Implementation of Multimode Fiber in Eight Channels Mimo Multiplexing System by Eliminating Dispersion with Optical Grating Methodologies

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Abstract: *In recent years, with the swift development of the internet industry, people urgently necessitate extra capacity and speedy network systems. Under this circumstance, optical fibers are becoming the most favourable delivering media as it has a major important role in the information business, with their huge bandwidth and excellent transmission performance. Dispersion compensation is the main important attribute required in an optical fiber communication system because the presence of dispersion leads to pulse spreading that causes the output signal pulses to overlap. For a long-haul transmission system, an 8x1 Wavelength Division Multiplexing Multi Input Multi Output (WDM MIMO) channel with a novel dispersion compensation system has been designed. Various dispersion compensation techniques are explored in this work, including dispersion-compensating fibers, fiber Bragg grating, Ideal compensation Bragg grating, and opti-grating, with a 2.5 Gbit/s data rate for each channel. With a power of 20 dBm, the proposed model is simulated with 32768 samples. The length of an optical fibre can range from 5 to 100 kilometres. Throughout the simulation, the operation frequency is 193.1 THz. The software opti-system-17.0 was used to design and implement the system. The 8-channel device was used to simulate and calculate metrics such as Q-factor, Bit Error Rate (BER), and Signal to Noise Ratio (SNR). The proposed model enhances performance in terms of BER and quality factor at the receiver end of systems.*

Keywords: *Multimode fiber, dispersion compensation, optical grating, q factor, bit error rate.*

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1. Introduction

Optical communication is a process of sending information to the corresponding destination employing a wired or wireless medium. Optical fibers are more attractive in the field of information transactions, as light inside fiber can travel almost the velocity of light [8, 9]. The laser source is the popular source of light generator which plays a major role in the advent of optical communication technology. The generalised structure for optical communication includes Transmitter, Channel and Receiver. The main components are the optical source, a transmitter to modulate the optical signals from the source, a transmission medium, and a photodetector that converts the received optical power back into electrical waveforms, an electronic amplifier to boost up the received signals and a demodulator to recover the signal [21]. Starting from the source to the transmitter, there are two kinds of optical sources that can be used which are Laser as well as Light Emitting Diode (LED) sources. Laser being coherent has its advantages and disadvantages than LED. Large bandwidth and high data rate necessity are increasing day by day [3]. Optical communication media is providing higher bandwidth than coaxial cable and twisted pair cables. The Coaxial cable shares the frequency of 30MHz to 300MHz in the Electromagnetic spectrum and waveguides shares a frequency of about 3GHz to 300GHz and optical fiber shares the frequency of 30THz to 300THz in the electromagnetic spectrum. Free space or satellite communication is complementary to fiber optics and both have their peculiar features. Wavelength Division Multiplexer (WDM) is a technology that uses multiple transmitters and receivers to transmit and receive different optical carrier wavelengths [11, 19]. WDM multiplexer and demultiplexer consist of 2n selection lines. Multiplexing is done by optical-electrical- optical conversion in the transport network. WDM with multimode fiber has the advantage of increased capacity over single-mode fiber [22].

Over the last couple of decades, optical fiber grating-based sensors have proven themselves as a potential platform for label-free optical biosensors and chemical sensors [15, 18]. A Long Period of Fiber Grating (LPFG) is of particular relevance because it is a periodic modulation of the Refractive Index (RI) in the core of an optical fiber. This grating structure has a period of a few hundred micrometres, which is substantially longer than a Fiber Bragg Grating (FBG) [16, 20]. The long periodic modulation of RI begins light interaction between the forward propagating core mode and forward propagating cladding modes, which has sparked attention in sensing applications [4, 14].

Mode Division Multiplexing (MDM) has been described as a seamless technique to take advantage of orthogonal spatially overlapping and co-propagation of modes. Modes are broadcast in parallel streams carrying data independently in MDM, and then de-multiplexed in a low inter-modal crosstalk environment. Controlling mode excitation will aid in the optimization of the channel impulse response, reducing differential mode delay and cross talk [10].

Guided system channels and unguided system channels are the two types of optical communication channels [17]. Because the fibre is conserved, guided channels exhibit minimal attenuation and dispersion. Multiple accesses are not directly supported by guided channels. With smaller transmitter and receiver apertures, unguided channels have a greater received power to transmit power ratio [12].

To meet the research gap for eliminating dispersion, various research papers are analysed. Ahmed *et al*. [1] Used an optical phase-shifting component for shifting the phase and modifying the intensity of the light beam injected into the fiber. The component is inserted upstream or downstream or at an intermediate position in the fiber. The optical thing uses two mirrors and multi-beam paths between the two mirrors.

The paper [2], gave insight into the dispersion compensation system. An O-band optical communication system comprises a transmitter, a receiver, and an optical fiber system coupled between the transmitter and the receiver.

According to [5], the compensation model was designed to analyze and simulate dispersion compensation technique which is based on deploying both fiber Bragg grating and emulator together till 250 km long of single-mode optical fiber. [6] Particularly focuses on analyzing the performance of FSO-WDM, Free Space Optics-Multi Input Multi Output (FSO-MIMO) and FSO-WDM-MIMO systems taking into consideration of diverse weather conditions. Performance of the various systems has also been compared in terms of received signal power and the quality factor of the received signal for haze atmosphere.

Dar and Jha [7] Provides the suggestion to divide the huge bandwidth of optical fiber into individual channels of subordinate bandwidth, so that multiple accesses with lower-speed electronics are attained. This paper focuses on one of the most common and important optical multiplexing techniques, called Wavelength Division Multiplexing (WDM). To summarize the overall survey, one may conclude that, dispersion due to fiber non-linearity strictly has to be mitigated without affecting the quality of the signal and thereby maximizing the capacity of the channel.

2. Proposed Methodology

The ultimate goal of this paper is to get maximum bandwidth and spectral efficiency by reducing bit error rate and dispersion. The proposed system uses Fiber Bragg grating, which acts as an optical filter to block unwanted frequency or wavelength- specific reflector shown in Figures 1, 2, and 3.

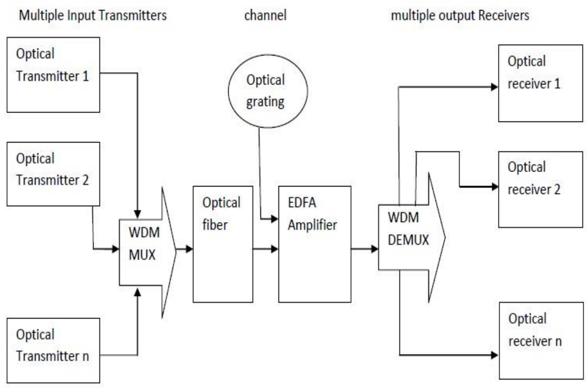

Figure 1. Modified block diagram of WDM MIMO 8x1 channel with dispersion compensation techniques.

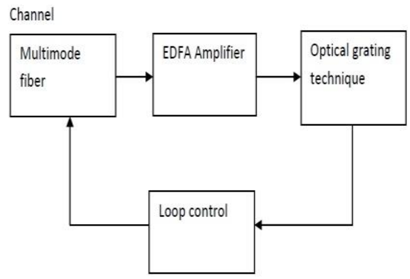

Figure 2. Proposed optical fiber channel design installed with grating technique.

Figure 1 shows how the light signals from several optical transmitters are merged and delivered across an optical cable using Wavelength Division Multiplexing Multiplexer (WDM MUX). An Erbium Doped Fiber Amplifier (EDFA) amplifier is used to amplify the light signals. As an optical element, an optical grating is used to split polychromatic light into its constituent wavelengths.

The polychromatic light incident on the grating is diffused, resulting in each wavelength being reflected at a slightly different angle from the grating. Wavelength Division Multiplexing DeMultiplexer (WDMDEMUX) is used to separate the amplified light signals, which are then received using optical receivers. This is the grating method used widely for dispersion compensation by using two-beam interference. The Ultra Violet (UV) laser is split into two beams which interfere with each other and thereby create a periodic intensity distribution along with the signal interference pattern. The refractive index of the photosensitive fiber changes according to the intensity of light in which it is exposed and hence interference is limited. The modified block diagrams are shown in Figures 1, 2, and 3. The proposed method model is modified from paper [13].

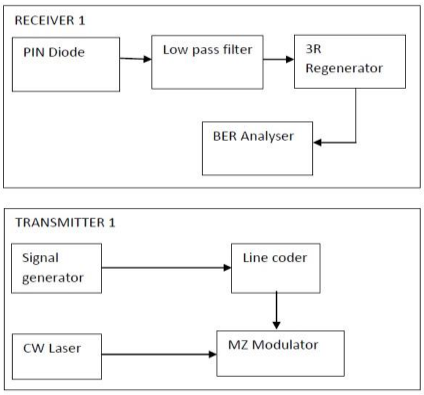

Figure 3. Transmitter and receiver sub block design.

In optical communication, Ideal compensation FBG is similar to Bragg grating. The bandwidth is a narrow band with 0.1 to 5nm. Ideal compensation FBG supports negative dispersion and positive dispersion. Negative dispersion up to +2000 ps/nm/km and positive dispersion up to -2000 ps/nm/km is the characteristics of the ideal grating. Minimum bending loss of about 0.14 dB/km is maintained. Opti-grating is a periodic optical arrangement of components that splits and diffracts light into numerous beams which travel in diverse directions. These beams directions depend on the spacing of the grating and the wavelength of the light as a result that the grating acts as the dispersive element. For commercial applications, gratings normally have ridges or rulings on their plane rather than dark lines. Optical gratings are the ones that modulate the phase rather than the amplitude of the incident light.

3. Results and Discussion

This section describes the details of the experiment carried out for execution. Opti-system-17.0 software was used to simulate the system. Tables 1, 2, 3, and 4 show the simulation parameters used to develop the model.

3.1. Fiber Bragg Grating

The digital information bits are generated by a pseudorandom generator having 2.5 Gbps of local data rate. The power of the transmitter and receiver is varied depending upon the distance between transmitter and receiver. The Frequency of simulation is 193.1THz, Effective Index is 1.45 with a length of 2mm, Noise Threshold of -100 dB, Noise Dynamic of 3 dB, Noise Bandwidth is1 THz, Number of Segments is 101 and the Maximum number of Spectral path is 1000.

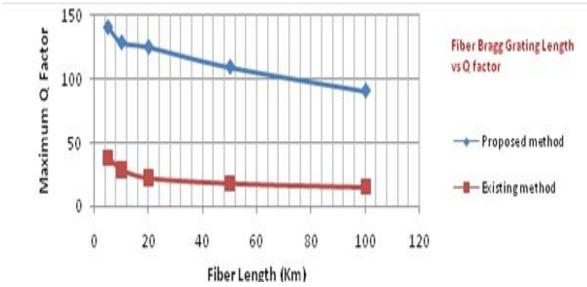

Figure 4. Comparison of Q and length in FBG.

Figure 4 and Table 1 show the results of FBG. Figures 5, and 6 depicts the eye plot and BER curve of FBG.

Table 1. Maximum Q factor versus optical fiber length in FBG.

Type : Fiber Bragg Grating Power : 20 dBm			
Fiber length	Max Q	Min BER	Receiver Threshold
5 km	140.065	0	0.0103655
10 km	128.211	0	0.0100203
20 km	124.587	0	0.0102461
50 km	109.024	0	0.0101433
100 km	90.415	0	0.0101747

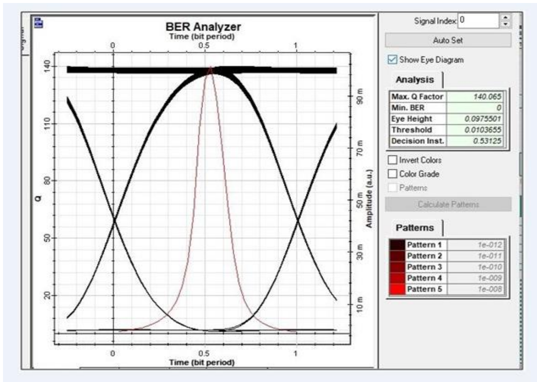

Figure 5. Eye diagram of FBG with Max. Q factor of 140.065.

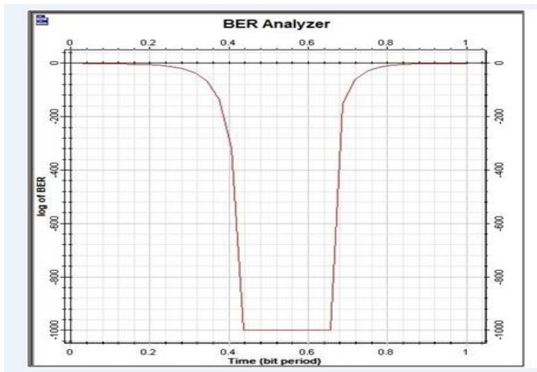

Figure 6. BER curve of FBG over several bit period.

Figure 5 shows a larger eye-opening in the eye diagram, indicating that the Inter Symbol Interference (ISI) is low. The quality factor and fiber length of FBG are compared in Figure 4. When compared to the existing method, the proposed method improves the performance of the quality factor as the fiber length increases. Table 1 confirms that the maximum quality factor in FBG is attained at a fibre length of 5km.

3.2. Ideal Compensation FBG

The extinction ratio of the transmitter is maintained at 10dB. Higher the distance more will be the attenuation. At the receiver side, a post-amplification Erbium Doped Fiber Amplifier (EDFA) amplifier of 5m is connected with the receiver. The input port signal type is optical, the transmission output port is optical and the Reflection port is optical which is optional. Noise Threshold of Ideal FBG is -100 dB, Noise Dynamic of 3 dB, Frequency of 193.1THz, Bandwidth of 125GHz with Dispersion -800 ps/nm and Depth of 100dB.

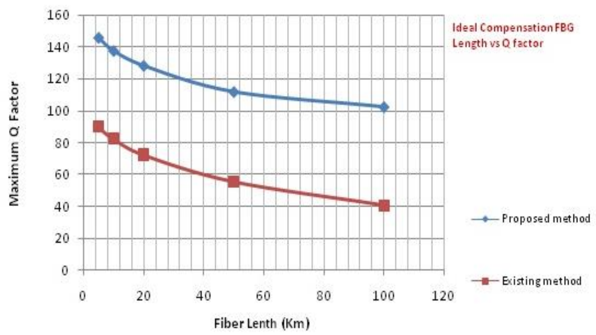

Figure 7. Comparison of Q and Length in Ideal FBG.

Table 2. Maximum Q factor versus optical fiber length in ideal FBG.

Type : Ideal Compensation FBG Power: 20 dBm			
Fiber length	Max Q	Min BER	Receiver Threshold
5 km	145.865	0	0.0104108
10 km	137.576	0	0.0103854
20 km	128.209	0	0.0103221
50 km	111.806	0	0.0101387
100 km	102.346	0	0.0101053

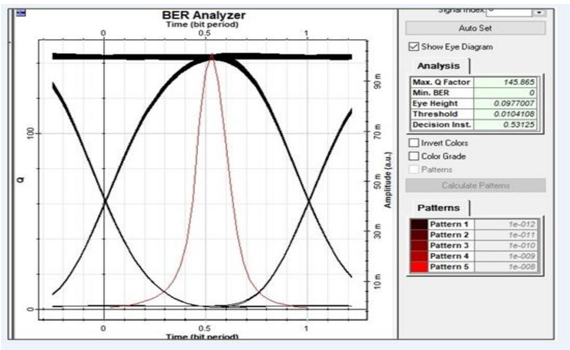

Figure 8. Eye diagram of Ideal Compensation FBG with Max. Q factor of 145.865.

Figure 7 and Table 2 show the results of the ideal compensation FBG. According to the graph, the proposed method improves the performance of the Quality factor in terms of fibre length. Figures 6, and 8 depicts the eye plot and BER curve of IFBG. Figure 9 shows the optimum compensating fibre bragg grating's BER curve across a number of periods.

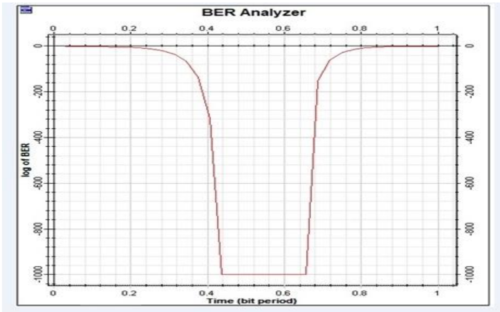

Figure 9. BER curve of Ideal compensation FBG over several bit period.

3.3. Dispersion Compensation Fiber

As discussed earlier, the digital information bits are generated by a pseudorandom generator having 2.5 Gbps of local data rate. The power of the transmitter and receiver is varied depending upon the distance between transmitter and receiver. The extinction ratio of the transmitter is maintained at 10dB.

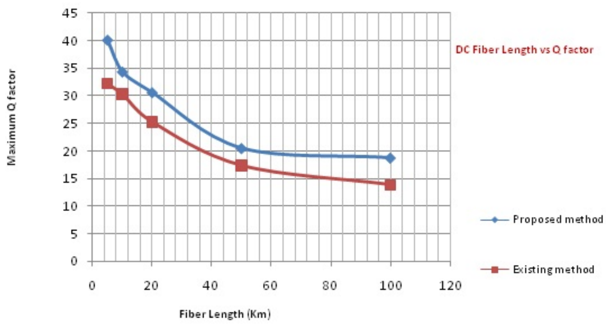

Figure 10. Comparison of Q and length in DCF.

Table 3. Maximum Q factor versus optical fiber length in DCF.

Type : Dispersion Compensation Fiber Power: 20 dBm			
Fiber length	Max Q	Min BER	Receiver Threshold
5 km	40.1107	0	0.0246863
10 km	34.3501	0	0.0217312
20 km	30.5877	0	0.0202556
50 km	20.4576	0	0.0201877
100 km	18.71640	0	0.0200993

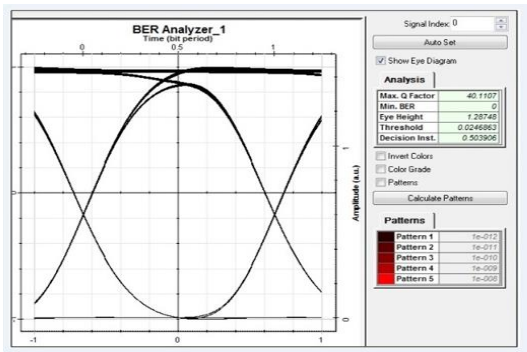

Figure 11. Eye diagram of DCF with Max. Q factor of 40.1107.

Figure 10 and Table 3 show the results of DCF. Figure 11 and Figure 12 depicts the eye plot and BER curve of DCF. The larger eye opening in the eye diagram indicates that the ISI for the quality factor of

40.1107 is low. The DCF curve improves BER performance over several bit periods.

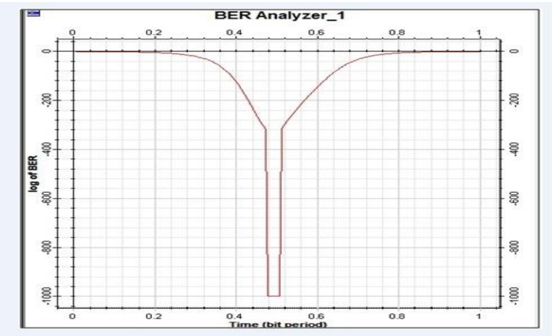

Figure 12. BER curve of DCF over several bit period.

3.4. Opti Grating

The power of the transmitter and receiver is varied depending upon the distance between transmitter and receiver. The extinction ratio of the transmitter is maintained at 10dB. The frequency range of the operation is 1550nm.

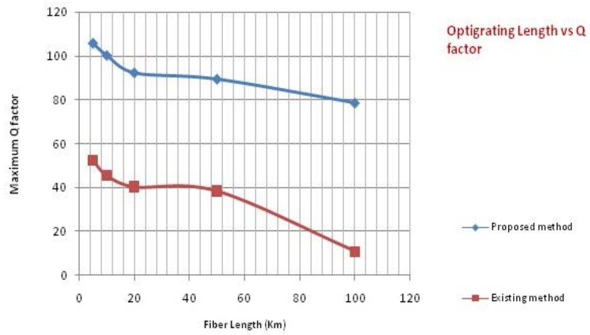

Figure 13. Comparison of Q and length in optigrating.

Table 4. Maximum Q factor versus fiber length in Opti-grating.

Type: Opti-Grating Power: 20 dBm			
Fiber length	Max Q	Min BER	Receiver Threshold
5 km	105.833	0	0.0363583
10 km	100.324	0	0.0317214
20 km	92.411	0	0.0305581
50 km	89.549	0	0.0301872
100 km	78.683	0	0.0301049

Figure 13 and Table 4 show the results of opti grating. Figures 14 and 15 depicts the eye plot and BER curve of DCF. The highest quality factor was achieved at a fiber length of 5km with negligible BER and a receiver threshold of 0.0363583.

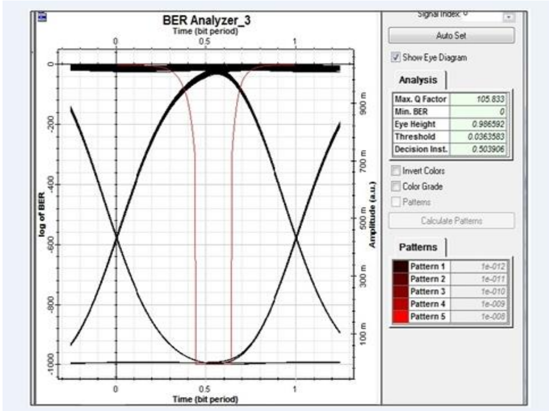

Figure 14. Eye diagram of opti-grating with max. Q factor of 105.833.

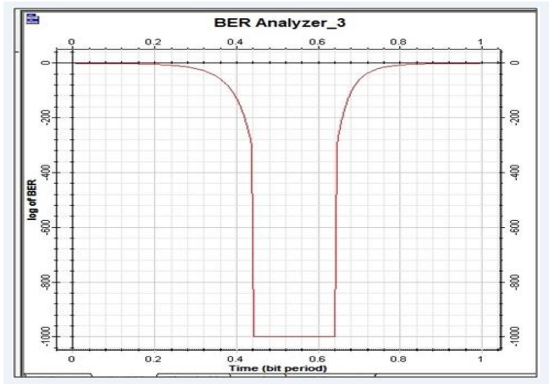

Figure 15. BER curve of opti-grating over several bit period.

4. Conclusions

The overall objective of this paper is achieved by mitigating the signal dispersions present in the optical fiber channel. This paper focused on the usage of optical grating methods with an 8x1 WDM MIMO communication system having a 2.5Gbps data rate in multimode fiber. The capacity of the design is made maximum and promising equal output response for all users present in the channel. Non- Return-Zero (NRZ) line coding techniques is analysed as line codec method irrespective of Return-to-Zero (RZ) because of the high sensitivity of NRZ. The results are obtained from the optisystem simulation tool. The improved Q factor of 140.065 is attained with FBG, 145.865 is obtained from Ideal compensation FBG, 40.1107 is achieved for DCF and 105.833 for Opti-grating method, considering minimum 0.6 dB/km attenuation. The output signal spectrum results from the spectrum analyser are dispersion free after compensation with grating technique. The bit error rate is minimised as much as possible at the receiver. As a result, the proposed technique improves Q-factor, lowers bit error rate, and transfers a large amount of data, improving an optical fibre network's overall performance. Electronic and digital compensation of fibers can be made for double dense wavelength division multiplexing systems. In the future, the proposed model could be implemented in single-mode fibre and its performance compared to that of multimode fibre. Furthermore, the number of channels can be increased to 16 or even more without compromising the quality factor and BER.

References

[1] Ahmed A., Singh A., Singh A., and Kaur S., "Performance Analysis of WDM-MIMO Free Space Optical System Under Atmospheric Turbulence," *in Proceeding of 6th International Conference on Signal Processing and Integrated Networks*, Noida, pp. 820-825, 2019.

[2] Amiri I., Rashed A., Kader H., Al-Awamry A., El-Aziz I., Yupapin P., and Palai G., "Optical Communication Transmission Systems Improvement Based on Chromatic and Polarization Mode Dispersion Compensation Simulation Management," *Optik*, vol. 207, pp. 163853, 2019.

[3] Anita H., Karpagarajesh G., Princy S., Jenefer W., and Martina M., "Assessment of Rz and Nrz Coders in Free Space Multiplexing System with Reduced Attenuation Effect and Increased Q Factor," *Our Heritage*, vol. 68, no. 1, pp.8930-8936, 2020.

[4] Bandyopadhyay S., Shao L., Wang C., Liu S., Wu Q., Gu G., Hu J., Liu Y., Chen X., Song Z., Song X., Bao Q., and Smietana M., "Study on Optimization of Nano-Coatings for Ultra-Sensitive Biosensors Based on Long-Period Fiber Grating," *Sensing and Bio-Sensing Research*, vol. 27, pp. 100320, 2020.

[5] Bobrovs V., Spolitis S., and Ivanovs G., "Comparison of Chromatic Dispersion Compensation Techniques for WDM-PON Solution," *in Proceeding of 2nd Baltic Congress on Future Internet Communications*, Vilnius, pp. 64-67, 2012.

[6] Chen W., Li S., Lu P., Wang D., and Luo W., "Dispersion Compensation Optical Fiber Modules for 40 Gbps WDM Communication Systems," *Frontiers of Optoelectronics in China*, vol. 3, no. 4, pp. 333-338, 2010.

[7] Dar A. and Jha R., "Chromatic Dispersion Compensation Techniques and Characterization of Fiber Bragg Grating for Dispersion Compensation," *Optical and Quantum Electronic*, vol. 47, no. 3, pp. 1-35, 2017.

[8] Dasan M., Francis F., Sarath K., Dipin E., and Srinivas T., *Optically Multiplexed Systems: Wavelength Division Multiplexing*, Multiplexing, IntechOpen, 2019.

[9] Eggleton B., Stephens T., Krug P., Dhosi G., Brodzeli Z., and Ouellette F., "Dispersion Compensation Using A Fibre Grating in Transmission," *Electronics Letters*, vol. 32, no. 17, pp. 1610-1611, 1996.

[10] Fazea Y., Amphawan A., Al-Gumaei Y., Al-Samman A., and Al-Rahmi W., "Modes Power Equalization Based-Singular Value Decomposition in Mode Division Multiplexing Systems for Multi-Hungry Bandwidth Applications," *Optical Fiber Technology*, vol. 61, pp.102389, 2021.

[11] Hussein T., Rizk M., and Aly M., "A Hybrid DCF/FBG Scheme for Dispersion Compensation Over A 300 Km SMF," *Optical and Quantum Electronics*, vol. 51, no. 4, pp .103, 2019.

[12] Karpagarajesh G. and Anita H., "Maximizing the Area Spanned by the Optical SNR of the 5G Using Digital Modulators and Filters," *The International Arab Journal of Information Technology*, vol. 18, no. 3, pp. 306-311, 2021.

[13] Kaur P., Gupta A., and Chaudhary M., "Comparative Analysis of Inter Satellite Optical Wireless Channel for NRZ And RZ Modulation Formats for Different Levels of Input Power," *Procedia Computer Science*, vol. 58, pp. 572-7, 2015.

[14] Kaur R. and Singh M., "Analysis on Dispersion Compensation with DCF Based on Optisystem-A Review," *An International Journal of Engineering Science*, vol. 17, pp. 390-395, 2016.

[15] Khatoon S., Jaiswal A., and Agrawal A., "Performance Evaluation of Post and Symmetrical DCF technique with EDFA in 32×10, 32×20 and 32×40 Gbps WDM Systems," *International Journal of Current Engineering and Technology*, vol. 7, no 4, pp. 1416-1420, 2017.

[16] Meena M. and Gupta R., "Design and Comparative Performance Evaluation of Chirped FBG Dispersion Compensation with DCF Technique for DWDM Optical Transmission Systems," *Optik*, vol. 188, pp. 212-224, 2019.

[17] Panda T., Mishra R., Parakram K., and Sinha A., "Performance Comparison of Dispersion Compensation in A Pre, Post and Symmetrical Arrangement using DCF for Long Haul Optical Communication," *An International Journal of Engineering and Technology*, vol. 3, no. 7, pp. 14-20, 2016.

[18] Poonkuzhali M. and Prakash P., "Analysis of Electronic Dispersion Compensation for 10 Gbps Using Equalizer," *in Proceeding of Innovations in Power and Advanced Computing Technologies*, Vellore, pp. 1-5, 2019.

[19] Rajesh k., Blessie A., and Krishnan S., "Performance Assessment of Dispersion Compensation using Fiber Bragg Grating (FBG) and Dispersion Compensation Fiber (DCF) Techniques," *Informacije Midem*, vol. 51, no. 4, pp. 215-223, 2021.

[20] Rendi Rahmadhan S., Effect of Weather on Performance of Free Space Optic System with

Mimo Ss-Wdm Technology Doctoral Dissertation, Thesis, Universitas Islam Negeri Sultan Syarif Kasim Riau, 2019.

[21] Sawant R., Bhumkar P., Zhu A., Ni P., Capasso F., and Genevet P., "Mitigating Chromatic Dispersion with Hybrid Optical Metasurfaces," *Advanced Materials*, vol. 31, no. 3, pp. 1805555, 2019.

[22] Sharma A., Singh I., Bhattacharya S., and Sharma S., "Performance Comparison of DCF and FBG as Dispersion Compensation Techniques at 100 Gbps Over 120 km Using SMF," *in Proceeding of Nanoelectronics, Circuits and Communication Systems*, pp. 435-449, 2019.

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