposed model using NRZ and RZ modulation with different input sequences applied to the data generator.

1) Q factor versus Transmitted Power

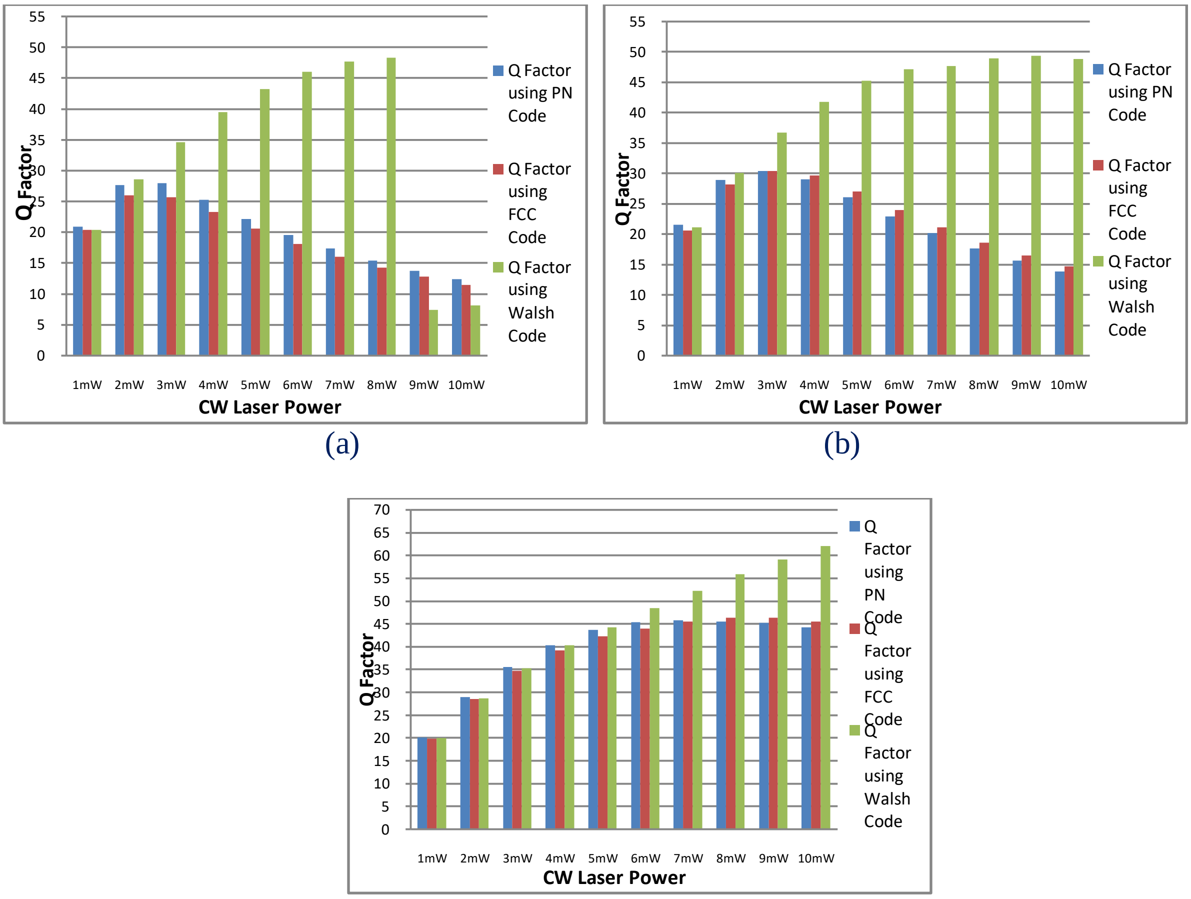
This section provides the different values of Q factor obtained by varying the input power from 1 mW to 10 mW for three configurations of the proposed model using NRZ and RZ modulations with different input sequence like PN, FCC and Walsh codes.

The value of Q-factor for the proposed model using NRZ modulation is shown in the Table 2. highest value of Q factor=48.3852 at 8 mW for pre configuration, Q factor=49.4263 at 9 mW for post configuration and Q factor=61.9986 at 10 mW for symmetrical configuration with Walsh code.

Table 2 Q factor versus Input Power for NRZ modulation

Power	Pre DCF with IDCFBG			Post DCF with IDCFBG			Symmetrical DCF with IDCFBG		
	PN Code	FCC Code	Walsh Code	PN Code	FCC Code	Walsh Code	PN Code	FCC Code	Walsh Code
1mW	20.9992	20.4404	20.479	21.6052	20.6739	21.1344	20.0638	19.8144	19.8723
2mW	27.6646	26.0068	28.6238	28.9471	28.2328	30.1787	28.9507	28.4413	28.6414
3mW	27.9984	25.6929	34.699	30.4571	30.4932	36.7473	35.4551	34.6336	35.1469
4mW	25.3307	23.3355	39.4881	29.0933	29.7414	41.7933	40.2943	39.1861	40.2055
5mW	22.229	20.654	43.2535	26.1473	27.116	45.3491	43.5594	42.2094	44.125
6mW	19.6525	18.2116	46.0236	23.0187	24.0739	47.1775	45.2809	43.8669	48.3488
7mW	17.3884	16.1008	47.7766	20.179	21.2192	47.755	45.6616	45.4232	52.2373
8mW	15.4655	14.3137	48.3852	17.7241	18.7006	48.9829	45.4087	46.2985	55.842
9mW	13.8431	12.8223	7.42621	15.6573	16.5354	49.4263	45.1595	46.3093	59.1187
10mW	12.4723	11.5575	8.18126	13.906	14.7014	48.86	44.1799	45.5113	61.9986

A comparative graph between Q factor and CW laser power ranges from 1 mW to 10 mW is drawn as shown in the Figure 4 for the pre, post and symmetrical configuration of the proposed model using NRZ modulation.



(a) (b) (c)

Figure 4 Q factor versus Transmitted Power for (a) Pre (b) Post and (c) Symmetrical DCF with IDCFBG configuration using NRZ modulation

From the graph it concludes 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 in all the three configurations. The value of Q-factor for the proposed model using RZ modulation is shown in the Table 3. It provides the highest value of Q factor=54.6423 for pre configuration, Q factor=54.2944 for Post configuration and Q factor=52.7711 for Symmetrical at 10 mW input power with Walsh code.

Table 3 Q factor versus Input Power for RZ modulation

Power	Pre DCF with IDCFBG			Post DCF with IDCFBG			Symmetrical DCF with IDCFBG		
	PN Code	FCC Code	Walsh Code	PN Code	FCC Code	Walsh Code	PN Code	FCC Code	Walsh Code
1mW	18.6855	17.8952	18.3601	19.1487	18.4315	18.2245	17.7025	17.4536	17.5539
2mW	26.4459	24.9831	26.0899	27.2692	26.2635	26.0259	25.3209	24.9215	25.1743
3mW	30.8472	28.8096	31.6495	33.1104	31.926	31.8195	30.8172	30.2627	30.8447
4mW	32.7055	30.109	35.9811	37.6203	36.3684	36.5285	35.0363	34.3187	35.4593
5mW	32.6507	29.6954	39.8699	41.0868	39.9563	40.4464	38.1046	37.3286	39.3416
6mW	31.3249	28.3522	43.4187	43.6551	42.7811	43.9168	40.1911	39.3587	42.6767
7mW	29.4632	26.5639	46.6352	45.7131	45.0618	46.9693	41.3478	40.4811	45.5516
8mW	27.3277	24.5646	49.5598	47.1937	46.7206	49.7097	41.8629	40.9393	48.0576
9mW	25.2748	22.6244	52.2258	48.0819	47.8818	52.1142	41.7939	40.7656	50.5209
10mW	23.3476	20.8616	54.6423	48.6736	48.624	54.2944	41.1907	40.2659	52.7711

A comparative graph is also drawn for the same proposed model using RZ modulation as shown in Figure 5. From this graph also concludes that Walsh code provides the higher value of Q-factor as compared to PN and FCC codes in all the three configurations.

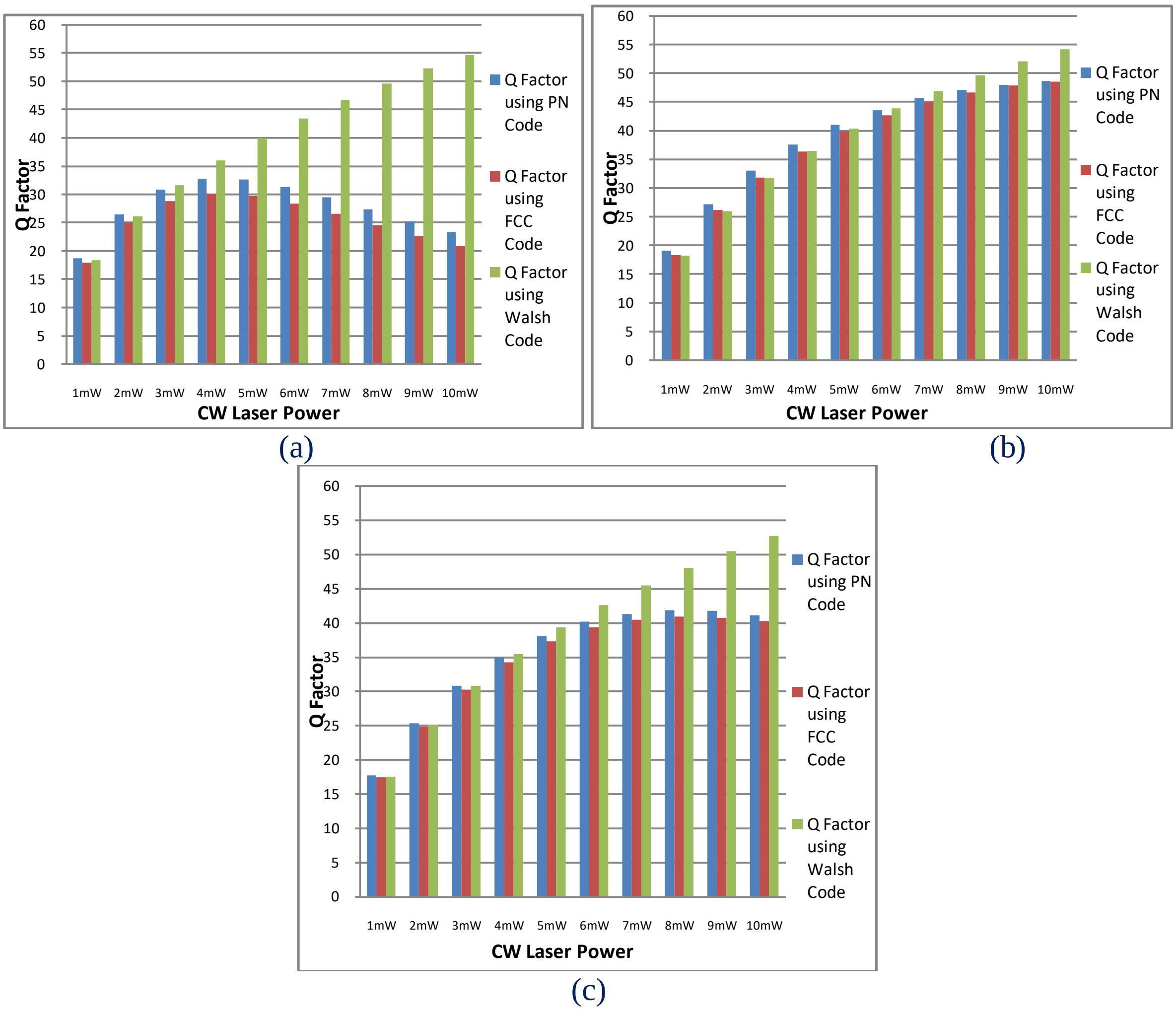


Figure 5 Q factor versus Transmitted Power for (a) Pre (b) Post and (c) Symmetrical DCF with IDCFBG Configuration using RZ modulation

2) BER versus Transmitted Power

This section provides the different values of BER obtained by varying the 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.

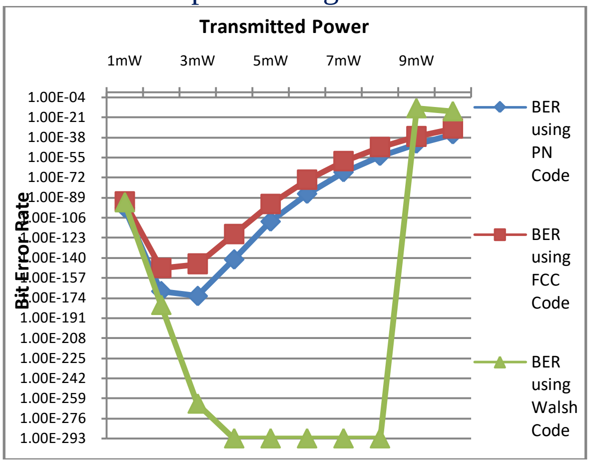
The value of BER obtained by varying the input power for the proposed model using NRZ modulation is given in Table 4. It provides the lowest value of BER = 0 at for symmetrical configuration with Walsh code from 4 mW to 10 mW.

Table 4 BER versus Input Power for NRZ modulation

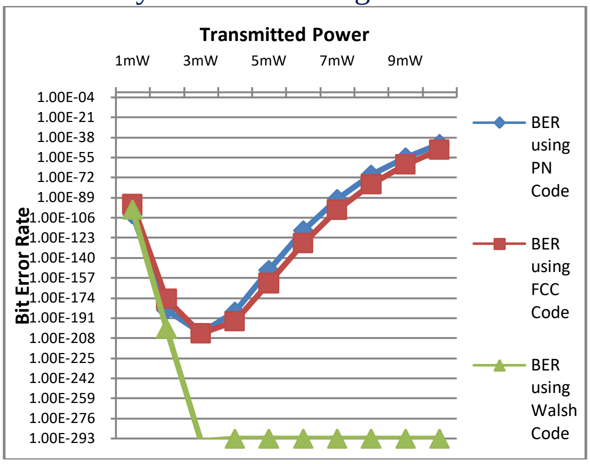
	Pre DCF with IDCFBG			Post DCF with IDCFBG			Symmetrical DCF with IDCFBG		
Power	**PN Code**	**FCC Code**	**Walsh Code**	**PN Code**	**FCC Code**	**Walsh Code**	**PN Code**	**FCC Code**	**Walsh Code**
1mW	2.11E-98	2.33E-93	1.04E-93	5.14E-104	1.89E-95	1.21E-99	4.77E-90	7.04E-88	2.20E-88
2mW	5.59E-169	1.25E-149	1.10E-180	9.25E-185	7.00E-176	1.37E-200	8.25E-185	1.89E-178	6.14E-181
3mW	4.93E-173	4.07E-146	2.69E-264	2.79E-204	9.32E-205	3.79E-296	7.14E-276	2.34E-263	3.83E-271
4mW	4.14E-142	5.74E-121	0	1.52E-186	7.90E-195	0	0	0	0
5mW	5.22E-110	2.59E-95	0	3.61E-151	2.21E-162	0	0	0	0
6mW	1.57E-86	1.18E-74	0	1.11E-	1.74E-	0	0	0	0

				117	128				
7mW	2.89E-68	7.13E-59	0	5.48E-91	2.35E-100	0	0	0	0
8mW	1.72E-54	5.15E-47	0	1.00E-70	1.82E-78	0	0	0	0
9mW	4.15E-44	3.58E-38	5.47E-14	1.09E-55	7.59E-62	0	0	0	0
10mW	3.20E-36	2.01E-31	1.39E-16	2.10E-44	2.36E-49	0	0	0	0

A comparative graph is drawn between BER and CW laser power ranges from 1 mW to 10 mW as shown in the Figure 6 for the pre, post and symmetrical configuration.



(a)



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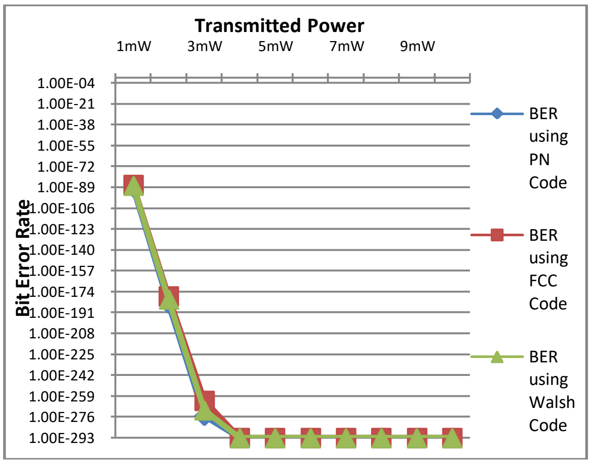


(c)

Figure 6 BER versus Transmitted Power for (a) Pre (b) Post and (c) Symmetrical DCF with IDCFBG configuration using NRZ modulation

From the graph it concludes 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 5. It provides the lowest value of BER=0 for pre, post and symmetrical configuration from 5 mW to 10 mW input power with all the input sequence code.

Table 5 BER versus Input Power for RZ modulation

'Power	Pre DCF with IDCFBG			Post DCF with IDCFBG			Symmetrical DCF with IDCFBG		
	PN Code	**FCC Code**	**Walsh Code**	**PN Code**	**FCC Code**	**Walsh Code**	**PN Code**	**FCC Code**	**Walsh Code**
1mW	2.09E-78	4.18E-72	8.81E-76	3.20E-82	2.41E-76	1.08E-74	1.28E-70	1.04E-68	1.79E-69
2mW	1.26E-154	2.89E-138	1.52E-150	3.12E-164	1.59E-152	8.01E-150	5.82E-142	1.35E-137	2.38E-140
3mW	1.86E-209	4.92E-183	2.48E-220	6.49E-241	3.73E-224	1.07E-222	4.64E-209	1.10E-201	2.05E-209
4mW	4.07E-235	1.10E-199	5.38E-284	3.10e-310	4.37E-290	1.22E-292	1.89E-269	1.23E-258	6.31E-276
5mW	2.42E-234	2.66E-194	0	0	0	0	3.20e-318	1.67E-305	0
6mW	6.51E-216	2.35E-177	0	0	0	0	0	0	0
7mW	2.56E-191	5.23E-156	0	0	0	0	0	0	0
8mW	5.93E-165	8.85E-134	0	0	0	0	0	0	0
9mW	1.79E-141	7.31E-114	0	0	0	0	0	0	0
10mW	4.32E-121	3.52E-97	0	0	0	0	0	0	0

A comparative graph for the same proposed model using RZ modulation is drawn as shown in Figure 7. These graphs also conclude that walsh code provides the lower value of BER as compared to PN and FCC codes when the input power varies from 0 mW to 10 mW.

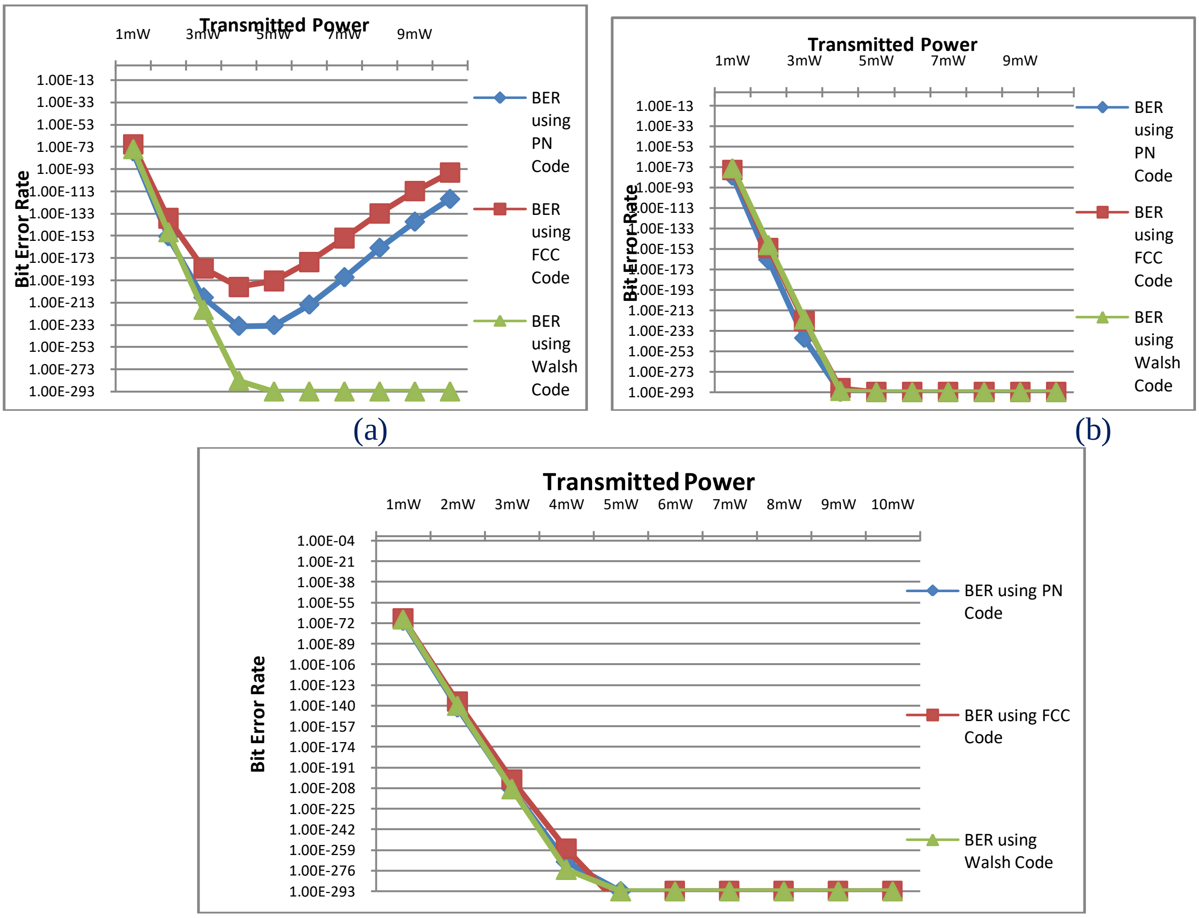
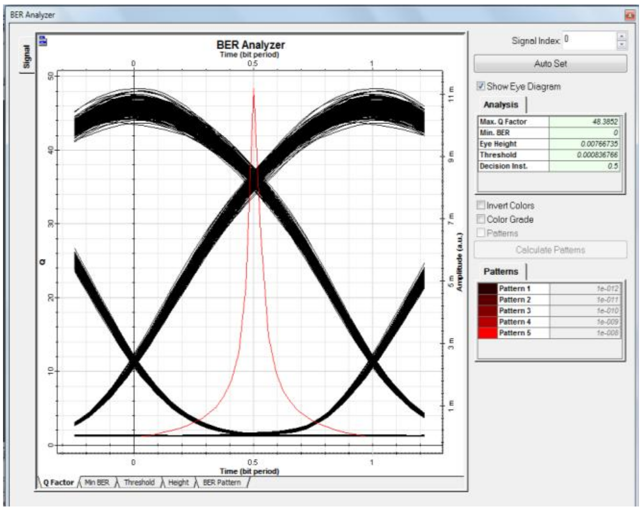
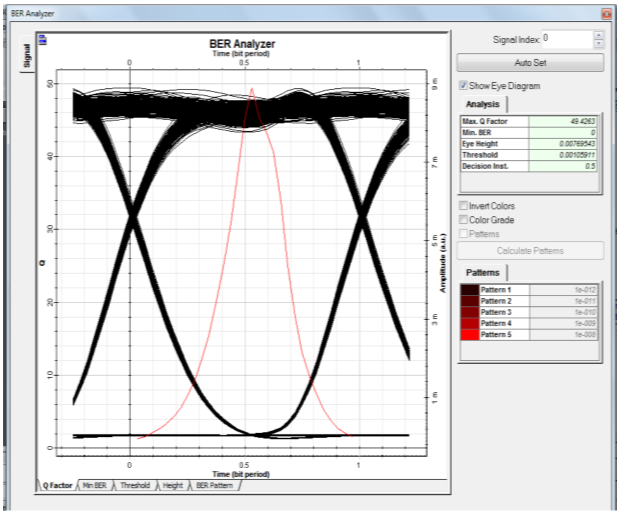


Figure 7 BER versus Transmitted Power for (a) Pre (b) Post and (c) Symmetrical IDCFBG compensation technique using RZ modulation

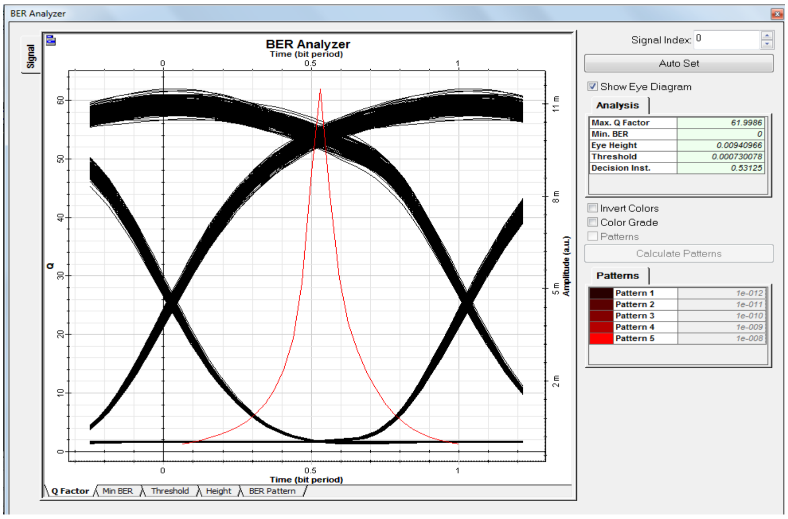
3) Eye Diagram

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 8 and Figure 9 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.



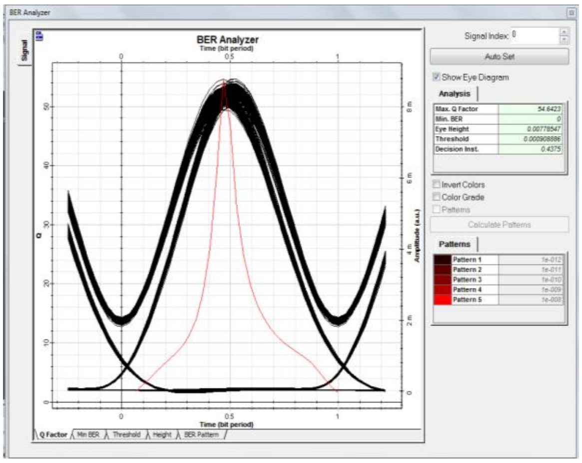


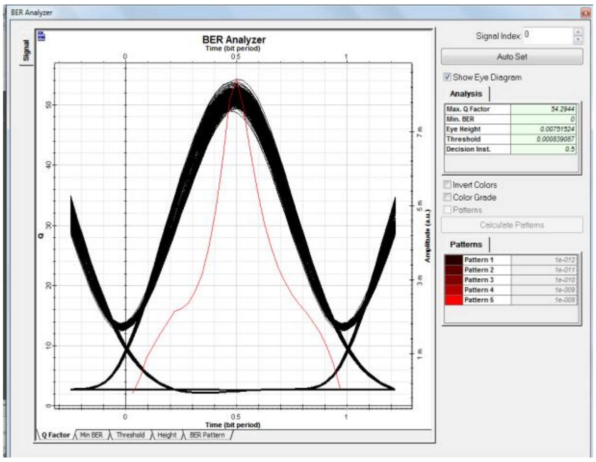
(a)Qfactor= 48.3852 and BER= 0 at 8 mw (b)Qfactor= 49.4263 and BER= 0 at 9 mw



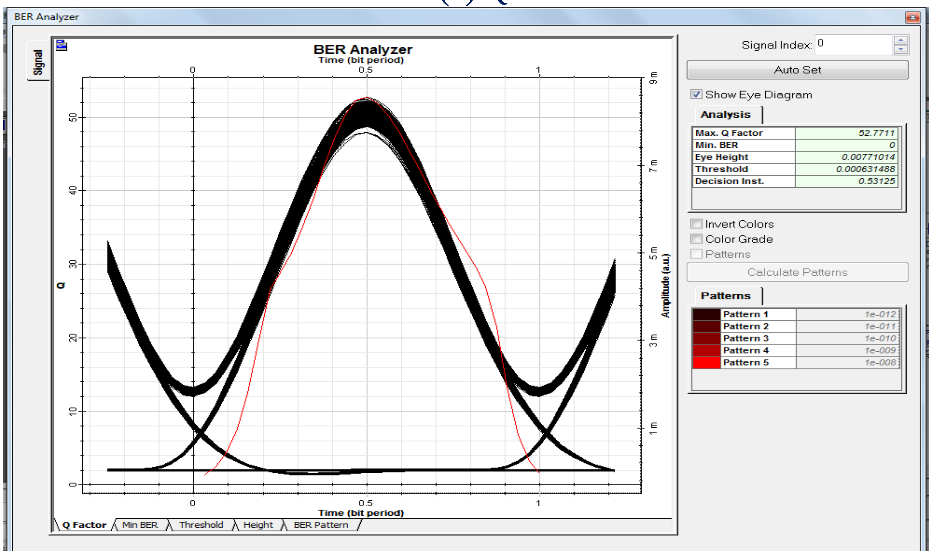
(c)Qfactor= 61.9986 and BER= 0 at 10 mw

Figure 8 BER analyzer diagram for (a) Pre (b) Post and (c) Symmetrical DCF with IDCFBG configuration using NRZ modulation with Walsh code





(a) Q factor= 54.6423 and BER= 0 at 10 mW (b) Q factor= 54.2944 and BER= 0 at 10 mW



(c) Q factor= 52.7711 and BER= 0 at 10 mW

Figure 9 BER analyzer diagram for (a) Pre (b) Post and (c) Symmetrical DCF with IDCFBG 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.

4. Conclusions

The presented work is completely focused on performance analysis of optical fiber link over a fiber length of 240 km (02 loops of 100 km-SMF + 20 km-DCF) for 10 Gbps data rate. The proposed model is designed and simulated using dispersion compensation (DCF-IDCFBG) techniques to compensate the dispersion effects. The performance of the designed system is investigated in terms of Q factor and BER for NRZ and RZ modulation formats with different input code sequences 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=61.9986 and BER=0 at 10 mW when the proposed model is used in symmetrical configuration with NRZ modulation at 10 mW. It is also concluded from the results 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 work, by using some more hybrid models including DCF with FBG, we can analyze the performance of optical link.

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