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MITIGATING THE PROBLEM OF DISPERSION IN OPTICAL FIBER COMMUNICATION LINK

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Abstract

Dispersion is a major factor that limits the quality of performance of transmitted signal in Fiber optics communication systems. It causes pulse distortion and broadening of transmitted signal which increases the bit error rate and degradation of signal. It also limits the number of channels on an optical fiber link. The purpose of this study is therefore to mitigate dispersion in an optical communication link. A design model was proposed which involve the combined use of Dispersion compensation fiber, Erbium Doped Fiber Amplifier (EDFA) and Fiber Bragg Grating (FBG) to compensate for the dispersion. The model was designed and simulated with Optisystem software version 7.0. The designed model performance was evaluated and analyzed at 2.5Gb/s in a single channel optical communication system at 25km, 50km, 100km, 200km and 500km transmission distance. The model performance was also analyzed in a Wavelength Division Multiplexing (WDM) four (4) multiple channels for the same transmission distances. For each case, the Signal power, Q- factor, Eye Height, Optical Signal to Noise Ratio (OSNR) and Bit Error Rate (BER) were parameters used to evaluate the performance analysis of the systems after signal propagation. Simulation results show that increase in communication distance is directly proportional to increase in dispersion in the optical communication network; however, the model is efficient in both single and multiple channels when compared with a communication system without compensation. Also, from the result the model is more efficient in single channel communication system in terms of performance when compared with the multiple channels system.

Keywords – Communication, Dispersion compensation fiber, EDFA, Fiber Bragg Grating, OSNR, Bit Error Rate, Q- factor.

1. Introduction

The advancement in telecommunication networks recently is as a result of the development in optical fiber due to its properties such as high bandwidth, high level security, large capacity, good performance and flexibility for high bit rate information propagation [1], and strong immunity to electromagnetic interference [2]. Optical fiber has the potential of transmitting vast data traffic at the speed of light over long distances up to thousands of kilometers. Optical Fiber communication has tremendous benefits when compared to conventional transmission lines in networks of developed nations. [3]. Despite its vast deployment optical fiber has several drawbacks which include dispersion, nonlinear effect and attenuation. Dispersion is the main limiting performance factor in optical fiber communication, for it greatly hampers the performance of the communication system [4]. Dispersion is a phenomenon that occurs when light pulses of different are passed into an optical fiber cable, these light pulses travel at different speed since their respective refractive index varies with the wavelength of transmission.. The light waves successfully travels through the fiber but spreads out after some distance is covered within the cable, .this phenomenon is observed throughout the length of the cable [5]. This implies that dispersion is a physical property of the fiber and is directly proportional to the fiber length.

2. Statement of Problem

Dispersion is regarded as a main problem in Optical fiber communication link because it limits the potential bandwidth and transmission performance of a fiber [6]. The speed of the information carrying capability of the fiber cable is dependent on the refractive index of the fiber which in turn depends on the wavelength of the signal. Pulse spreading is the main cause of dispersion in fiber optics communication. This is because; the light signals are of different velocities since their respective wavelength are different [7]. This causes the light pulse to arrive at the end of the fiber at different times leading to pulse spreading. The later is not peculiar to multimode fibers but also exist in single mode fibers. The single mode fiber does not convey signals with a single frequency, rather the pulse signal is made of a collection of wavelength known as the spectral width of the transmitting signal. The implication of pulse spreading is that; the original information sent at the transmitting end will vary with that which is received at the end of the fiber. This degrades the quality of information conveyed along the fiber.. If the data rate of the information signal in optical fiber communication is increased, the pulses at the output overlaps each other [8], leading to a phenomenon known as Inter Symbol Interference (ISI). ISI renders pulses to overflow their time slots, overlap adjacent bits and make them undetectable, which is known as a form of distortion of signal. At the output the receiver may find it difficult discerning or interpreting adjacent bits, thus, increasing the Bit Error Rate. As a result dispersion is a major performance limiting factor on data rate in optical fiber communication. Figure 1 summarizes how dispersion leads to overall system degradation.

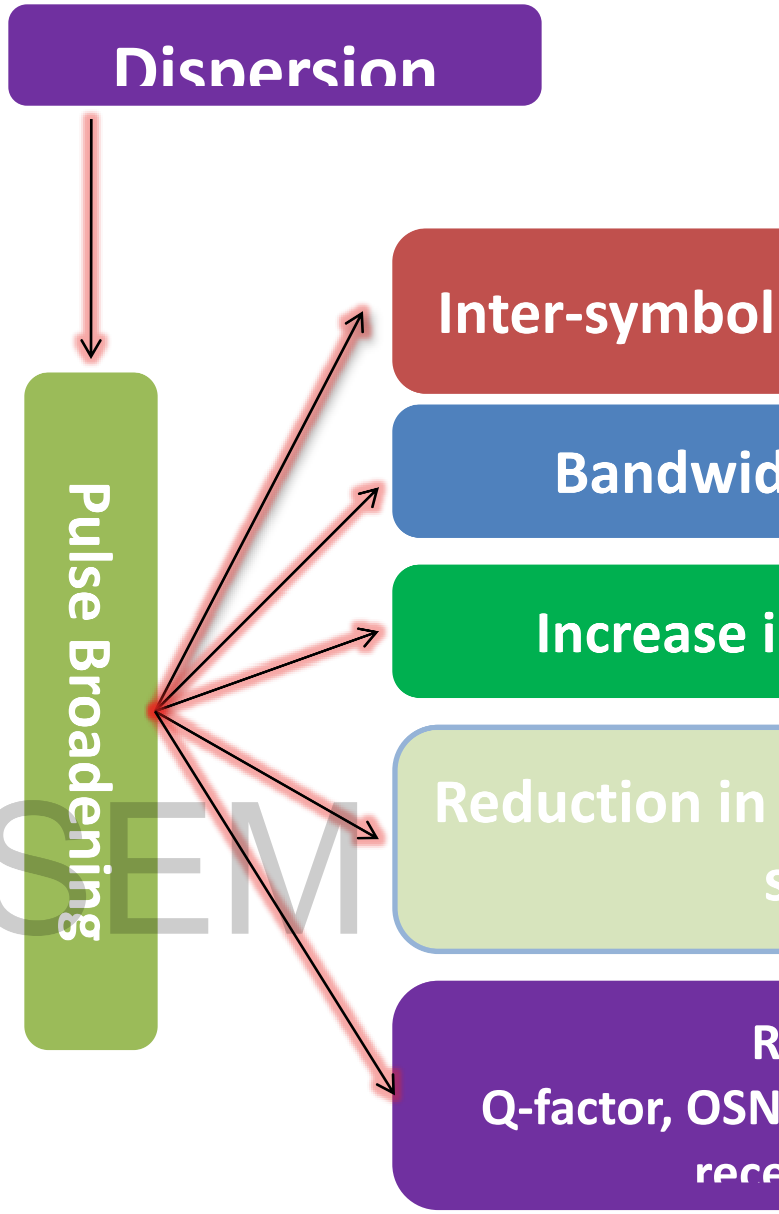

Figure 1: Dispersion effects on optical Systems

In order to achieve high data rates, keep the bandwidth and transport performance at desired level and mitigate other problems associated with dispersion, it is important to adopt dispersion compensation technique presented in this work in deploying optical fiber communication links for better system performance.

3. Literature Review of related work

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Fiber Bragg Grating (FBG) is one of the dispersion compensation techniques. The idea of FBG was initially introduced in 1980 and ever since then, it has found several applications [8]. One of the fundamental merit of applying the Fiber Bragg Grating as approach to compensate dispersion is that it occupies less space, it has high reflectivity, high reliability, wide reflection bandwidth, its insensitivity to polarization, low insertion loss and are compatible with SMF and are very cost effective [9 – 11]. FBG can also be applied in WDM add/drop filters, pump lasers and wavelength stabilizers [12][13].

In [5], chromatic dispersion in single mode fiber was investigated to compensate for waveform distortion. This study was achieved by using an optical phase conjugate wave transmitted at 5Gb/s and 6Gb/s. The dispersion compensation that was performed was evaluated by determining the bit error rate characteristics and by observing the heterodyne eye pattern. The performances of the proposed Phase Conjugation method were investigated and compared with that of Fiber Bragg Grating (FBG) approach. The outcome of the result which was seen in the eye diagram, and the strength of the received signal reveal that the phase conjugate method proved to be efficient and a suitable substitute for Fiber Bragg Grating (FBG) technique. However, Phase Conjugation method is more complex and costly for dispersion compensation when compared to FBG.

Another technique used for compensating dispersion is by the use of Dispersion Compensating Fiber (DCF). DCF technique is based on the principle of adding fiber that posses negative dispersion to that of a standard fiber to mitigate the entire dispersion on the system [14]. Dispersion compensation fiber helps to annul the effect of dispersion that would be present in a normal fiber by adding a negative dispersion [15]. In [16], the ability of negative dispersion fiber used to compensate dispersion was discussed.. They conducted experiment on a single span dispersion compensating fiber (DCF) and a single channel system transmitting at a speed of 10Gb/s with the transmission wavelength of 1550nm over 120km of conventional SMF. However these could induce different penalties like non-linear effects and insertion loss [17].

4. Methodology

The techniques being proposed for optimal optical fiber dispersion compensation is the combined use of Dispersion Compensation Fibers (DCF) with Erbium Doped Fiber Amplifier (EDFA) – Wavelength Division Multiplexing (WDM) and Fiber Bragg Grating (FBG). The design and simulation of the long distance optical fiber communication system was done with the OptiSystem version software 7.0. The proposed model was tested in single and the multiple optical fiber communication systems. The distances considered in these design methods are 25km, 50km, 100km and 500 km in each case.

The choice of DCF in this approach was as a result of study work done by [9] which noted that DCF is made from fiber profiles with multi and matched cladding refractive index with a high degree of negative dispersion coupled with a negative slope. [18] Also pointed out that DCF is fiber cables that have the opposite or negative dispersion of the fiber being used for the wave propagation. It is used to cancel out the positive dispersion of Single Mode fiber. They are implemented in-line of the optical fiber network.

FBG was also among the choice chosen so as to optimize the quality of the received signal and to overcome chromatic dispersion in the optical link. It consists of a periodic modulation of the refractive index in the core of a single-mode optical fiber. The Bragg grating condition satisfies both energy and momentum conservation. The first-order Bragg condition is simplified as follows:

$$\lambda_{\square} = 2n_{e}\Lambda$$

Where the Bragg grating wavelength $\lambda_{\square}$ is the free space wavelength of the input light reflected from the grating, n_e is the effective refractive index of the fiber core at the free space center wavelength, and Λ is the grating spacing of the FBG [19]. For this simulation, the FBG parameters was set such that Frequency 193.1 THz, Effective index 1.41, Length of Grating 2mm, Apodization function uniform, Linear Parameter 0.0001 um, Tanh parameter 0.5 and sample rate 500 GHz.

The choice of EDFA is as a result of not to solve one problem (dispersion) and allow another such as attenuation in the optical link. Optical amplifiers or repeaters are used to amplify the weak signals. Special types of optical amplifiers such as SOA, EDFA, and Raman amplifiers have been introduced that can regenerate the weak light pulses and counter the attenuation effects. However, EDFA still provide better results [20 – 22]. Erbium Doped Fiber Amplifiers (EDFA) was used due its features such as high gain, Low insertion loss, wide optical bandwidth, low Signal to Noise Ratio (SNR) and they are not affected by polarization [23]. Table 1 shows EDFA parameters used in the simulation.

Table 1: Erbium Doped Fiber Amplifier (EDFA) simulation Parameters

S/N	Parameters	Values
1	Core radius	2.2 µm
2	Er doping radius	2.2 µm
3	Er metalistic lifetime	10ms
4	Numerical aperture	0.24
5	Er ion density	$10e + 025m^{-3}$
6	Loss at 1550nm	0.1 dB/m
7	Loss at 980nm	0.15 dB/m
8	Length	5m
9	Forward pump power	100mW
10	Backward pump power	0mW
11	Forward pump wavelength	980 nm
12	Backward pump wavelength	980 nm

The proposed model was tested in WDM due to the fact that optical network that applies WDM is currently widely used in existing telecommunication infrastructures and is expected to play a significant role in next generation networks and the future internet connections [24][25].

A Mathematical model (see equation below) was also used for improved dispersion compensation.

$$D_1 L_1 + D_2 L_2 = 0$$

Where
L_1 is the length of the Single Mode Fiber (SMF)
L_2 is the length of the Dispersion Compensated Fiber
D_1 is the dispersion (16.75 ps/nm/km) of the Single Mode Fiber
D_2 is the dispersion (-80 ps/nm/km) of the Dispersion Compensated Fiber.
The exact length of Dispersion Compensation Fiber (L_2) was obtained with the Equation with an assumed L_1 for the communication distances considered in the study.
Design and simulation of the model at 2.5 Gb/s for 25km, 50km, 100km, 200km and 500km Communication distance in both single and multiple optical fiber systems using Optisystem Software.

Figure 2 shows the design set up for single channel 100km communication distance. While figure 3 shows the design set up for WDM multiple channels for 100km distance.

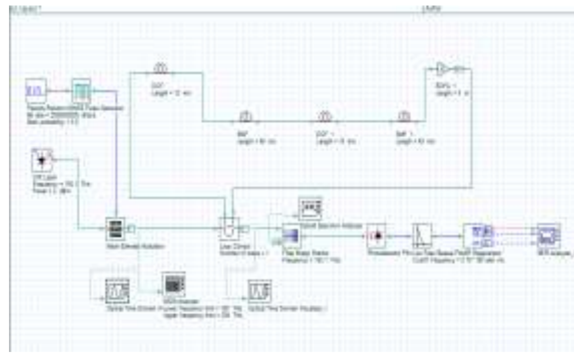


Figure 2: The Model Design setup for a single channel over a 100km Optical fiber communication distance

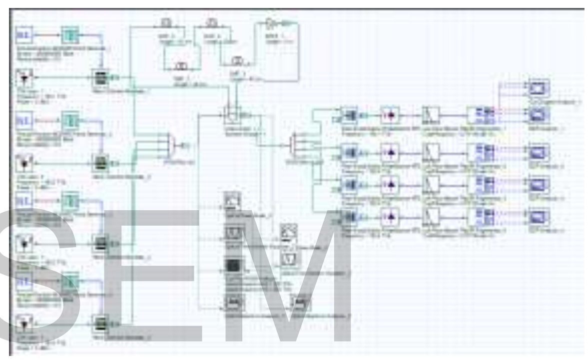
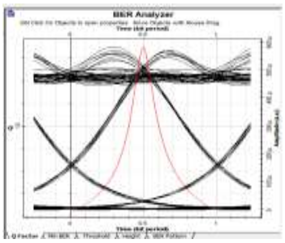


Figure 3: WDM Optical fiber communication systems with the model over a 100km distance

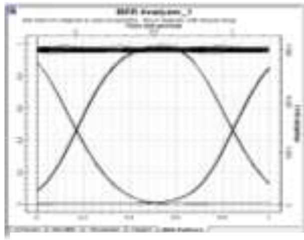
In each case, the system performance was analyzed based on: Calculated Minimum BER, OSNR, Signal Power, Estimated Maximum Q-factor, and Observing the Eye Height pattern.

5. Results and Discussions

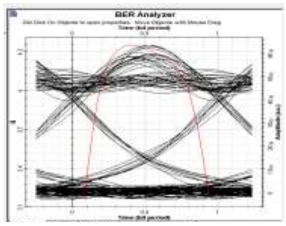
The model proposed was first simulated for single channel optical fiber communication system link. The system considered comprises of a Single Mode Fiber (SMF), Dispersion Compensated Fiber (DCF) with Erbium Doped Fiber Amplifier (EDFA) and Fiber Bragg Grating (FBG) across communication distances of 25km, 50km 100km, 200km and 500km
The figures below show the eye pattern simulation results before and after compensation at 50km, 100km and 200km communication distance. It can be observed that the proposed designed model offers a reduced signal distortion and an improved eye opening in the after compensation figures. This indicates that dispersion was reduced and there were less noise generated during transmission.



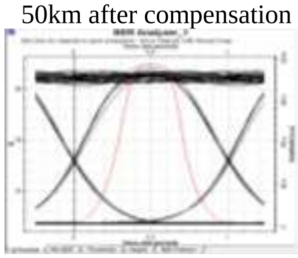
50 km before compensation



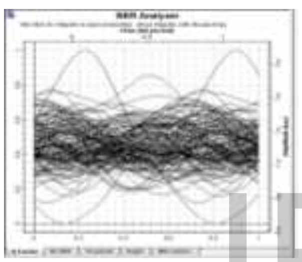
50km after compensation



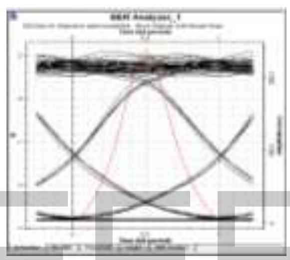
100km before compensation



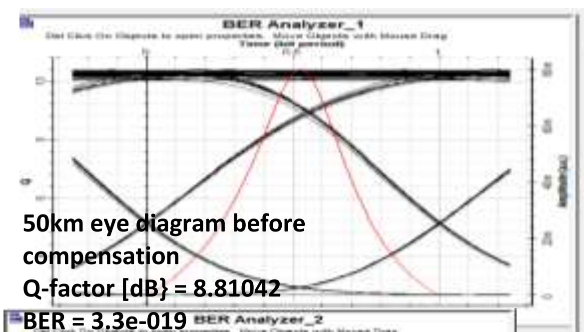
100km after compensation



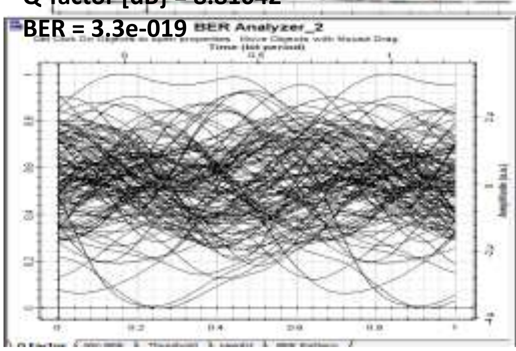
200km before compensation



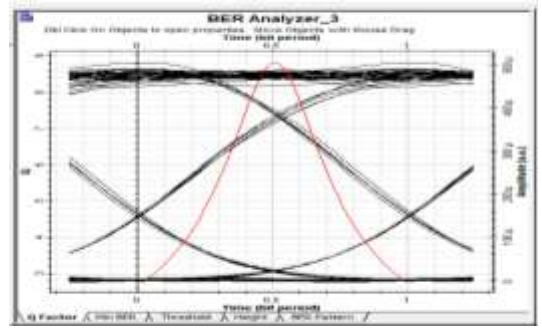
200km after compensation



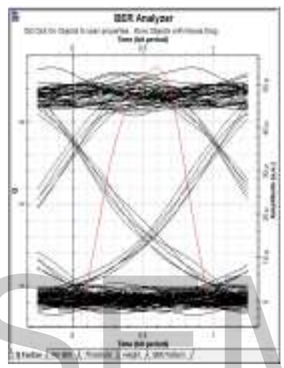
50km eye diagram before compensation
Q-factor [dB} = 8.81042
BER = 3.3e-019



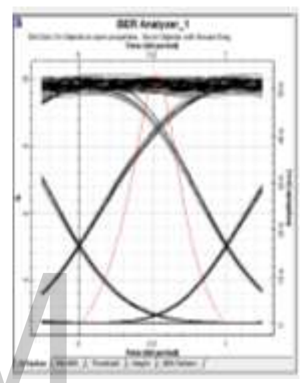
200km eye diagram before compensation
Q-factor [dB} = 0
BER = 1



The proposed model was also adapted in Wavelength Division Multiplexing (WDM) multiple channel for four channel as shown in figure 3. Below are the eye pattern, Q-factor and BER simulation results for 50km, 100km and 200km before and after compensation.

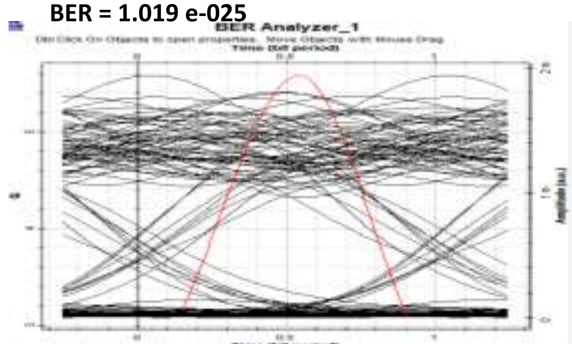


100km eye diagram before compensation
Q-factor [dB} = 6.66103
BER = 1.35e-011



100km eye diagram after compensation
Q-factor [dB} = 10.1524
BER = 1.254e-025

50km eye diagram after compensation
Q-factor [dB} = 10.3945
BER = 1.019 e-025



200km eye diagram after compensation
Q-factor [dB} = 5.57845
BER = 9.26-009

Table 2 shows the simulation results for both single and multiple channels. A comparative analysis is discussed further.

Table 2: Outcome of the Simulation Results

Communication Distance (km)	Signal Power (dBm)	Maximum Q-factor	Minimum BER	Eye height	OSNR (dB)
Single channel Optical fiber communication System					
25	17.0907	213.865	0	0.347	47.418
50	16.4051	100.968	0	0.292	42.262
100	11.7989	34.833	2.3e-266	0.096	31.643
200	10.3334	11.2042	1.83e-29	0.151	27.467
500	4.05989	2.70181	0.002501	-0.003	20.491
Multiple channels Optical fiber communication System					
25	12.0899	10.3508	1.61e-25	5.7e-2	48.435
50	11.7322	10.3945	1.019e-25	5.3e-2	43.554
100	9.85894	10.1524	1.3e-024	3.4e-2	33.192
200	7.83896	5.57845	9.26e-009	5.98e-4	12.529
500	5.91382	3.353233	3.01e-04	7.4e-5	9.505

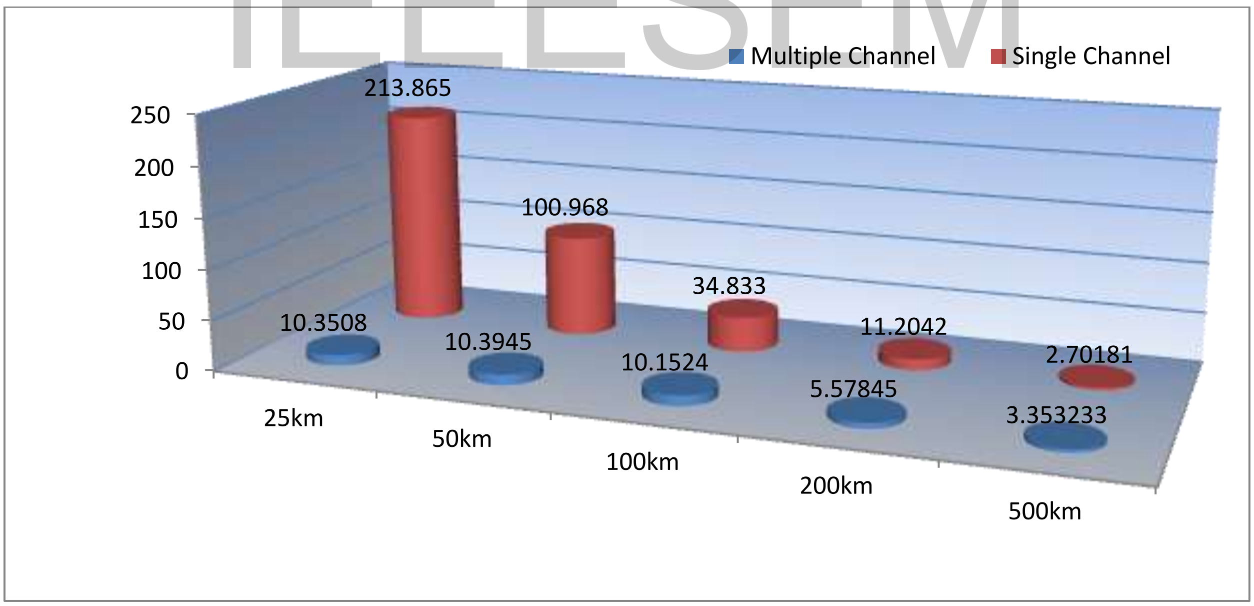


Figure 5: Maximum Quality Factor Chart for single and multiple channel propagation

Figure 5 shows the comparative chart of quality factor for both channels. Q-factor is an important parameters used to analyze the performance of a signal transmission. It deals with the amount of energy loss during optical transmission. The higher the Q-factor the lower the energy loss of the signal transmitted. From observation in the figure 5 above, the Q-factor simulation results of the multiple channels are less than that of single channels. This implies that the signals propagated in single channel were less affected by transmission losses.

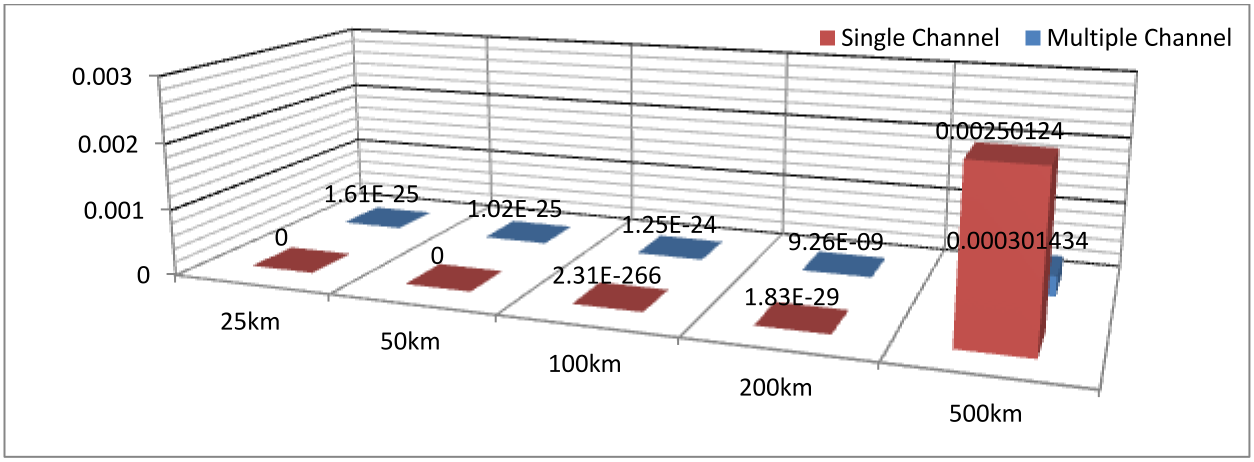


Figure 6: Minimum BER chart for Single and Multiple Channels

The Minimum BER for both the single and multiple channels is shown in figure 6. The BER is the probability made for the ratio of error bits over the total number of bits transmitted. It is measured in the simulation with the help of eye diagram analyzer. Its result indicates the level of noise generated along the optical signal transmission. When the Bit Error Rate (BER) decreases, the dispersion in the system decreases. In Figure 6 it can be observed that the BER for 500km is more in both the single and multiple channels. Others had a very smaller and far reduced BER, this implies a much less dispersion in the system.

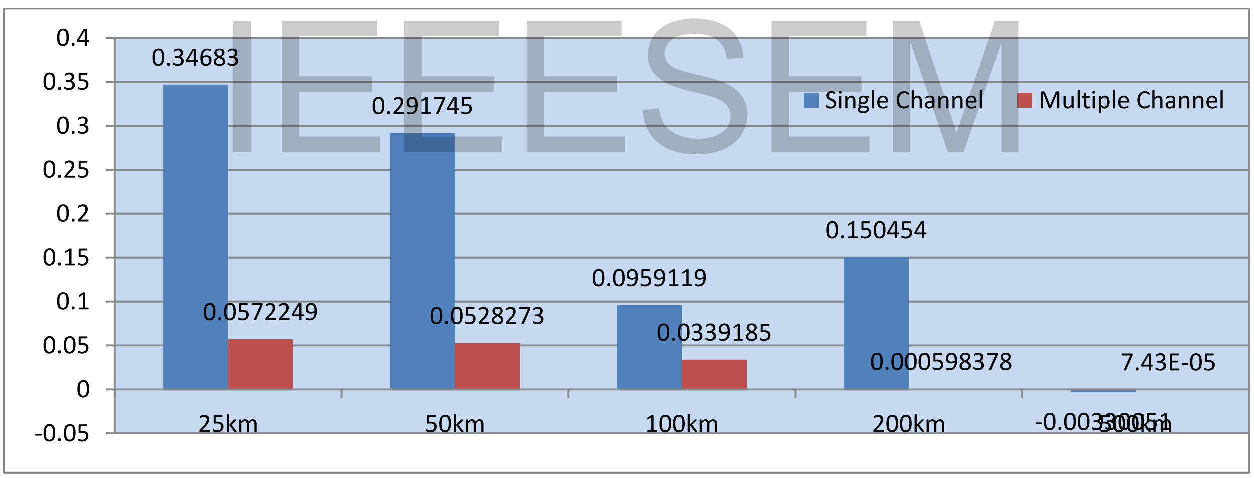


Figure 7: Eye height chart for Single and multiple channels

The Eye height provides visual information o the assessment and troubleshooting of the digital transmission system. The more eye opening translates to how better the signal quality is in the transmission channel. If the eye opening is at maximum the system performs better. The curves forming the eye pattern inform on us on the amount of additive noise to the signal. The more under the curves are the more close the eye and system immunity to noise decreases. From the chart in figure 7 we can observe that the eye height of single channel propagation has a better eye opening than that of multiple channels at the communication distances considered in this study. This implies that the signal transmitted in single channel performed better.

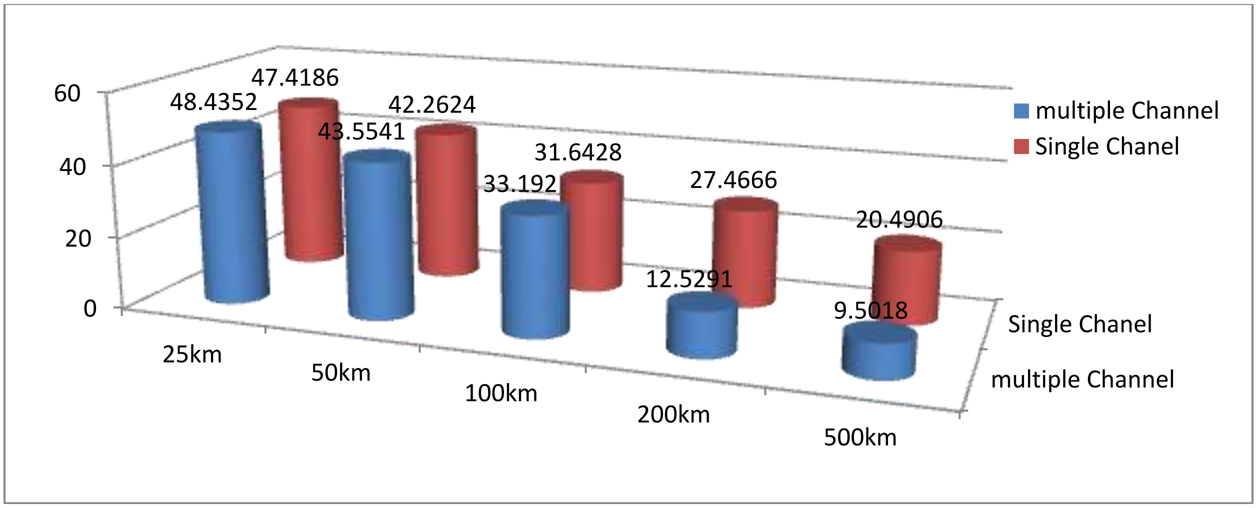


Figure 8: Optical Signal to Noise Ratio (OSNR) chart for the single and multiple Channels

The OSNR is also an important parameter used to ascertain the performance of propagated signal. It is a measure of Signal power to noise power in an optical channel. It is important because it informs us on the degree of impairment affecting the optical signal. A high OSNR value means a good signal quality. From figure 8, we can clearly observed that the OSNR results for 25km, 50km and 100km communication distance for multiple channel propagation are more when compared to that of single channel. But at 200km and 500km the OSNR result for multiple channels was lesser to that of single channel.

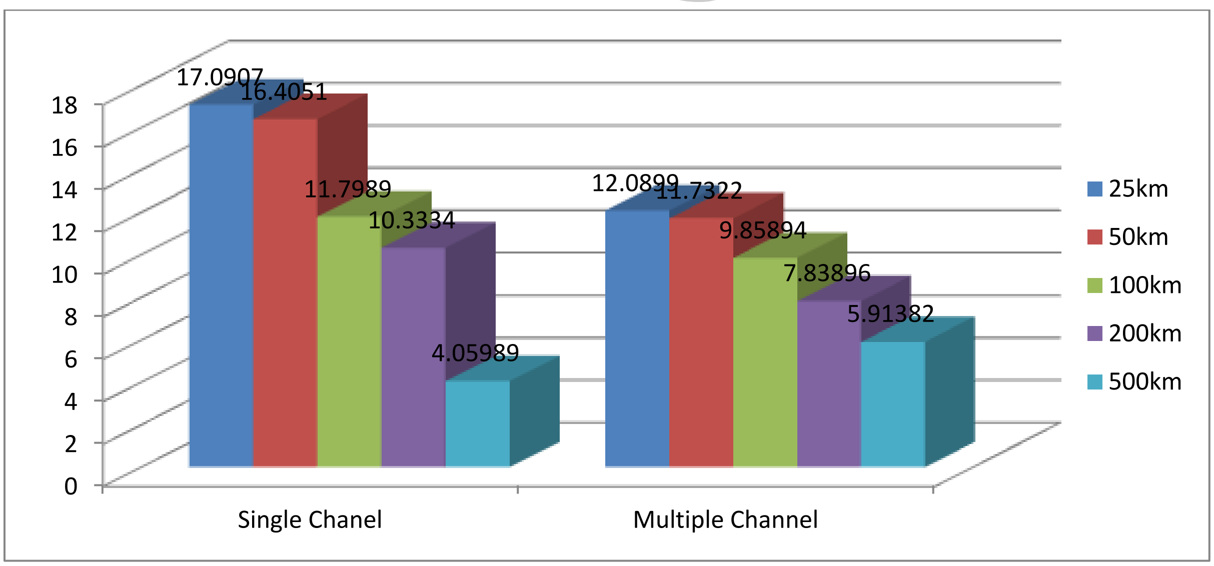


Figure 9: Signal Power chart for the single and multiple Channel optical communication systems

It can be observed in Figure 9 that the output signal power (dBm) is likely to decrease with increase in communication distance in both the single and multiple channel signal propagation. The shorter communication distances have higher signal power which makes them less affected by impairments such as attenuation and dispersion.

The results indicate an improvement in the performance of the proposed model at different optical fiber communication distance for signal propagation both in single and multiple channels. This implies high data rate for enhanced instant communication, reduced information loss, high speed internet access, improved bandwidth and transport performance of optical fiber communication systems.

The model simulation results was also compared to the study done by [18], our result proved that the system OSNR, Signal Power (dBm), Q-factor and BER for 100km communication distance performed better than their own result in terms of these parameters.

6. Conclusion

The aim of this work was demonstrated in mitigating the problem of dispersion experienced in optical fiber communication link. From the outcome of the result, it was seen that; (1) dispersion degrades the overall performance of the Optical fiber system, (2) increase in communication distance brings about a corresponding increase in the dispersion along the communication link. Thus, it can be concluded that; dispersion compensation is highly recommended along a fiber optic communication link. The proposed model (DCF with EDFA and FBG) improved fiber optical system performance in both single and WDM Channel although, they performed better in single mode channell.

7. References

[1]. Zhao J. et al., (2009): “Chromatic dispersion compensation using full optical-field maximum likelihood sequence estimation”, Optical fiber conference San Diego CA, USA, pg 22-26.

[2].Agrawal, G. P., (2010): *Fiber-Optic Communication Systems.4th edition*, John Wiley & Sons, Inc, New York.

[3]. Sani A. M., Yahya A. and Kwatri L. M. (2019): “Analysis of Dispersion Compensation in A Single Mode Optical Fiber Communication System”, International Journal of Advanced Academic Research | Sciences, Technology & Engineering, Vol. 5, Issue 1.

[4]. Pawan K. D. and Vibha S. (2014): “Dispersion in Optical Fiber Communication”, International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064 Vol 3 Issue 10..

[5]. Kishore B., Maruf A. and Abdul M. (2012): “Reduction of Dispersion in Optical Fiber Communication by Fiber Bragg Grating and Optical Phase Conjugation Techniques”, International Journal of Mobile Network Communications & Telematics (IJMNCT) Vol.2, No 3.

[6] Retrieved from www.fiber-optical-networking.com.

[7]. Killey R.I., Watts P.M., Glick M., and Bayvel P. (2005): “Electronic dispersion Compensation by signal pre-distortion,” Optical Networks Group, Department of Electronic and electrical Engineering, University College London, Torrington Place.

[8]. Mehtab S. (2015): “Different Dispersion Compensation Techniques in Fiber Optic Communication System: A Survey”, International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE) Vol 4, Issue 8..

[9]. In-Ru and Ni Yan Rong (2015): “Investigation on the Dispersion Compensation Algorithm in Optical Fiber Communication with Large Capacity.” International Journal of Future Generation Communication and Networking, Vol. 8, No. 3, pp. 235-246.

[10]. Haque M. M., Rahman M. S., Habib M. S., Razzak S. M. (2014): “Design and characterization of single mode circular photonic crystal fiber for broadband dispersion compensation”.Optik-International Journal for Light and Electron Optics, Vol. 125, No. 11, pp.2608-2611, 2014.

[11] .Yanfeng Li, Bowen Liu, Qingyue W. (2004): “Influence on photonic crystal fiber dispersion of the size of air holes in different rings within the cladding”. Chin Opt Lett, Vol.2, No. 2, pp.75-77.

[12]. Haunstein H. F., Greff W. S., Dittrich A., Sticht k. and Urbansky R. (2004): “Principles for Electronic Equalization of Polarization-Mode Dispersion,” Journal of Lightwave Technology, vol. 22, no. 4, pp. 1169-1182.

[13]. Lenz G. and Madsen C.K (1999): “General Optical All-Pass Filter Structures for Dispersion Control in WDM Systems,” Journal of Lightwave Technology, Vol. 17, no. 7, pp.1248-1254.

[14]. Yanrong N. and Ru I. (2016): “Investigation on the Dispersion Compensation Algorithm in Optical Fiber Communication with Large Capacity”. International Journal of Future Generation Communication and Networking, Vol. 8, No. 3, pp. 235-246.

[15]. Watts P.M, Killey R.I, Glick M., and Bayvel P. (2006): “Electronic dispersion Compensation by signal pre-distortion,” Optical Networks Group, Department of Electronic and electrical Engineering, University College London, Torrington Place.

[16]. Pawase R., et al., (2011): “Dispersion post compensation using DCF at 10gbps”, Global Journal

of Computer Science and Technology Vol 11, issue 3 version 1

[17]. Pragya M. and Swatantra T. (2017): "A Review of Chromatic Dispersion Compensation in Optical Fiber Communication System and its Simulation." International Advanced Research Journal in Science, Engineering and Technology Vol. 4, Issue 6.

[18]. Kaur R. and Singh M., (2016): "Dispersion Compensation in Optical Fiber Communication System Using WDM with DCF and FBG." IOSR Journal of Electronics and Communication Engineering, Vol 11, Issue 2, Ver. II pp 122-130

[19]. Kumar K., J. A. (2014): "Performance analysis of dispersion compensation using Fibber Bragg Gratting in optical comunication", International Journal of current Engineering and Technology, pp 1527-1531.

[20]. Anuseetal P. and Singh. S. (2016): "Analysis of EDFA based 16-Channel C-Band Optical WDM System for Different Pumping Schemes," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 5, no. 6.

[21]. Singh S., Singh A., and Kaler R. S., (2011): "Performance evaluation of EDFA, RAMAN and SOA optical amplifier for WDM systems," *ELSEVIER*, Vol. 124, no. 2, pp. 95–101

[22]. Semmalar S. and Malarkkan S., (2013): "Output Signal Power Analysis in Erbium-doped Amplifier with Pump Power and Length variation using Various Pumping Techniques," *ISRN Electronics*, vol. 6.

[23]. Nadir, H. et al. (2007). A Numerical Analysis of R-EDFA for long haul optical communication system. International Conference: Science and Electronics Technologies of Information , pp 1 - 4.

[24] Ismail M. M, Othman M. A., Zakaria Z. et al., (2012): "EDFA-WDM Optical Network Design System," in Proceedings of the Malaysian Technical Universities Conference on Engineering and Technology, MUCET 2012, pp. 294–302, Malaysia, November 2012.

[25].Chakkour M., Hajaji A, and Aghzout O., (2015): "Design and Study of EDFA-WDM Optical Transmission System using FBG at 10 Gbits/s Chromatic Dispersion Compensation Effects," in *Mediterranean Conference on Information & Communication technologies*, May 2015.