International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-14 Issue-4, March 2025

Performance Evaluation of Chromatic and Polarization Dispersion of Fiber Optic Transmission Link in Broadband Communication

Yussuff, Abayomi I. O., Ayodele, Adedeji A.

Abstract: *This study involved quantitative evaluation of the performance of dispersion and polarization of light in fibre optic link for broadband communication. The dispersion that occurs in the transmission of signal over a separation of 120km at 100 Gbps were studied, and uniform chirped fiber Bragg grating dispersion compensation adopting three particular setups of Pre, Post and Mix dispersion compensation procedures. Optical fiber is a medium of slender glass or plastic strands, empowers high-speed data transmission across extensive frequency ranges, spanning up to 25THz, and this was achieved without signal amplification. However, as data rates and transmission distances escalate, challenges stemming from nonlinearities and dispersion intensify, impacting overall performance. This study is devoted to tackling these challenges through the deployment of Fiber Bragg Gratings (FBGs) in three distinct configurations: Pre, Post, and Mix dispersion compensation. Its principal objective is the correction of dispersion in a 120 km transmission operating at 100 Gbps. The results obtained from each of the three compensations methods employing Optisystem simulation application software were then analysed using key performance metrics such as Bit Error Rate (BER), Quality Factor (Q-Factor), and received power to identify the best compensation method with the ultimate aim of significantly enhancing signal transmission performance. Post-compensation of UFBG shows best performances by exhibiting the highest quality factor, lowest BER and power requirements of the three compensation techniques. Hence, UFBG Post-compensation is recommended to mitigate chromatic and polarization dispersions in fibre optic transmission systems. The findings of the work will provide useful information in the design and manufacture of fibre optic transmission equipment for long-haul data communication systems.*

Keywords: *Optical Fiber, High-Speed Data Transmission, Dispersion, Fiber Bragg Gratings*

I. INTRODUCTION

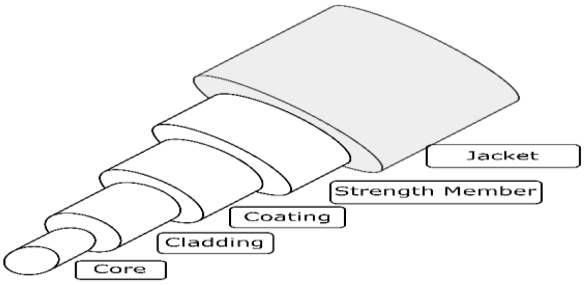
Optical fiber, often referred to as fiber optic cable, is a vital component of modern communication systems. Comprising slender strands of glass or plastic [1]. It plays a crucial role in transmitting data across an extensive frequency range, exceeding 25THz, and covering considerable distances [2]. The fundamental structure of an optical fiber, as depicted in Figure 1 consists of four key components: the core, cladding, coating, and strength member.

Manuscript received on 18 January 2025 | First Revised Manuscript received on 29 January 2025 | Second Revised Manuscript received on 20 February 2025 | Manuscript Accepted on 15 March 2025 | Manuscript published on 30 March 2025.

*****Correspondence Author(s)

Yussuff I. O. Abayomi***,** Associate Professor, Department of Electronic and Computer Engineering, Lagos State University/Industry, Lagos, Nigeria. Email ID: abayomi.yusuff@lasu.edu.ng, ORCID ID: 0000-0003-3829-9944

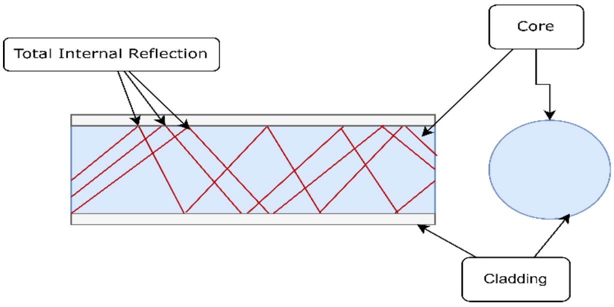
Adedeji Ayodele, Department of Electronic and Computer Engineering, Lagos State University/Industry, Lagos, Nigeria. Email ID: bitmaptechnologies@yahoo.com



[Fig.1: Structure of Optic Fiber] [2]

The operation of optical fibers hinges on transmitting data through light pulses that travel within the slender fiber strands [3]. The fiber core, as thin as a human hair, is surrounded by a cladding layer with a lower refractive index, causing light to bend inward due to the phenomenon of total internal reflection as depicted in Figure 2. This effect ensures containment within the core, preventing dispersion [4]. Finally, an outermost layer, the coating, serves as protection against damage and moisture for the fiber optics.

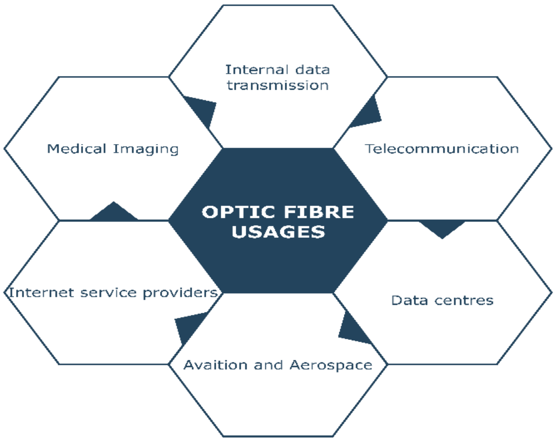
The versatility of optical fibers is demonstrated through a range of applications, including internal data transmission, telecommunications, and medical imaging, as illustrated in Figure 3. They outperform traditional copper wires in several key aspects, such as offering longer transmission distances, a higher bandwidth, immunity to electromagnetic interference, and minimal signal loss [5]. These qualities make optical fibers an ideal choice for broadband communication. As a result, the introduction of fiber optics has brought about a revolution in long-distance communication methods.



[Fig.2: Operation of Optic Fibers] [4]

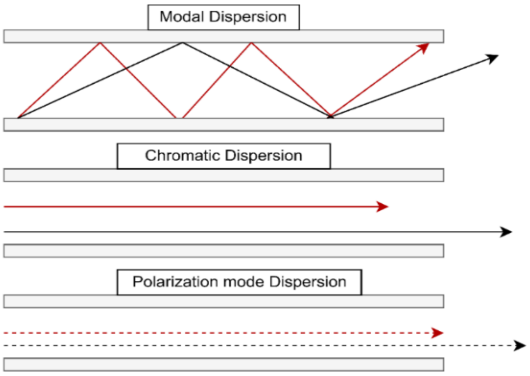
Retrieval Number: 100.1/ijitee.F820813060325
DOI: 10.35940/ijitee.F8208.14040325
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)



[Fig.3: Applications of Fiber Optics] [6]

Fiber optic transmission systems are susceptible to three significant types of dispersions [6], namely modal dispersion, polarization mode dispersion (PMD) [7], and chromatic dispersion, as illustrated in Figure 4 [8]. Modal dispersion arises from the different paths and modes light pulses can take [9], causing variations in signal arrival times and potentially leading to signal smearing [10]. PMD results from variations in light wave speeds with different polarization orientations, impacting signal quality, especially in high-speed transmission [11]. Chromatic dispersion, on the other hand, is rooted in the diverse speeds of different light wavelengths within the fiber, potentially causing signal degradation due to varying arrival times [12]. The collective impact of these dispersions can lead to signal distortion and reduced signal quality in fiber optic transmission systems [13].



[Fig.4: Dispersion Mode in Fiber Optics] [13]

The evolution of fiber optic transmission systems, designed to support higher data rates across extended distances, has introduced challenges related to the compromised performance of transmission media. This degradation is manifested in the form of nonlinearities and dispersion, and it has a substantial impact on the efficiency of optical fiber transmission. A particularly critical concern arises from residual Chromatic Dispersion (CD), which becomes a limiting factor, especially in the context of high-speed systems. Addressing and mitigating CD is pivotal in ensuring the continued success of advanced fiber optic communication.

Effectively addressing the challenge requires the development of innovative solutions aimed at enhancing the Chromatic Dispersion (CD) tolerance of high-speed systems, alongside the provision of cost-effective and adaptable compensation methods for Polarization Mode Dispersion (PMD). This necessitates the advancement of more dynamic and precise PMD and CD compensation techniques. Embracing cutting-edge approaches in this regard will not only surmount the limitations posed by transmission media degradation but will also open the doors to optimal performance in fiber optic transmission systems. By doing so, we ensure reliable and efficient data transfer even over extended distances, meeting the ever-growing demands of modern communication networks.

This study aims to access the influence of polarization mode and chromatic dispersions on the performance of optical fiber transmission links in the context of broadband communication. In recent years, significant advancements have been made in optical transmission systems, with transmission capacities surpassing 1 petabit per second (1pbps). However, as these systems have evolved to handle higher data rates and longer distances, nonlinearities and dispersion have emerged as substantial constraints, impacting the effectiveness of transmission links and, consequently, the overall performance of broadband communication systems.

II. MATERIALS AND METHOD

This involves experimental study, simulation, and data analysis.

A. Experimental Study

The experimental study entails establishing an optical fiber transmission link system within a laboratory setting, with the objective of assessing link performance across diverse conditions of chromatic and polarization mode dispersions. To achieve this, the following steps are taken:

Link Setup, for construction of a fiber optic transmission link utilizing standard single-mode fiber as the medium.

Dispersion Introduction, which involves induction of chromatic and polarization mode dispersion into the transmission link by manipulating factors such as fiber length and twisting angle.

Performance Measurement, for the evaluation of transmission link performance through the utilization of a range of performance metrics, including eye diagrams, signal-to-noise ratios, and bit error rates.

Performance Comparison, involving comparative analysis of transmission link performance in two scenarios. One is without compensation techniques for polarization and chromatic mode dispersion, while the other incorporates these compensation techniques.

By executing the steps, the experimental study provided valuable empirical insights into the ramifications of dispersions and the influence of compensation techniques on the performance of optical fiber transmission links.

B. Simulation

This was achieved with OptiSystem 7 .0 software. This is a robust tool for simulating and analyzing optical communication systems. The simulation process involves the following stages:

Designing Model. That’s is, constructing a model of the fiber optic transmission link

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

utilizing the capabilities of OptiSystem software.

Dispersion Introduction, where polarization and chromatic mode dispersion were incorporated into the transmission link model to accurately mimic real-world scenarios.

Effect Evaluation, for assessing the influence of dispersions by varying their performance effects. This assessment will be based on key parameter evaluation metrics such as eye diagrams, signal-to-noise ratios, and bit error rates.

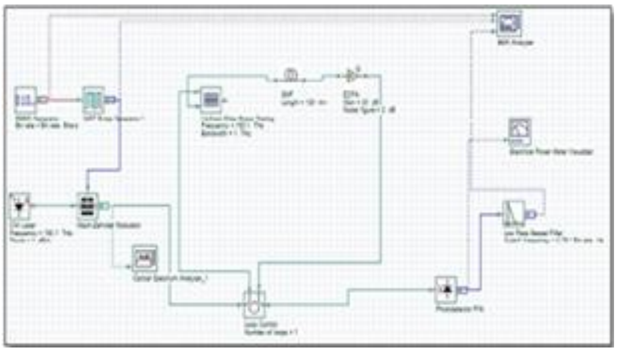
Performance Comparison involves contrasting the performance of the transmission link model under two conditions: one without compensation techniques for polarization mode dispersion and chromatic mode dispersion, and another with these compensation techniques.

By following the steps, the impact of dispersions and the efficacy of compensation techniques on the performance of fiber optic transmission links in broadband communication were observed.

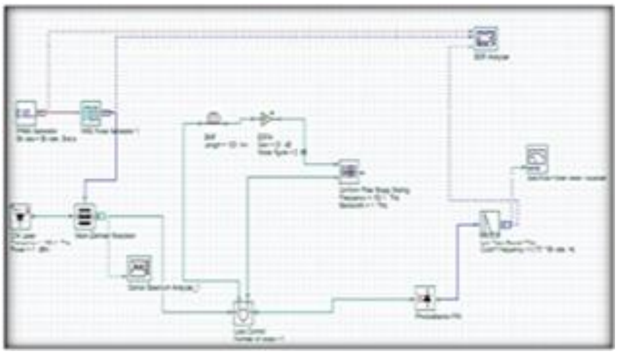
i. Simulation Setup

The accomplishment of dispersion compensation utilizing Uniform Fiber Bragg Gratings (UFBGs) as the dispersion compensator, employing OptiSystem7.0 software was implemented. The focus is on a single channel scenario, and simulation setups are conducted at both the transmitter and receiver ends.

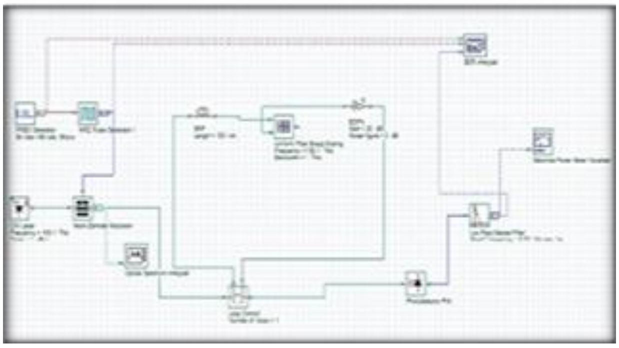
At the transmitter segment, a pseudo-random binary sequence (PRBS) generator was used to create consistent irregular bit patterns. A Mach-Zehnder modulator, where one input follows a non-return-to-zero (NRZ) modulation format and the other input was from a continuous wave laser acting as a light source was employed. The modulated optical signals were transmitted through the optical channel at a rate corresponding to 100 Gbps, with input power ranging from 1 dBm to 10 dBm. The simulations were conducted at a frequency of 193.1 THz. The received signals were directed to a pin detector, which serves as a transducer by converting optical signals into electrical signals. The position of the UFBG was adjusted to observe its impact on data transmission pulses and bandwidth. This adjustment was made in three configurations: pre-compensation, post-compensation, and mixed compensation. An erbium-doped fiber amplifier (EDFA) was integrated into the model to mitigate attenuation, placed after each instance of the UFBG. The simulation circuits for the three specific setups of UFBG (pre-compensation, post-compensation and mix-compensation) are illustrated in Figures 5, 6, and 7 respectively.



[Fig.5: Simulation Circuit for Pre-Compensation Using Uniform Fiber Bragg Grating]



[Fig.6: Simulation Circuit for Post-Compensation Using Uniform Fiber Bragg Grating]



[Fig.7: Simulation Circuit for Mix Compensation Using Uniform Fiber Bragg Grating]

The evaluation primarily revolves around observing the Q-factor and bit error rate (BER) to determine the most suitable design among the three. The parameters for UFBG and simulation details are outlined in Tables 1 and 2 respectively.

Table1: Parameters Used for UFBG Simulation

Value (Unit)	Parameter Measured
120km	Length of Fiber
-100dB	Noise Threshold
0.99	Reflectivity
500GHz	Sample Rate

Table 2: General Parameters Used in Simulation

Value (Unit)	Parameter Measured
100Gbps	Bit Rate
1THz	Bandwidth
30dB	Extinction Ratio
6.4THz	Sample Rate
1-10dBm	Power
20dB	Gain
2dB	Noise
193.1THz	Frequency

C. Data Analysis

The data gathered from both simulation and experimental studies were analyzed utilizing statistical methods, aimed at elucidating the impact of polarization and chromatic mode dispersion on optical fiber transmission link performance by employing the following procedure:

Performance Metrics Evaluation. This is for assessment of performance metrics within each scenario, followed by a comparative analysis of the outcomes.

Optimal Compensation Technique Identification, for recognition of the most effective compensation techniques for mitigating polarization and chromatic mode dispersion effects in optical fiber transmission links.

Factor Identification, used in determination of factors that exert an influence on the efficiency of compensation techniques.

Validation Process, involves validation procedure that cross-references simulation outcomes with the experimental findings to confirm the reliability of the results.

Hence, a comprehensive understanding of the interplay between dispersions, compensation techniques, and optical fiber transmission link performance is attained.

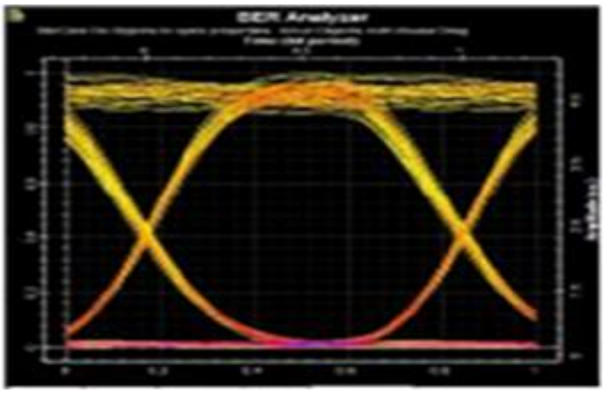
III. RESULT AND DISCUSSION

The analysis of the UFBG for Pre-compensation, Mix Compensation, and Post-compensation was conducted based on key performance metrics such as the Q-factor, BER, eye height, and received power.

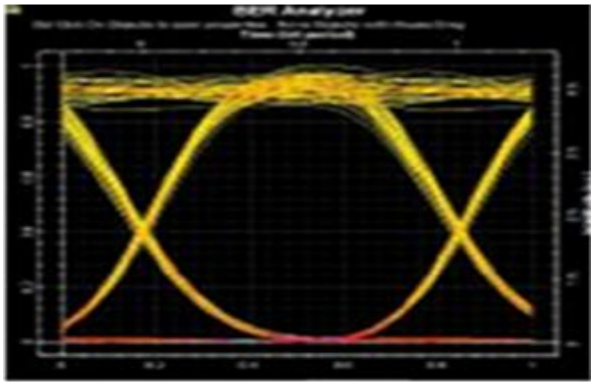
Figures 8, 9, and 10 illustrate the eye charts for Pre-, Post-, and Mix compensations, each employing the UFBG. Notably, the input power is set at 10 dBm in these eye diagrams, as this power level demonstrates distinct schemes of the UFBG showcasing the maximum Q-factor and minimal BER in comparison to other power levels ranging from 1 dBm to 10 dBm.

Tables 3, 4 and 5 provide a detailed breakdown of BER, Q-factor, received power, and eye heights across the three schemes at varying power levels. These Tables offer a comprehensive overview of the performance characteristics observed in each compensation setup, providing valuable insights into the effects of dispersion compensation using UFBG under different conditions.

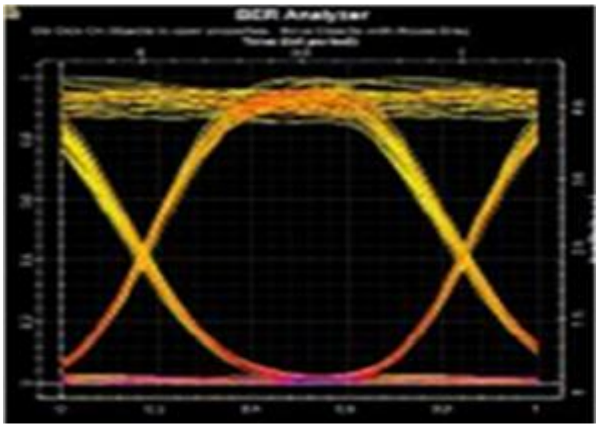
From Tables 3, 4 and 5, it is observed that Post dispersion compensation has the highest quality factor and the lowest BER, a desired and optimal compensation technique condition.



[Fig.8: UFBG Pre Compensation]



[Fig.9: UFBG Post Compensation]



[Fig.10: UFBG Mix Compensation]

Table 3: Results of Inputs from 1dBm to 10dBm for Pre-Compensation of FBG

Input Power (dB)	Max. Q Factor	Min. BER (Gbps)	Eye Height (m)	Threshold	Received Power
1	7.86135	1.78E-12	0.000301	0.000291	1.26E
2	9.13437	3.02E-20	0.000412	0.000319	1.89E
3	10.5549	2.18E-26	0.000555	0.000354	2.90E
4	12.1228	3.56E-34	0.000737	0.000398	4.49E
5	13.8473	5.75E-44	0.000969	0.000441	7.01E
6	15.7283	4.15E-56	0.001263	0.000504	1.10E
7	17.7594	6.10E-71	0.001637	0.000561	1.74E
8	19.9478	6.47E-89	0.002112	0.00065	2.74E
9	22.2657	3.25E-11	0.002714	0.000763	4.33E
10	24.7116	3.18E-13	0.003477	0.000838	6.86E

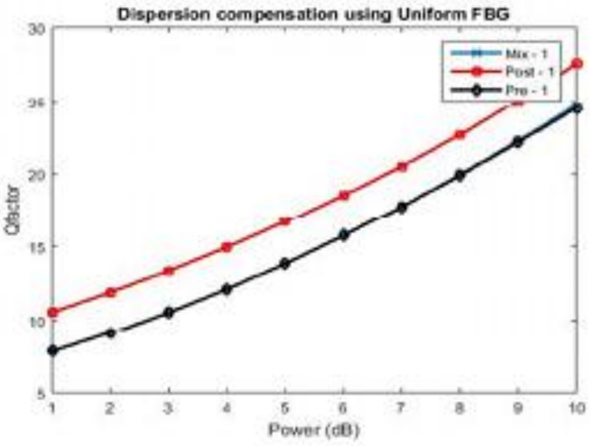
Table 4: Results of Inputs from 1dBm to 10dBm for Post-Compensation of UFBG

Input Power (dB)	Max. Q Factor	Min. BER (Gbps)	Eye Height (m)	Threshold	Received Power
1	10.5753	1.56E-26	0.00036	0.0001132	1.09E
2	11.913	4.04E-33	0.0004752	0.0001343	1.73E
3	13.369	3.55E-41	0.0006205	0.0001531	2.73E
4	14.9508	5.97E-51	0.0008056	0.00018449	4.32E
5	16.663	9.12E-63	0.00104	0.0002099	6.85E
6	18.512	6.11E-77	0.00133935	0.00023831	1.09E
7	20.5079	6.61E-94	0.001718	0.0002698	1.72E
8	22.6786	2.55E-11	0.002197	0.0002909	2.72E
9	25.028	1.04E-13	0.002805	0.00033431	4.31E
10	27.54	1.95E-16	0.00357	0.0003932	6.84E

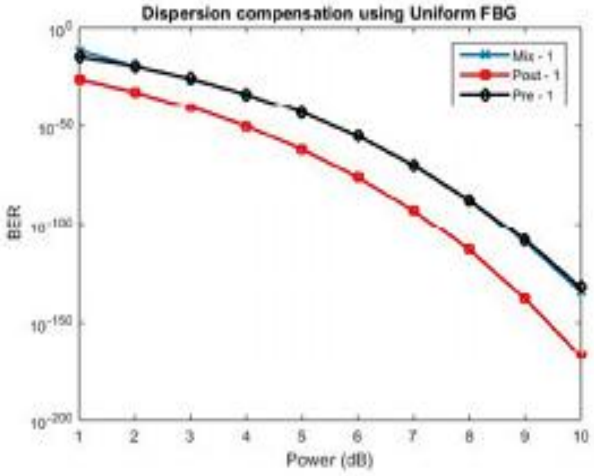
Table 5: Results of Inputs from 1dBm to 10dBm for Mix Compensation of UFBG

Input Power (dB)	Max. Q Factor	Min. BER (Gbps)	Eye Height (m)	Threshold	Received Power (dB)
1	7.86036	1.79E-15	0.000301	0.000291	1.75E
2	9.13275	3.07E-20	0.000413	0.000319	2.52E
3	10.5523	2.24E-26	0.000555	0.000354	3.72E
4	12.1191	3.72E-34	0.000737	0.000397	5.58E
5	13.8391	6.43E-44	0.000969	0.000441	8.49E
6	15.7154	5.08E-56	0.001263	0.000502	1.30E
7	17.7315	1.02E-70	0.001638	0.000581	2.02E
8	19.8949	1.86E-88	0.002112	0.000644	3.15E
9	22.1653	3.02E-10	0.002715	0.000752	4.93E
10	24.5084	4.73E-13	0.003477	0.000819	7.75E

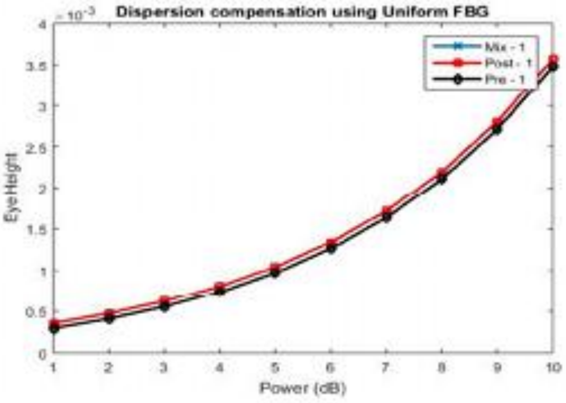
By analysing all the graphs as shown in Figures 11, 12, 13 and 14, it is clear that Post-compensation of UFBG shows best performances at 100Gbps for 120km range. Again, Pre- and Mix compensations overlapped in Figures 10 through 14. In Figure 11, UFBG Post-compensation exhibited the highest quality factor of the three compensation techniques.



[Fig.11: Q-Factor Against Input Power Plot]

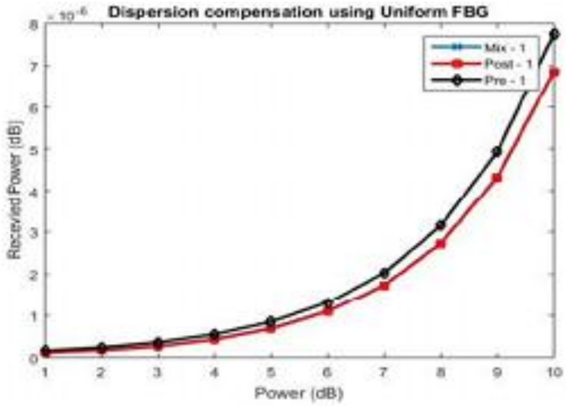


[Fig.12: BER Against Input Power Plot]



[Fig.13: Eye Height Against Input Power Plot]

Figure 12 shows that Post-compensation UFBG has the lowest error rates while the eye plots (Figure 13) are closely related although post-compensation has a slightly lower eye height per dB than Pre- and Mix compensations. Also, Post-compensation received the lowest power than Pre- and Mix compensations, which were again overlapped.



[Fig.14: Received Power Against Input Power Plot]

IV. CONCLUSION

This work investigated the performances of adaptive optical fiber compensation design techniques involving compensation and monitoring modules, which are expected to produce experimental results in optical fiber transmission system of 40Gbps CSRZ format. Optical fiber is a vital component of modern communication systems, comprising slender strands of glass or plastic for transmitting data across an extensive frequency range, exceeding 25THz, and covering considerable distances. However, fiber optic transmission systems are susceptible to modal, polarization and chromatic dispersions. Hence, three different compensation techniques were identified and investigated in the efforts to mitigate chromatic and dispersions in the fibre optic transmission medium. These are Pre-compensation, post-compensation and Mix compensation methods, utilizing Uniform Fiber Bragg Gratings (UFBGs) as the dispersion compensator, and employing Optisystem7.0 software. The focus is on a single channel scenario, and simulation setups are conducted at both the transmitter and receiver ends.

The results of the investigation suggested that when analysed using key performance metrics such as BER, Q-factor), and power requirement, Post-compensation of UFBG shows best performances at 100Gbps for 120km range, while Pre- and Mix compensations overlapped. Furthermore, UFBG Post-compensation exhibited the highest quality factor, lowest BER and power requirements of the three compensation techniques.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been sponsored or funded by any organization or agency. The independence of this research is a crucial factor in affirming its impartiality, as it has been conducted without any external sway.
- **Ethical Approval and Consent to Participate:** The data provided in this article is exempt from the requirement for ethical approval or participant consent.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors Contributions:** The authorship of this article is contributed equally to all participating individuals.

REFERENCES

1. Fiber Technology and Its Application in the Modern Society (2022). In Stem Cell Research International (vol. 5, issue 1, 1,03). DOI: http://doi.org/10.33140/scri.05.01.01
2. R. Ajemian, Transmission Techniques: Fiber Optics (2008). In Handbook for Sound Engineers (pp. 449–485). DOI: http://doi.org/10.1016/b978-0-240-80969-4.50019-5
3. O. Strobel and J. Lubkoll (2010). Fiber-optic communication - An overview. In 20th International Crimean Conference. In Microwave & Telecommunication Technology, Sevastopol, Ukraine (pp. 16-20). DOI: http://doi.org/10.1109/CRMICO.2010.5632426
4. P. Kaushik, D. P. Singh and S. Rajpoot (2020). Fibre Optic Communication. In 21st Century, In International Conference on Intelligent Engineering and Management (ICIEM), London, UK, 2020, (pp.125-129). DOI: http://doi.org/10.1109/ICIEM48762.2020.9160141
5. L. Pierno, A. M. Fiorello, A. Secchi and M. Dispenza (2015). Fibre optics in radar systems: Advantages and achievements. In IEEE Radar Conference (RadarCon), Arlington, VA, (pp. 1627-1633). DOI: http://doi.org/10.1109/RADAR.2015.7131259
6. F. Nahar and A. Ahmed (2016). Measurement of pulse dispersion in optical fiber communication system. In 5th International Conference on Informatics, Electronics and Vision (ICIEV), Dhaka, Bangladesh (pp. 1073-1077). DOI: http://doi.org/10.1109/ICIEV.2016.7760163
7. I. Roudas (2017). Modeling of modal dispersion in multimode and multicore optical fibers. In 26th Wireless and Optical Communication Conference (WOCC), Newark, NJ, USA (pp. 1-6). DOI: http://doi.org/10.1109/WOCC.2017.7928979
8. L. Gan et al. (2018). Realistic Model for Frequency-Dependent Crosstalk in Weakly-Coupled Multicore Fiber. In Optical Fiber Communications Conference and Exposition (OFC), San Diego, CA, USA (pp. 1-3). DOI: https://doi.org/10.1364/ofc.2018.tu3b.6
9. T. Shanthi Priya and I. Muthumani (2016). Chromatic dispersion monitoring in optical systems. In 2016 IEEE International Conference on Engineering and Technology (ICETECH), Coimbatore, India (pp. 1111-1114). DOI: http://doi.org/10.1109/ICETECH.2016.7569422
10. Nandwalkar, J. R., & Pete, D. J. (2020). Furtherance in Splicing Technique of Optical Fiber Communication. In International Journal of Engineering and Advanced Technology (Vol. 9, Issue 3, pp. 3605–3609). DOI: https://doi.org/10.35940/ijeat.c6208.029320
11. So-Ki Jung, Optical Line Monitoring System using Optical Fiber Closure. (2019). In International Journal of Recent Technology and Engineering (Vol. 8, Issue 2S4, pp. 942–948). DOI: https://doi.org/10.35940/ijrte.b1187.0782s419
12. G. Siva Sravani, K.Gouthami, K. Sai Mounika, J.Chandra Sekhar, Simulation of Signal Processing Scheme for Fiber Optic Rotationary Sensor. (2019). In International Journal of Innovative Technology and Exploring Engineering (Vol. 8, Issue 6S4, pp. 596–601). DOI: https://doi.org/10.35940/ijitee.f1123.0486s419
13. Mishra, R. R., & Soren, K. (2021). Optical BPSK Modulation and Demodulation using Opti System Simulator. In International Journal of Inventive Engineering and Sciences (Vol. 9, Issue 1, pp. 1–4). DOI: https://doi.org/10.35940/ijies.c1045.129121

AUTHOR'S PROFILE

Yussuff Abayomi Isiaka O., (PhD) is an Associate Professor of communication Engineering. He obtained his bachelor and master's degrees in Electronic and Computer Engineering from Lagos State University, Nigeria in 1994 and 2003; and a PhD in Electrical Engineering from Universiti Teknologi Malaysia (UTM), Skudai, Malaysia in 2014. He is currently a researcher and lecturer in the Department of Electronic and Computer Engineering, Lagos State University, Epe campus, Nigeria. His research area of interests includes radio propagation, rain attenuation, satellite communication, network security, and emerging technologies. He has published a few papers in international journals related to satellite rain attenuation issues in the tropical regions. He is a member of Nigeria Society of Engineers (NSE) and IEEE; and licensed by the Council for Regulation of Engineering in Nigeria (COREN).

Ayodele Adedeji Andrew, is the MD/CEO of Bitmap Technologies Ltd. He obtained his Higher National Diploma (HND) in Electrical/Electronics Engineering at Yaba College of Tech in 1998, Post graduate Diploma (PGD) and master's degree in Electronics and Computer Engineering from Lagos state university in the year 2020 and 2023. He has deployed and project managed 0ver 4,000km of fibre optic cable for different network structure like FTTH, FTTT, FTTC etc. for both data and voice solutions, within the telecoms space in Nigeria. Presently running a fibre O&M Operations spanning across 7 States in Nigeria with a total distance of 3,750km. A member of the Nigerian Society of Engineers (NSE) and IEE: licensed by the Council of Regulation of Engineering in Nigeria (COREN), with over 15 years consultancy services to some of the Mobile Network operators, services providers and OEM vendors in Nigeria such as MTNN, Globacom, ZTE, IHS, IPnx, Extended Networks, WTES and several other individual clients.