Dispersion compensation of optical systems utilizing fiber Bragg grating at 15 Gbits/s

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ABSTRACT

Nowadays the technological advancement of the information transmission is developing very rapidly and it becomes necessary to achieve a high speed in the transmission of data as well as higher data rate. Developments in optical communication systems address these needs. However, despite all the features and advantages of optical communication systems, the dispersion is still the main challenges. In this paper and to this end, fiber Bragg grating (FBG) is used in order to overcome the dispersion issue in the wavelength division multiplexing (WDM) transmission system. The WDM transmission system is simulated using the advanced tools of Optisystem 13. The simulation program was used at a speed of 15 Gbits/s with 50Km optical fiber length based on the different input design parameters such as input signal power, optical fiber length and attenuation coefficient. In addition, the output performance parameters are discussed in terms of quality factor (Q-factor) and eye diagram. Moreover, a comparison between the proposed design and previous related works is presented.

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1. INTRODUCTION

Due to the rapid development, optical fiber communications have become one of the most important factors for modern communication systems [1-4]. This is why modern communication networks have become more sophisticated. The Fiber-optic networks that implement wavelength division multiplexing (WDM) are now extensively used in modern communications and studies indicate that it will form a very important part in the next generation of the networks and the Internet in the future. Mostly these systems consist of multiple channels, a structure of topology are different, source of a non-Gaussian noise also non-linear devices, which makes their analysis and design are very complex and require very intense work one of the most important determinants of transmission performance is the chromatic dispersion caused when using the "Erbium-Doped Fiber Amplifiers " to compensate the losses of transmission in the optical communication systems [5].

To eliminate and overcome this limitation, FBG networks are introduced as part of the system to modifying the index of refraction in the core of the optical fibers [6]. This paper presents a detailed study of 4-channel multiplexes with different wavelengths based on the europium doped fiber amplifier-wavelength division multiplexing "EDFA-WDM" optical transmission system [7-8]. FBG was implemented for improved the quality of the signal at the receiver. Input power (dBm), length of optical fiber (km), and coefficient of attenuation (dB/km) were entered. Where each Q-Factor (dB) and was calculated an eye diagram [9-10].

There are several types of FBGs, such as chirped FBGs that provide different wavelengths (frequencies) so that they are very suitable for use as dispersal compensation elements for one wavelength of several waves. FBG has many advantages that make it very suitable for dispersion compensation applications such as low loss of insertion, high losses of return, or extinction, and it is a low cost. In this paper, we compare our result with the related works [11, 12] respectively.

The optical fiber transmission system is stimulated and discussed by analyzing the effect of the components in a data receiver by using different parameters setting. The investigation of the value of parameters has been presented such as noise figure, output power, gain at the receiver and attenuation coefficient at cable section [11]. The simulation results and discussion of the transmission system have been analyzed based on different parameters by using optisystem simulator [12]. A suitable settings of the system which contain fiber cable length, input power, and attenuation coefficient at cable section is simulated, the Q-factor parameter will be studied in details at the receiver.

2. BASIC CONCEPT OF EDFA

A wavelength selective coupler (WSC) using to mixed the high-power light beam with the input signal. The excitation light and the input signal should be of significantly different wavelengths [13, 14]. By directing light after mixing to a part of optical fibers with the inserted ions of erbium into the heart, where this light beam of high-energy raises ions of erbium to their high-energy state and when the signal which is contained the photons are met with another different wavelength of the pumping light, the raised ions of erbium it will dispense with some of the signal strength and return to its low-power state as in Figure 1 [14]. An important point must be clarified, that the energy will be transferred from the erbium in the form of additional photons so that they are exactly at the same stage and direction of the signal to be amplified [15]. Therefore, the amplified signal only along the direction of propagation. The atom when it is 'faded', always transferred its energy at the same level and same direction for the incoming light [16]. As a result, all additional signal strength will be directed to the same position and direction of the incoming signal. In order to prevent all back reflections from surrounding fibers, the insulator is usually placed in the output, as these reflections will disrupt the operation of the amplifier and in extreme cases, it can cause the amplifier to become a laser. The activated erbium amplifier is a high gain amplifier. EDFAs are usually used to cover an estimated maximum distance of 800km (km). For the reposition, the intermediate repeater must exist for longer distances and filter the accumulated noise of different forms of light scattering from the bends in the optical fibers. Additionally, "EDFA" that cannot amplify any wavelengths below 1525nm [13].

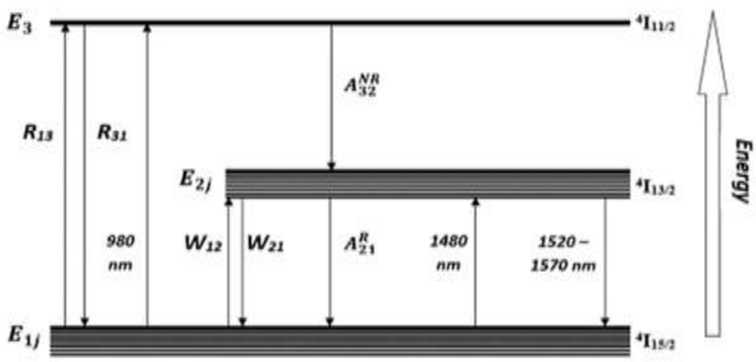


Figure 1. Energy level illustration for Er-doped silica fiber [17]

3. PRINCIPLE OF OPERATION TO FBG

To reduce costs in optical networks, optical fibers (FBG) is used because it a low-cost filter and simple to choose the appropriate wavelength that contains different applications as well as to improve quality [18]. FBG performs some operations such as low loss, filtering, reflection, and high efficiency. In the optical transmission system, the FBG acts as a compensator for color (chromatic) dispersion. Consequently, the pressure in the transverse pulse may be suitable to compensate for the dispersion of chromatic in a communication system as the expected final effect [11]. The Bragg fibers are single-mode, manufactured by exposing the heart to a periodic pattern of intense laser light. As a result of this exposure, there will be a permanent increase in the refractive index of the optical fiber core and create a fixed index modulation called (grating). At any small periodic refraction change, the reflected light will be produced, then this small reflected light will turn into a large reflective light with a special wavelength. When the grating period is approximately half the wavelength of the input light, therefore the wavelength is called Bragg. Where the rest of the light will be transparent (except for Bragg lighting) as shown below in Figure 2 [19]. The first order Bragg condition is simplified as given in the (1),

$$\lambda\_B=2\ n\_(eff\ \ )\ \Lambda \quad (1)$$

Where the n_(eff is the Bragg grating effective refractive index and λ_B is a light input wavelength at free-space that will be reflected from the grating of Bragg.

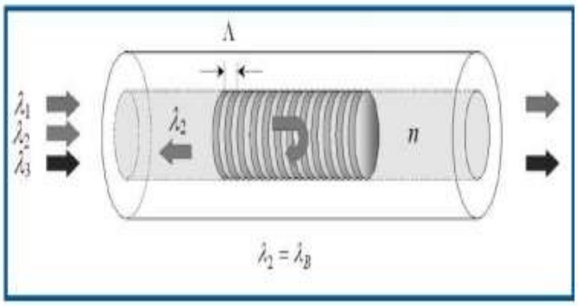


Figure 2. Principle of operation of FBG [19, 20]

4. WAVE DIVISION MULTIPLEXING (WDM)

In the transmitter, the WDM can be used as a multiplexer to join multiple signals together and in the receiver use it as a demultiplexer for split the signals away. For an optical add-drop multiplexer, it is possible to have a device that does both simultaneously. In 1970 and by 1980 the concept was first published for WDM [21] systems and the work was to achieve its laboratory. Two signals only were established at the first of WDM systems [10, 22]. The most WDM systems can operate in single-mode fiber, for modern systems about 160 signals can handle and can thus expand to a 100 Gbit/s system over a single fiber, which has a core diameter of 9 µm. In addition, the certain forms of the WDM can be used in the multi-mode fiber cables with core diameters of 50 or 62.5µm. optical wavelength number (N) can be used as a data carrier, these wavelengths can be combined with an optical WDM multiplexer, though using it as a demultiplexer for separation of these wavelengths division multiplexing as individual channels will be done as shown in Figure 3. The gap between wavelengths control the channel spacing to avert the overlapping which happing in the optical carriers [21].

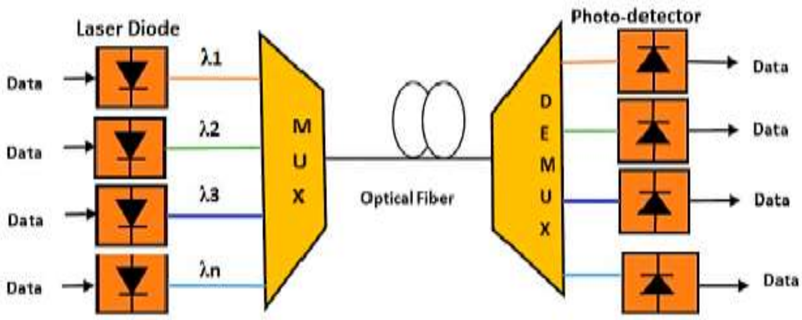


Figure 3. Wavelength Division Multiplexing configuration [21, 23]

5. SIMULATION SETUP

Simulation setup is shown in Figure 4 and consists of three sections, transmitter, receiver and optical fiber, which are the means of transmission medium in this case. For bandwidth control, the source signal contains a binary sequence (0 and 1) created by a pseudorandom generator with a bit rate of 15G/s, and using binary sequence non-return to zero pulses has been generated. The nnon-return to zero (NRZ) pulse generator has a very important advantage because of the generator's ability to return the signal to zero between bits. A sequence generator for a random bit can be used to scramble the data signal in terms of bit rates. Mach zehnder modulator (MZ) has two inputs (optical and electrical signals) and one (optical) output. The input signal is then formed using a semiconductor laser represented by a continuous wave (CW) laser frequency of 193.1 (THz) with input signal power range from 0 to 20 dBm and attenuation coefficient equal to 0.2 dB/km. Which is externally modulated at 15 Gbits/s and fiber length equal to 50Km. Lastly, the receiver contains an erbium-doped fiber amplifier (EDFA) having a gain of 20 dB with the Noise Figure (NF) of 4 dB. A positive intrinsic negative (PIN) diode used as a photodetector to translate the optical signals into electrical signals. Then output signals have been filtered through a low pass bessel filter (LPBF) and optical regeneration. The results of the eye pattern simulation for the calculation of the bit error rate (BER) and the Q-factor are shown when the eye-diagram analyzer was used for the proposed model. In order to operate the design as an optical transmission system, the initial settings of the parameters should be as input power: 10dB, transmitter frequency: 1550nm, fiber length: 50km and attenuation coefficient at cable section: 0.2 dB/km.

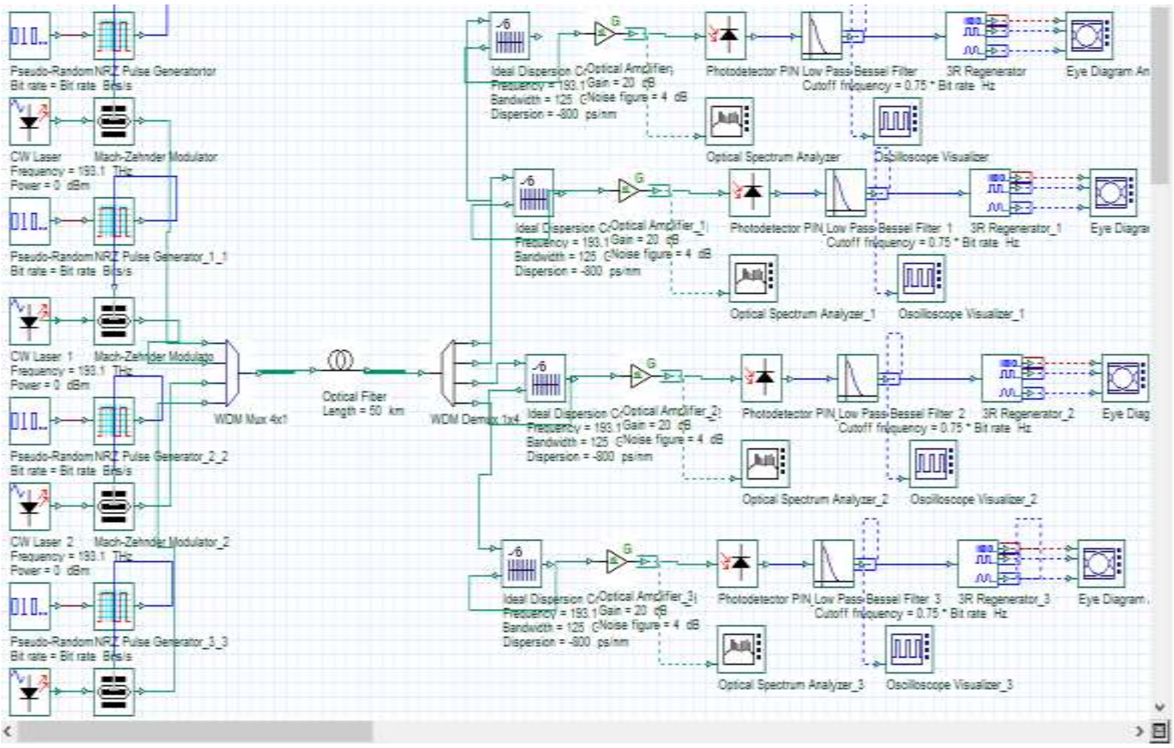


Figure 4. Simulation Setup

6. RESULTS AND DISCUSSION

The simulation results are discussed in terms of eye diagram and output Q-factor in (dB) at the receiver utilizing different values of input signal powers in (dBm). Table 1 shows the relationship between the length of the optical fiber (from 5 Km to 100 Km) and the quality factor (Q-Factor) as well as the eye diagrams for these different fiber lengths are presented in Figure 5. Note that for greater than 100Km the dispersion is very high. From Table 1, and after analyzing the data on it is shown that when input power increases, the Q factor decreases and it is clear that in Figure 5. The eye closure happens to decrease with increasing of fiber length. Furthermore, the Q-factor and eye diagram are analyzed with input signal power range from 0 dBmto a step of 5 dBm as depicted in Table 2 and Figure 6, respectively.

We notice from Table 2 that the Q factor decreases as the input power increases, as shown in Figure 6. Table 3 shows the relationship between the output readings and the attenuation coefficient at the optical fiber. From Figure 7, it is shown that when the attenuation coefficient increases, the Q-factor is found to decrease.

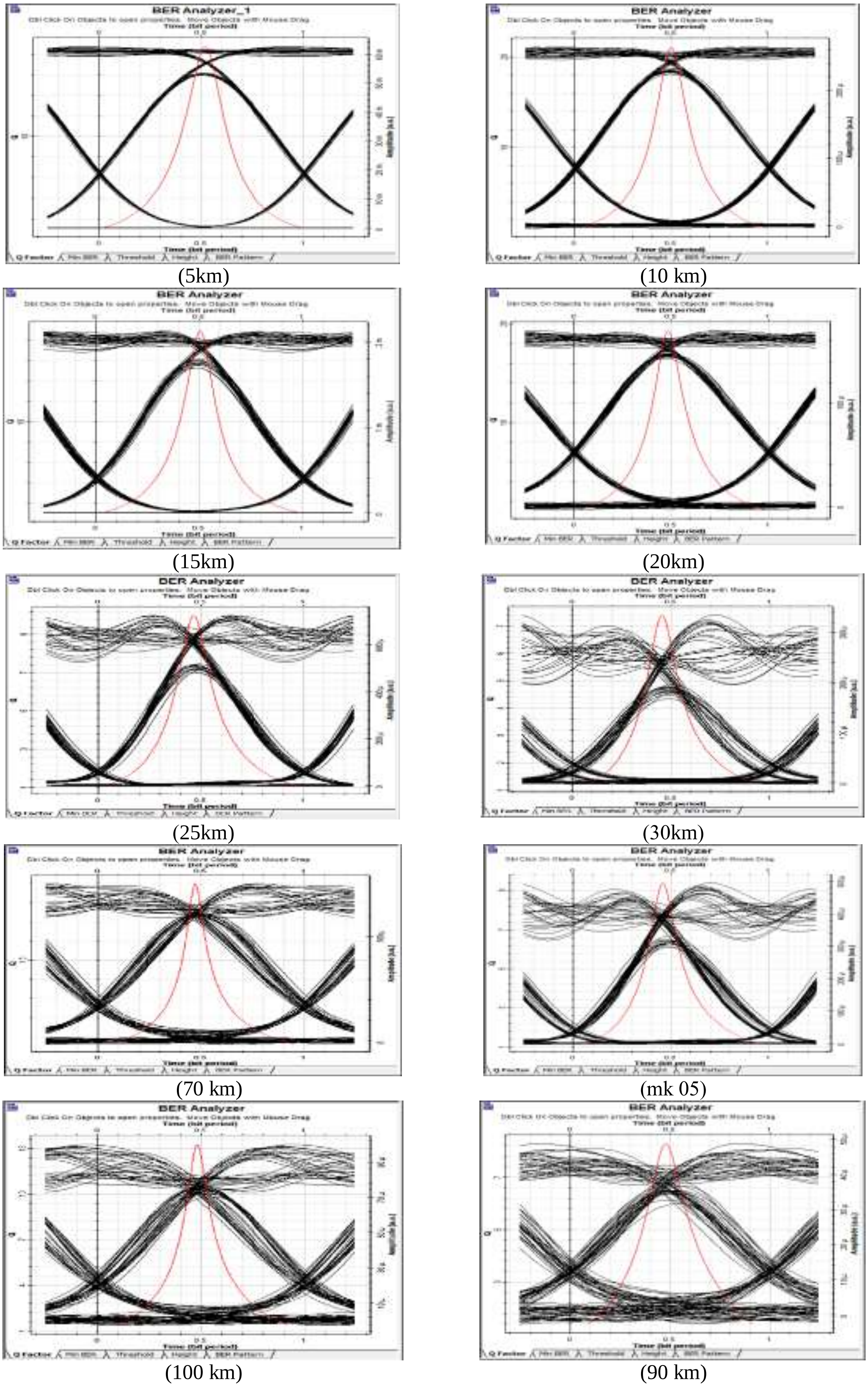


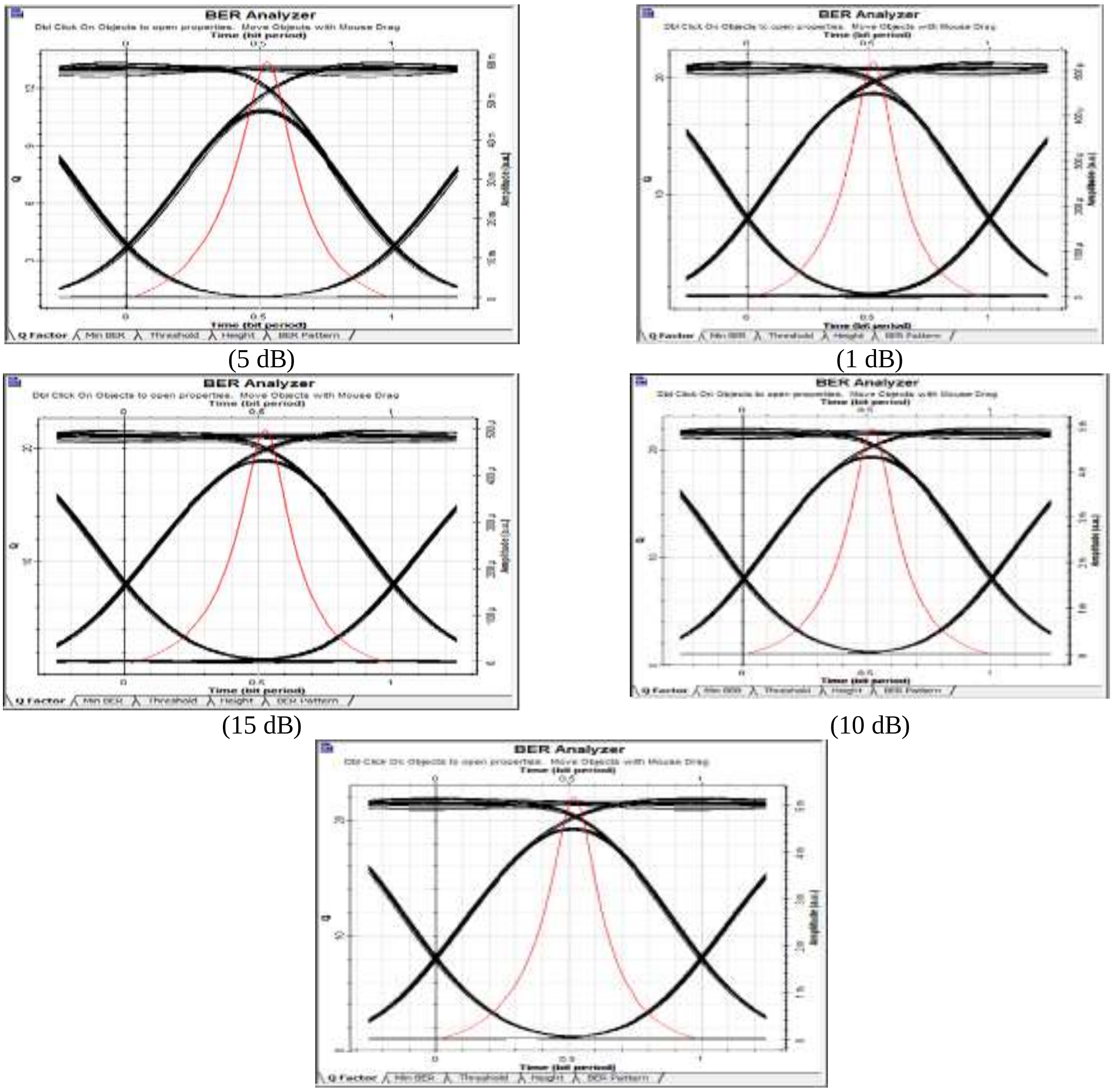
Figure 5. Eye Diagrams of different optical fiber length values

Table 1. Output Readings versus the optical fiber length in (Km)

Optical fiber length (Km)	Q-factor (dB)
5	91.243
10	64.002
15	44.503
20	30.442
25	28.101
30	21.022
50	19.923
70	15.242
90	11.540
100	8.430

Table 2. Output Readings versus the input power

Input power (dBm)	Q-factor (dB)
0	61.501
5	59.201
10	56.643
15	55.320
20	52.902

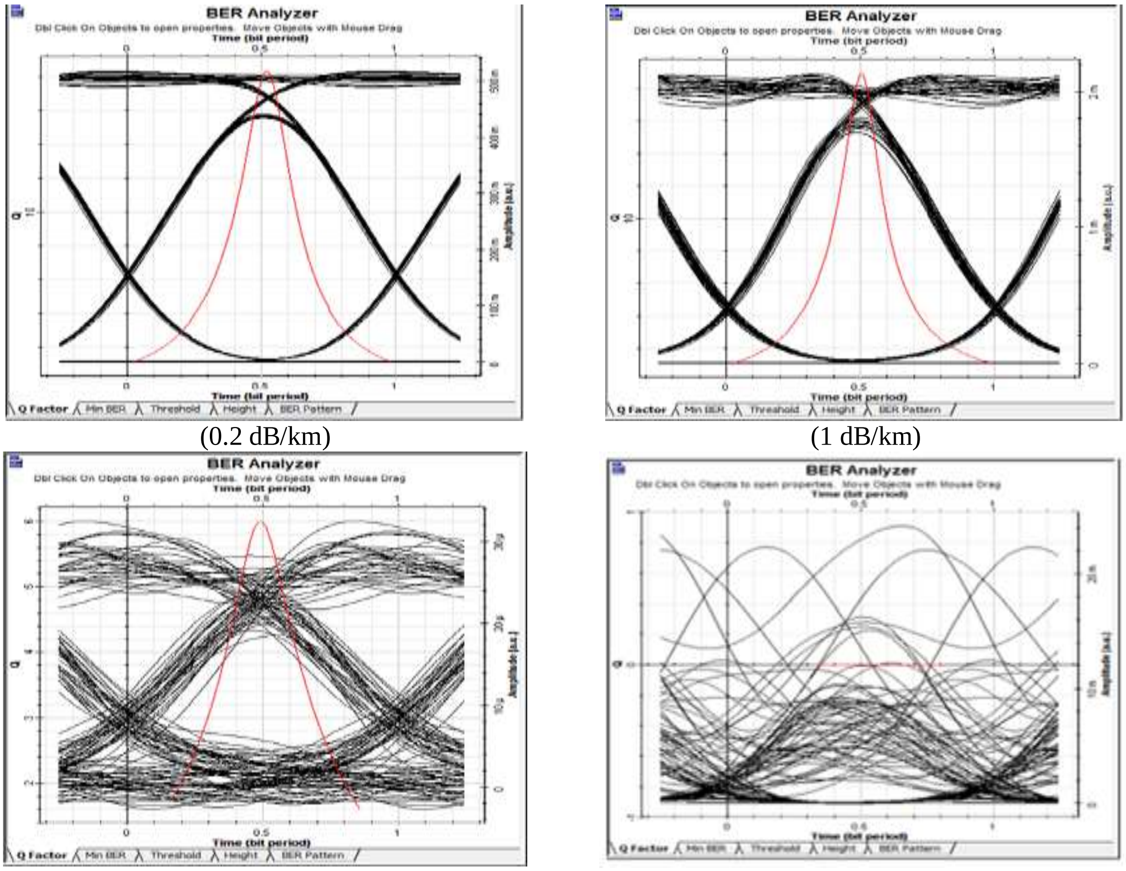


(5 dB) (1 dB)

(15 dB) (10 dB)

(20 km)

Figure 6. Eye diagrams of different input power values



(3 dB/km) (5 dB/km)

Figure 7. Eye diagrams of different Attenuation Coefficient (dB/Km) values

Figure 5 shows the effect of dispersion compensator on the eye-diagram of receiving signals at 50km optical transmission system. It can be saw that the eye-opening or eye gap is much higher and clearer because of the high quality of receiving signals. Hence, the FBG offers better dispersion compensator for WDM long-haul optical communication systems, when compared to the existing reported work in the literature with 5km cable length and 10 Gbit/s [12, 24], single-channel in the proposed design used 4-channel [20], 20 Gbit/s NRZ transmission system over 210km long single-mode fiber (SMF) but with chirped fiber Bragg grating (CFBG) [24], 180Km long single-mode fiber also with chirped fiber Bragg grating [25], over 210 km long SMF but with CFBG [19] design the dispersion compensation with double EDFA [11], cascaded FBG system is proposed to reduce the dispersion in the optical signal in single-mode optical fibers for distance 200km [26]. And additional with 10km optical fiber length and 10 Gbit/s [11]. Tables 4-6 shows the optical fiber length, input power and attenuation coefficient of the proposed model compared with reference [14].

Moreover, the results of the proposed model are compared with reference [12] for different optical fiber lengths, input power and attenuation coefficient as shown in Tables 7-9 respectively.

Table 3. Output readings versus the attenuation coefficient

Attenuation Coefficient (dB/Km)	Q-factor (dB
0.2	63.8
1	59.4
3	55.32
5	1

Table 4. The comparison between Reference [11] & Proposed model for length of single-mode fiber

Length (Km)	Reference [11] Gain dB	Proposed model Gain dB	Reference [11] Noise Figure dB	Proposed model Noise Figure dB	Reference [11] Output mw	Proposed model Output mw
5	12. 286	20	11.271	4	6.320	10
10	12.239	19.924	12.231	4.52	6.168	9.89
15	12.187	19.884	13.206	5.32	6.003	9.51
20	12.129	19.730	14.184	5.94	5.838	8.73
25	12.061	19.601	15.174	6.01	5.663	8.50
30	11.981	19.522	16.174	6.52	5.480	8.23

Table 5. The comparison between Reference [11] & Proposed model for input power

Input power dBm	Reference [11] Gain dB	Proposed model Gain dB	Reference [11] Noise Figure dB	Proposed model Noise Figure dB	Reference [11] Output mw	Proposed model Output mw
0	15.980	23.241	12.175	10.212	5.479	7.742
5	12.239	21.523	12.231	10.506	6.168	8.102
10	7.459	10.220	12.565	11.720	6.815	8.843
15	2.756	8.540	13.419	12.043	7.789	9.501
20	-1.164	3.323	15.024	13.140	10.46	10.789

Table 6. The comparison between Reference [11] & Proposed model for the attenuation coefficient

Attenuation coefficient dB/Km	Reference [11] Gain dB	Proposed model Gain dB	Reference [11] Noise Figure dB	Proposed model Noise Figure dB	Reference [11] Output mw	Proposed model Output mw
0.2	12.239	18.202	12.231	11.992	6.168m	8.114 m
1	11.474	16.540	20.257	13.852	4.343m	5.475 m
3	-1.187	11.922	41.092	23.033	15.769μ	11.844 μ
5	-20.999	-2.453	61.128	35.254	1.142μ	2.453 μ

Table 7. The comparison between reference [12] and proposed model for optical fiber length (Km)

optical fiber Length (Km)	Reference [12] Q-factor dB	Proposed model Q-factor dB
5	89.848	**91.243**
10	57.848	**64.002**
15	50.602	**44.503**
20	32.435	**30.442**
25	25.814	**28.101**
30	22.253	**21.022**

Table 8. The comparison between reference [12] & proposed model for Input power

Input power (dBm)	Reference [12] Q-factor dB	Proposed model Q-factor dB
0	57.904	**61. 501**
5	57.848	**59.201**
10	55.311	**56.643**
15	54.421	**55.320**
20	50.454	**52.902**

Table 9. The comparison between Reference [12] & proposed model for attenuation coefficient

Attenuation Coefficient (dB/Km)	Reference [12] Q-factor dB	Proposed model Q-factor dB
0.2	57.848	**63.8**
1	54.254	**59.4**
3	54.112	**55.32**
5	0	**1**

7. CONCLUSION

The simulated transmission system was calculated and analyzed in this paper on the basis of different variables. This is done by simulating the optical communication model system using the most appropriate system settings, including the optical fiber length (km) and the energy input (dBm) as well as the attenuation coefficient (dB/km) in the optical fiber. We analyzed the compensation for dispersion by using the optical fiber network with different lengths of fibers, and we also calculated and analyzed the quality of the received signal in terms of eye diagram and Q-factor at a speed of 15 (Gbits/s) transmission systems. From the result of the simulation, it can be deduced that the length of optical fiber (km) and the coefficient of attenuation (dB/km) are inversely proportional to the Q-factor. The results obtained in the previous searches that have been explained above have been improved through all the comparison tables obtained, which include both the quality factor, the noise figure, and the output power, and this was done by using the technique of connecting the basic circuit, which is detailed in Figure 4 and come out with the best results.

REFERENCES

[1] R. Hui, *Introduction to fiber-optic communications*. Academic Press, 2019.

[2] Ali, Adnan H., Hayder J. Alhamdane, and Begared S. Hassen. "Design analysis and performance evaluation of the WDM integration with CO-OFDM system for radio over fiber system." *Indonesian Journal of Electrical Engineering and Computer Science* 15.2 (2019): 870-878.

[3] Alsowaidi, Naif, Tawfig Eltaif, and Mohd Ridzuan Mokhtar. "Hybrid optical CDMA and DWDM system implemented under the influence of non-linear effects." *Indonesian Journal of Electrical Engineering and Computer Science* 15.3 (2019): 1485-1490.

[4] Chung, J-P., and S-R. Lee. "Symmetric-type dispersion maps in dispersion-managed optical link with mid-span spectral inversion." *Indonesian Journal of Electrical Engineering and Computer Science* 20.1 (2020): 222-230.

[5] R. Patidar and D. Bansal, "Chromatic Dispersion Compensation in Optical Fiber Communication System using FBG and EDFA," *J. Semicond. Devices Circuits*, vol. 6, no. 3, pp. 1–7, 2020.

[6] S. Spolitis, I. Lyashuk, and V. Bobrovs, "Design and performance evaluation of FBG-based temperature sensors network," in *2017 Progress in Electromagnetics Research Symposium-Fall (PIERS-FALL)*, 2017, pp. 2673–2678.

[7] H. Chun *et al.*, "LED based wavelength division multiplexed 10 Gb/s visible light communications," *J. Light. Technol.*, vol. 34, no. 13, pp. 3047-3052, 2016.

[8] J. Gujral and M. Singh, "Performance Analysis of 4-Channel WDM System with and without EDFA 1," 2013.

[9] Y.-L. Yu, S.-K. Liaw, and Y.-W. Lee, "Eye-diagram and Q factor evaluation of fiber ring laser in lightwave transmission," *Opt. Fiber Technol.*, vol. 31, pp. 55-60, 2016.

[10] M. H. Ali, A. K. Abass, and S. A. Abd Al-Hussein, "32 Channel × 40 Gb/s WDM optical communication system utilizing different configurations of hybrid fiber amplifier," *Opt. Quantum Electron.*, vol. 51, no. 6, 2019, doi: 10.1007/s11082-019-1842-8.

[11] M. A. Othman *et al.*, "An analysis of 10 Gbits/s optical transmission system using fiber Bragg grating (FBG)," *IOSR J. Eng.*, vol. 2, no. 07, pp. 55–61, 2012.

[12] M. Chakkour, A. Hajaji, and O. Aghzout, "Design and study of EDFA-WDM optical transmission system using FBG at 10 Gbits/s chromatic despersion compensation effects," in *Mediterranean conference on information & communication technologies*, 2015.

[13] Y. Gaurav and R. K. Chauhan, "Performance Analysis of EDFA Gain using FBG for WDM Transmission," *J. Telecommun. Electron. Comput. Eng.*, vol. 11, no. 4, pp. 1–4, 2019.

[14] J. A. Bebawi, I. Kandas, M. A. El-Osairy, and M. H. Aly, "A comprehensive study on EDFA characteristics: temperature impact," *Appl. Sci.*, vol. 8, no. 9, p. 1640, 2018.

[15] T. Qayoom and G. Qazi, "Influence of Energy Transfer Mechanisms in Enhanced Configurations of Erbium Doped Fiber Amplifiers (EDFA)," in *2018 International Conference on Computing, Power and Communication Technologies (GUCON)*, 2018, pp. 50–54.

[16] H. Wu *et al.*, "Phonon energy dependent energy transfer upconversion for the red emission in the Er3+/Yb3+ System," *J. Phys. Chem. C*, vol. 122, no. 17, pp. 9611–9618, 2018.

[17] R. Dardaillon, C. Palermo, M. Lancry, M. Myara, R. K. Kribich, and P. Signoret, "Accurate modeling of radiation-induced absorption in Er-Al–doped silica fibers exposed to high-energy ionizing radiations," *Opt. Express*, vol. 28, no. 4, pp. 4694–4707, 2020.

[18] S. A. Kadhim, K. A. Kazr, A. H. Ali, and A. I. Mahmood, "Fiber Communication System based on FBG as Dispersion Compensator, Design an Experimental Setup," in *Journal of Physics: Conference Series*, 2019, vol. 1294, no. 2, p. 22019.

[19] S. O. Mohammadi, S. Mozaffari, and M. M. Shahidi, "Simulation of a transmission system to compensate dispersion in an optical fiber by chirp gratings," *Int. J. Phys. Sci.*, vol. 6, no. 32, pp. 7354–7360, 2011.

[20] S. R. Tahhan, A. K. Abass, and M. H. Ali, "Characteristics of chirped fiber bragg grating dispersion compensator utilizing two apodization profiles," *J. Commun.*, vol. 13, no. 3, 2018, doi: 10.12720/jcm.13.3.108-113.

[21] A. H. Ali and A. D. Farhood, "Design and performance analysis of the WDM schemes for radio over fiber system with different fiber propagation losses," *Fibers*, vol. 7, no. 3, p. 19, 2019.

[22] P. Ivaniga, S. Kureková, and T. Ivaniga, "The Influence of Bit Error Rate on DWDM System with Different Pumping Powers in EDFA," *IOSR J. Electron. Commun. Eng.*, vol. 14, no. 1, pp. 22-30, 2019.

[23] S. R. Tahhan, M. H. Ali, and A. K. Abass, “Characteristics of Dispersion Compensation for 32 Channels at 40 Gb/s under Different Techniques,” *J. Opt. Commun.*, vol. 41, no. 1, pp. 57–65, 2017, doi: 10.1515/joc-2017-0121.

[24] D. Meena and M. L. Meena, “Design and Analysis of Novel Dispersion Compensating Model with Chirp Fiber Bragg Grating for Long-Haul Transmission System,” in *Optical and Wireless Technologies*, Springer, 2020, pp. 29–36.

[25] A. F. Sayed, T. M. Barakat, and I. A. Ali, “A novel dispersion compensation model using an efficient CFBG reflectors for WDM optical networks,” *Int J Microw Opt Technol*, vol. 12, no. 3, 2017.

[26] A. F. Sayed, F. M. Mustafa, A. A. M. Khalaf, and M. H. Aly, “An enhanced WDM optical communication system using a cascaded fiber Bragg grating,” *Opt. Quantum Electron.*, vol. 52, no. 3, pp. 1–21, 2020.

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