Evaluation of optical communication networks utilizing fiber Bragg grating and dispersion mitigation methods

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Article history
Submitted: 10 May 2026
Revised: 15 June 2026
Accepted: 10 July 2026
Published: 15 July 2026

Keywords
Eye diagrams with bit error rate (BER)
Fiber Bragg Grating (FBG)
Ideal Dispersion Compensation Filter (Ideal-DCF)
Mach-Zehnder Modulator (MZM)

Abstract
This would improve optical communication system performance through the combination of Fiber Bragg Grating (FBG) networks, with attenuation mitigation techniques to improve signal clarity and reduce attenuation and phase distortion impacts during high-speed data transmission. A full optical communication system simulation was created by the researchers, incorporating both a Continuous Wave (CW) laser and a Mach-Zehnder Modulator (MZM). Significantly, the application of FBG-based models allowed for increasing spectral selectivity, which in turn led to an increase in Signal-to-Noise Ratio (SNR). The study analyzed various parameters to investigate the effect of fiber length, structure of Erbium-Doped Fiber Amplifiers, and Ideal Dispersion Compensation Filters on the system performance. Simulations showed that the signal quality of transmission was improved when a FBG network with dispersion compensation was used. high reliability of a bit error rate (BER) of 6.32665 X 10-9 for long-distance optical transmission of the optical fiber link across 170 kilometers. Further analyses were made on the eye diagrams and measurements of the spectrum of the optical signal to evaluate the effect of additional noise and spectral signals on the integrity of a signal. It is concluded that the novel FBG networks, together with basic and advanced forms of dispersion compensation, could help overcome the data degradation limitation for flat and broadband optical communications and could also be advantageous to the overall system throughput. In other words, the combination of these technologies represents a promising solution for future fiber optical communication systems and next-generation 6G networks. The experimental verification of Opti System and MATLAB simulations.

1. Introduction

When facing similar situations, the main issue will also be to ensure that dispersion and optical signals are preserved over significant distances. Fiber optic communication is nowadays using Wavelength Division Multiplexing technology in order to increase capacity [1]. These rudiments reflect specific wavelengths well and transmit other wavelengths, which improves the spectral efficiency and lowers cross-talk between channels. Erbium-Doped Fiber Amplifiers directly amplify the light in the fiber, eliminating the need to regenerate the signals and thus avoiding problems associated with regenerating signals at longer distances and making them ideal for long-distance communication links. Collectively, these technologies allow for the building of optical communications systems that can deliver high speed data transmission to support the current high-capacity needs. The optical signal is provided by a continuous wave laser, operating at a frequency of 193.1 THz. The Mach-Zehnder Modulator (MZModulator) carries out modulation by precisely controlling phase and amplitude values of the signal [3]. FBG Filters are wavelength-selective reflectors that do not permit the unwanted interference to proceed through the system, thus keeping the desired wavelengths on path while ensuring stability of the signals, which remain stable along the optical path [4]. There are several Erbium-Doped Fiber Amplifiers (EDFAs) along the fiber transmission path that amplify the signal, but preserve an excellent SNR. Even though design methods for these systems have developed further, chromatic dispersion continues to be a major issue when attempting high-speed data transmission within optical systems. Thus, DCFs with values of dispersion compensation of −800 ps/nm are used in order to maintain the signal quality over long distances. It employs fiber lengths of up to 170 km in order to accurately simulate the conditions of long-distance transmission. The optical signal is then converted into electrical signal by using a PIN photodiode. Low-pass Gaussian filtering is first applied to the electrical signal in order to eliminate high frequency noise, and the resulting signal is then fed into a 3R Regenerator which reshapes, retimes and reamplifies the signal.

The performance and reliability of optical links under different environmental conditions is usually assessed through the use of Bit/Error Rate (BER) analyzing software packages along with an eye diagram analyzer that analyzes the performance of the system. The systems are arranged such to perform a wide analysis of aspects of transmission such as interference, scattering and losses through optics. The same perceptivity is

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applied to develop sophisticated methods to improve the quality of signals and systems adaptability. Some recent systems have indicated the use of artificial intelligence and bulk data processors as a means to increase performance of the systems, achieving data transmission rates in excess of 100Gbps [11]; [12]; [13]; [14]; [15]; [16].

Working principle of FBG

The Fiber Bragg Grating (FBG) operates through repeated changes in the refractive index found within the optical fiber's core. The periodic structure acts as a wavelength-selective filter by reflecting particular wavelengths such as the Bragg wavelength and transmitting other wavelengths through the fiber [17]. When broadband light propagates along the fiber, only the wavelength that satisfies the Bragg condition known as the Bragg wavelength (λ_B) is reflected, whereas the remaining spectral factors continue to propagate through the fiber without interruption [18]; [19]; [20]. The Equation 1 determines the Bragg wavelength;

$$\lambda_B = 2n_{eff}\Lambda \quad (1)$$

Where: λ_B Is Bragg wavelength, n_{eff} *is* effective refractive index of the fiber core, and Λ Is the grating period.

FBGs are extensively utilized in optical communication frameworks for wavelength selection, dispersion correction, and sensing functionalities, owing to their capability to accurately manipulate the reflected wavelength through the modification of the grating period and the refractive index variation [20]. Figure 1 shown a FBG concept and working principle.

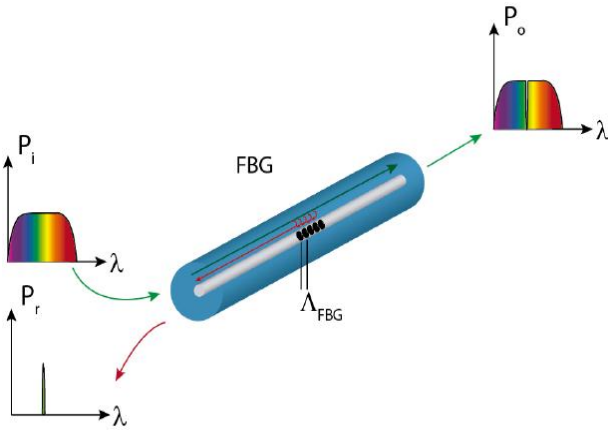

Figure 1. FBG concept and working principle [21]

2. Method

2.1. The operation principle of the Ideal-DCF

The Perfect Dispersion Compensation Filter (DCF) functions based on the concept of mitigating the dispersion effects in optical communication networks, especially those employing fiber optics. Within a fiber optic transmission network, signal pulses expand over distance due to chromatic dispersion, leading to various wavelength components of the signal traveling at different velocities. This causes pulse widening and deterioration of signal integrity [22].

The Optimized DCF addresses this variation by incorporating a filter that exhibits a negative dissipation particularity, allowing it to negate or offset the dissipation caused by the fiber. By employing the DCF, the expansion of beats can be minimized or entirely reversed, performing in enhanced signal quality and dropped bit error rates in the communication system.

2.2. An Overview of System Architecture and Simulation Using Opti System and MATLAB

In optic communication frameworks, a variety of pivotal factors are employed, including Fiber Bragg Gratings (FBGs), a MZM, single- mode optic fibers, signal amplifiers, Ideal Dispersion Compensation Filters (Ideal DCFs), PIN photodiodes, Low Pass Filters (LP Filters), and fresh instruments to assess BER and Eye diagrams. The architecture of the system is illustrated in a diagram, utilizing both Opti System and MATLAB for the system's design and simulation. The integration of these tools facilitates comprehensive performance analysis,

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encompassing the examination of signal integrity through BER and visual definition of signal conduct in Eye diagrams. Figure 2 illustrates the System diagram.

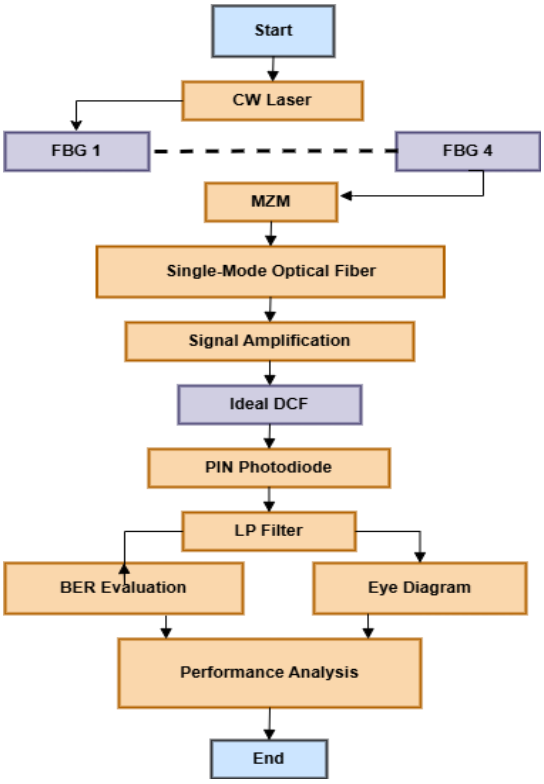

Figure 2. Illustrates the System diagram

2.3. Comprehensive Overview of the Optical System Simulation Utilizing Opti System.

The simulated optic communication system integrates FBG technology with dissipation compensation to enable data transmission across a 170 km fiber-optic link. To maintain signal integrity over this extended distance, the system utilizes Erbium-Doped Fiber Amplifiers (EDFAs) alongside dispersion compensation Filters. At the receiver end, the quality and trustability of the transmitted signal are estimated using spectrum analyzers, eye illustration analyzers, and BER analyzers, furnishing a comprehensive assessment of overall system performance.

2.4. Transmission System

The transmission process begins with a Pseudo-Random Bit Sequence (PRBS) creator that produces digital data at a rate of 10 Gbps. The data undergoes decoding through Non-Return-to-Zero (NRZ) garbling before being transformed into an electrical signal. The optic carrier remains stable when a Continuous Wave (CW) ray operates at 193.1 THz with 5 dBm of affair power. The Mach-Zehnder Modulator (MZM) executes modulation by imprinting the electrical NRZ signal onto the optic carrier to enable fiber channel transmission.

Multiple Fiber Bragg Grating (FBG) filters process a signal before transmission to enable precise wavelength selection and spectral shaping which minimizes optical interference. Optical power measurements of signals before transmission enable operators to maintain power within parameters essential for efficient long-haul signal transmission.

2.5. Transmission Medium (Optical Channel)

The transmission path for optical signals includes numerous fiber segments which cover a total distance of 170 km to maintain high signal quality across the transmission route. The signal travels 60 km through optical fiber before it reaches an Erbium-Doped Fiber Amplifier (EDFA) which boosts signal strength while minimizing attenuation. The Ideal Dispersion Compensation Filter works to minimize polychromatic dispersion while simultaneously decreasing Inter-Symbol Interference (ISI).

Following this, the signal travels through a fresh 25 km of optical fiber, where another EDFA amplifier before it is subjected to another dispersion compensation filter. The signal also undergoes a concluding 25 km fiber transmission before reaching the receiving unit. Throughout the entire transmission, Optical Spectrum

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Analyzers continuously cover the optic signal, detecting any spectral variations and precluding signal declination due to dispersion or noise.

2.6. Reception System

At the receiver unit, the optical signal is captured with a PIN Photodiode, which transforms the light signal back into an electrical current. The signal is also transferred through a low-pass Gaussian Filter to exclude high-frequency noise and ameliorate signal chastity. Latterly, the signal is examined in the frequency sphere using an RF Spectrum Analyzer previous to witnessing processing through a 3R Regenerator that executes Reamplification, Retiming, and Reshaping to restore the integrity of the signal. The effectiveness of the system is assessed through an Eye Diagram Analyzer, which visually depicts the signal dedication and the effects of distortion. Likewise, a BER Analyzer quantifies the bit error rate, offering a numerical evaluation of the system's transmission integrity and robustness against dissipation and noise. A fully simulated communication system with all its components can be seen in Figure 3.

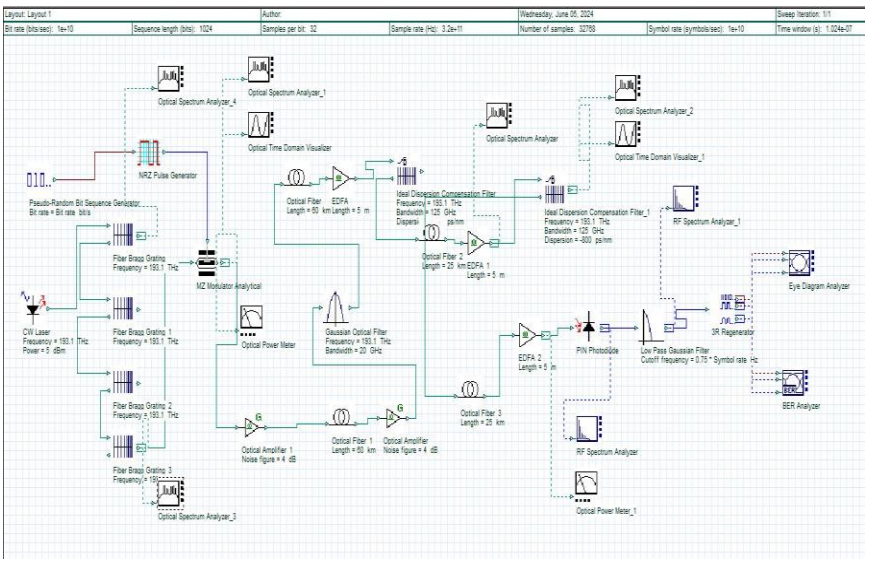

Figure 3. A fully simulated communication system with all its components

3. Results and Discussion

In Figure 4 and Figure 5, we employ an Optical Spectrum Analyzer (OSA) to examine signals like power, frequency, and spectral range. This instrument decomposes the signal into its rudiments according to wavelength, easing a detailed perspective on the distribution of optic power across different wavelengths. It offers precious perceptivity into the variation of the signal's intensity throughout the optic diapason, abetting in the appreciation of the system's performance regarding its effectiveness and spectral attributes.

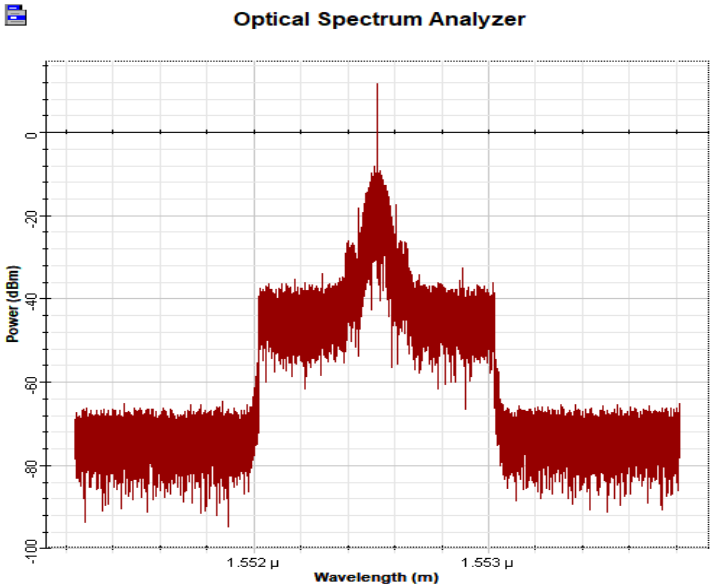

Figure 4. Analyzing Optical Signals Through

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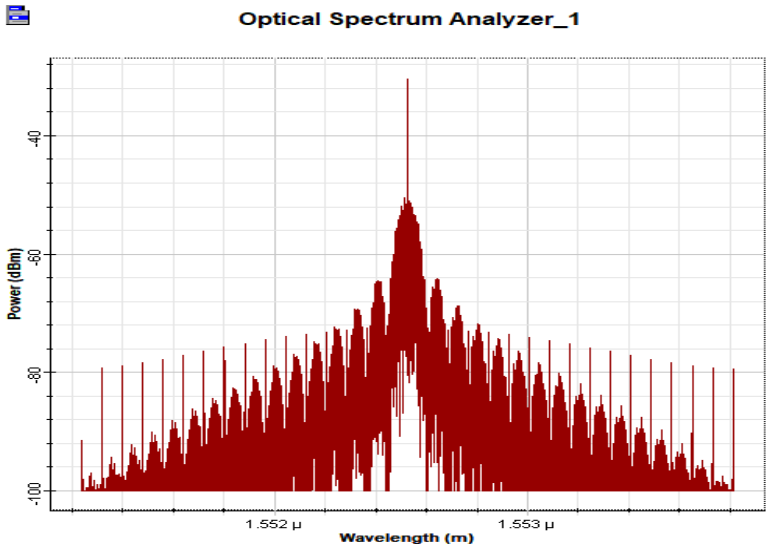

Figure 5. Comprehending Optical Signals Through an Optical Spectrum Analyzer

In the realm of telecommunications, the Quality Factor (Q Factor) stands as a vital parameter for assessing signal quality by measuring the Signal-to-Noise Rate (SNR) within the network. Assaying the data reveals that the Bit Error Rate (BER) of the signal was assessed over a fiber optical transmission span of 170 km, performing in a figure of 6.32665×10^{-9}, as depicted in Figure 6. This figure signifies the rate of inaptly entered bits compared to the total bits transferred, offering a quantitative assessment of the system's effectiveness regarding error rates across the designated transmission span.

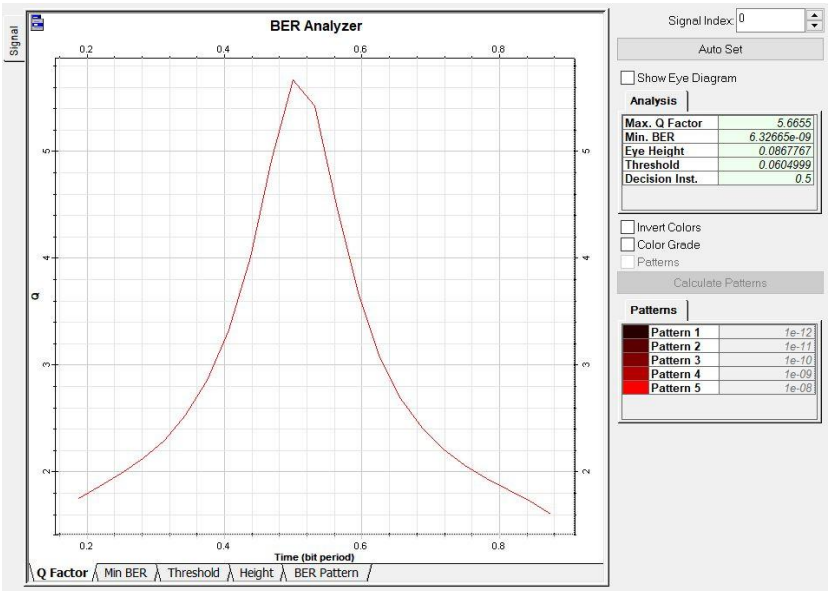

Figure 6. Illustrates the Q-Factor value.

The Eye Diagram evaluation illustrated in Figure 7 serves to gauge the quality of the optical signal while assessing the transmission clarity and stability of the data conveyed. The signal manifests as an eye diagram, which delivers insights into the degree of signal overlap and the stability of the signal at various time intervals. In this context, with a BER value of 6.32665×10^{-9} across a 170 km channel, the eye diagram reflects a commendable level of quality. The graphical representation of the signal is clear and well-defined, with little to no blurring or deformation. This clarity indicates that the signal can be directly interpreted, thereby adding confidence in the overall effectiveness of the system.

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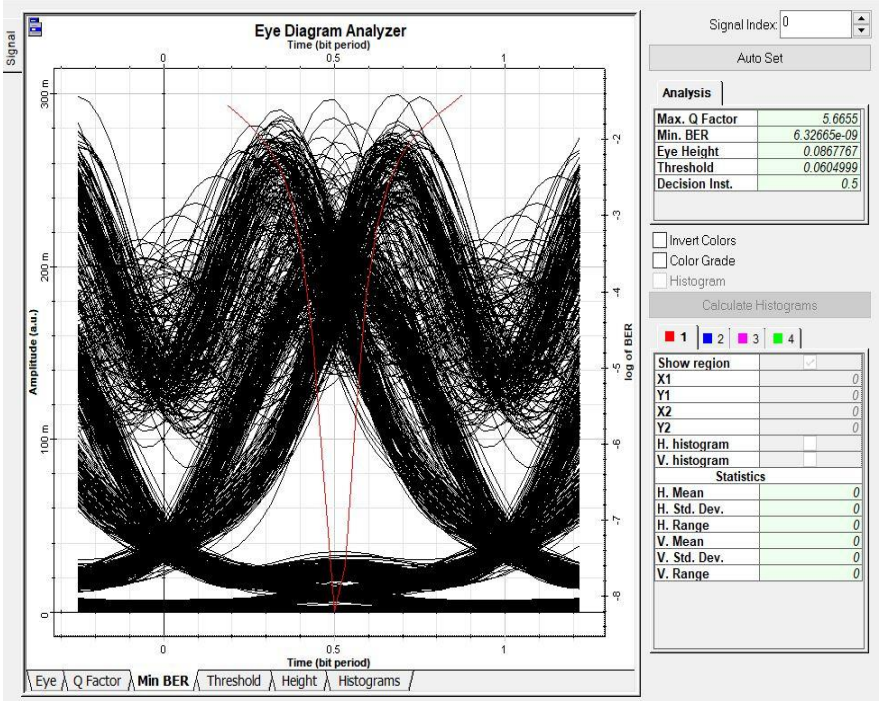

Figure 7. The Eye Diagram analysis is presented.

When testing the system at a power level of 5 dBm, it was noted that it outperformed a similar system working on lower power supplied. The system displayed degradation of both BER and an improved Q Factor which is a sign of performance. This development highlights the role FBG and the Ideal Dispersion Compensating Filter (Ideal DCF) play in refining the system's performance, especially in long-haul transmission.

The performance characteristics of the system were showcased through the low BER and high Q Factor achieved, allowing for sustained efficiency even at the long-range limits, like the 170 kilometers of optical fiber used in the tests. This proves the benefits of using FBGs in conjunction with an Ideal DCF to improve the quality and reliability of long-distance optical communication systems. In Table 1, a comparison of the performance of the system at different optical power levels is given along with the plot of corresponding BER values.

Table 1. Comparison of the performance of the system at different optical power levels is given along with the plot of corresponding BER values

Optical fiber length (km)	It contains FBG and Ideal-DCF (BER) with 1 dBm.	It contains FBG and Ideal-DCF (BER) with 5 dBm.
140	1.47324e-09	2.14231e-14
170	1.283e-05	6.32665 e-9

4. Conclusion

This research focuses on the major possibilities on optic detector networks with attenuation compensation based on FBG networks to boost the efficiency of FBGs in communication systems. The design including a CW laser, Mach-Zehnder modulator, and FBGs showed notable improvement in attenuation, dissipation phase shift issues, and overall SNR. The application of Ideal DCF particularly helped in dispersion issues and a reduction of impairments overall improved system performance.

The achieved result in the simulation depicts that the quality of the received signal was improved substantially with a BER of 6.32665×10^{-9} for 170Km optic fiber link which showcases the reliability of the system for long-distance, high-speed communication. The eye diagrams and signal spectra also confirmed the capability of the system to mitigate noise and maintain the integrity of the signal over long distances. Comparing to a similar system using an optical power of 1dBm, this system was found to have a significant decrease in the error rate when the value was increased to 5dBm, thus making the communication link stronger and more efficient.

This study highlights the importance of FBG integration with dispersion compensation in improving the performance of optic communication networks. The findings indicate that data loss is minimized, system performance is improved, and therefore, this method is best applicable for higher order fiber-optic networks and 6G communication systems.

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Author Contributions

All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

Funding

No funding support was received.

Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/ or publication of this article.

Data Availability

The datasets generated during and/ or analysed during the current study are available from the corresponding author on reasonable request.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript.

References

[1] Winzer PJ. The future of communications is massively parallel. *Journal of Optical Communications and Networking*. 2023 Oct 1;15(10):783-7.

[2] Al-Tarawneh L, Alqatawneh A, Tahat A, Saraereh O. Evolution of optical networks: from legacy networks to next-generation networks. *Journal of Optical Communications.* 2024 Feb 13;44(s1): s955-70.

[3] Ip E, Lau AP, Barros DJ, Kahn JM. Coherent detection in optical fiber systems. *Optics express.* 2008 Jan 9;16(2):753-91.

[4] Alhussein AN, Qaid MR, Agliullin T, Valeev B, Morozov O, Sakhabutdinov A. Fiber Bragg grating sensors: design, applications, and comparison with other sensing technologies. *Sensors.* 2025 Apr 4;25(7):2289.

[5] Regaieg R, Koubaa M, Karar AS, Monga KJ, Adibnia E, Zayani HM, Salhi M, Bahloul F. Optimizing Few-Mode Erbium-Doped Fiber Amplifiers for high-capacity optical networks using a multi-objective optimization algorithm. *Optical Fiber Technology.* 2025 Sep 1; 93:104186.

[6] Wu Y, Wang Y, Jiang L, Yu J. Dispersion Compensation Scheme with a Simple Structure in Ultra-High-Speed Optical Fiber Transmission Systems. *InPhotonics* 2026 Jan 1 (Vol. 13, No. 1, p. 39).

[7] Li H, Wang D, Zuo M, Duan X, Zhang D, Cao S, Zhang Y, Li J, Sun J, Ge D. Making long-haul large-capacity 400G optical network a reality. *Nature Reviews Electrical Engineering*. 2026 Apr 1:1-2.

[8] Selim Ünlü M, Dosunmu O, Emsley M. High-Speed Photodetectors for Optical Communications. Wiley Encyclopedia of Telecommunications. 2003 Apr 15.

[9] Hugar NR, Piruthiviraj P, Dhinesh V. Simulation and Analysis of Bit Error Rate in Optical Fiber Communication Using Optisystem. In2024 7th International Conference on Devices, *Circuits and Systems (ICDCS)* 2024 Apr 23 (pp. 67-71). IEEE.

[10] Chanana G. *AI-Driven Design and Optimization of Optical Fiber Sensor Networks. InOptical Fiber Sensors and AI: Exploring the Fusion* 2025 Jul 3 (pp. 105-120). Singapore: Springer Nature Singapore.

[11] Thrane J, Wass J, Piels M, Diniz JC, Jones R, Zibar D. Machine learning techniques for optical performance monitoring from directly detected PDM-QAM signals. *Journal of Lightwave Technology*. 2016 Aug 2;35(4):868-75.

[12] Turitsyn SK, Prilepsky JE, Le ST, Wahls S, Frumin LL, Kamalian M, Derevyanko SA. Nonlinear Fourier transforms for optical data processing and transmission: advances and perspectives. *Optica*. 2017 Feb 28;4(3):307-22.

[13] Cvijetic M, Djordjevic I. Advanced optical communication systems and networks. *Artech House*; 2013.

[14] Hira U, Ahmad MN. Optical Fiber Sensors. InOptical Technologies for Advancing Communication, Sensing, and Computing Systems 2024 Dec 3. *IntechOpen*.

[15] Han B, Cheng Q, Tao Y, Ma Y, Liang H, Ma R, Qi Y, Zhao Y, Wang Z, Wu H. Spectral manipulations of random fiber lasers: principles, characteristics, and applications. *Laser & Photonics Reviews.* 2024 Jul;18(7):2400122.

[16] A. T. Jaber, R. J. A. Ali, S. S. Ahmed, and M. H. Nida, "Performance analysis of optical communication networks utilizing optical fibers and OFDM technology," *Journal of Optical Communications*, vol. 2024, pp. 1–8, 2024.

[17] A. Othonos and K. Kalli, *Fiber Bragg Gratings: Fundamentals and Applications in Telecommunications and Sensing*. Boston, MA, USA: Artech House, 1999.

[18] R. Kashyap, *Fiber Bragg Gratings*, 2nd ed. San Diego, CA, USA: Academic Press, 2009.

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ISSN: 3110-1577

[19] B. Lee, "Review of the present status of optical fiber sensors," *Optical Fiber Technology*, vol. 9, no. 2, pp. 57–79, Apr. 2003, doi: 10.1016/S1068-5200(02)00527-8.

[20] H. J. Patrick, A. D. Kersey, and F. Bucholtz, "Analysis of the response of fiber Bragg gratings to longitudinally applied strains," *Journal of Lightwave Technology*, vol. 16, no. 9, pp. 1606–1613, Sep. 1998, doi: 10.1109/50.712247.

[21] I. García, J. Zubia, G. Durana, G. Aldabaldetreku, M. A. Illarramendi, and J. Villatoro, "Optical fiber sensors for aircraft structural health monitoring," *Sensors*, vol. 15, no. 7, pp. 15494–15519, 2015, doi: 10.3390/s150715494.

[22] E. M. Chidi and I. B. Aslanuba, "Mitigating the problem of dispersion in optical fiber communication link," *IEEE-SEM*, vol. 7, no. 12, Dec. 2019.

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