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Comparative Analysis of Digital Signal Processing Techniques for Chromatic Dispersion Compensation in High-Speed Optical Communication Systems

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Abstract

This paper addresses the critical gap in comparative analysis of digital signal processing techniques for chromatic dispersion compensation in high-speed optical communication systems. Previous studies have demonstrated individual technique effectiveness but lacked integrated assessment frameworks necessary for informed implementation decisions, particularly regarding the trade-off between performance and computational efficiency. The research aimed to design and simulate an optimized Digital Signal Processing (DSP) model for chromatic dispersion compensation using MATLAB, with specific objectives to develop a comprehensive simulation framework, implement multiple compensation techniques, evaluate performance across critical metrics, and compare proposed approaches with existing methods. MATLAB-based simulation using 16-QAM modulation at 25 G Baud with Root Raised Cosine pulse shaping, incorporating realistic fibre characteristics with 17 ps/(nm·km) chromatic dispersion was employed. Four compensation techniques were evaluated: baseline uncompensated transmission, Finite Impulse Response (FIR) standard filtering, FIR weight-optimized filtering, and frequency domain standard compensation. Performance assessment encompassed six transmission distances (100-1500 km) and six OSNR conditions (10-30 dB), generating comprehensive datasets for statistical analysis. The findings revealed that whilst all compensation techniques achieved comparable bit error rate performance clustering around 5×10^{-1}, significant differences emerged in computational complexity. The frequency domain standard technique demonstrated superior efficiency requiring only 9.83×10^{5} operations compared to 4.19×10^{6} operations for FIR standard filtering, representing a 76% reduction in processing requirements. Statistical analysis confirmed that performance differences were not statistically significant at the 95% confidence level, establishing computational efficiency as the primary differentiating factor.

Keywords: *Digital Signal Processing, Finite Impulse Response (FIR), Bit error rate, Quadrature Amplitude Modulation (QAM), Chromatic dispersion compensation.*

1.0 Introduction

Digital signal processing (DSP) has revolutionized dispersion compensation strategies, offering unprecedented flexibility and computational efficiency compared to traditional optical compensation techniques (Yankov *et al*., 2018). Contemporary research demonstrates that DSP-based approaches can effectively mitigate Chromatic Dispersion (CD) effects through sophisticated algorithmic interventions, particularly in coherent optical communication systems. Frequency-domain equalization (FDE) and time-domain equalization (TDE) have emerged as prominent techniques, with researchers exploring their potential for managing complex dispersion scenarios (Sebestyen *et al*., 2020).

Advanced coherent detection technologies have further amplified DSP's capabilities in dispersion compensation. By enabling precise amplitude and phase information recovery, these techniques provide nuanced control mechanisms for signal restoration (Chagnon *et al*., 2019). Machine learning algorithms, particularly neural network-based approaches, are increasingly being integrated into DSP frameworks, offering adaptive and intelligent dispersion compensation strategies that can dynamically respond to transmission channel characteristics (Come *et al*., 2021). The integration of machine learning paradigms with DSP techniques represents a transformative approach to dispersion compensation. Neural network architectures trained on extensive signal datasets can develop sophisticated compensation models capable of anticipating and correcting transmission impairments with unprecedented accuracy (Djordjevic *et al*., 2020). This data-driven methodology promises more robust and adaptive compensation mechanisms that can dynamically respond to varying transmission channel characteristics.

Recent investigations have highlighted the multifaceted nature of dispersion compensation, emphasizing the need for adaptive and intelligent approaches. Volterra-based equalization techniques, for instance, offer enhanced capabilities in managing both linear and nonlinear signal distortions, representing a sophisticated evolution in DSP-based compensation strategies (Ip & Kahn, 2018). Such approaches not only mitigate chromatic dispersion but also address broader signal degradation mechanisms inherent in complex

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optical transmission environments. As global data demand continues to escalate, the significance of advanced dispersion compensation techniques becomes increasingly pronounced. DSP-based approaches offer a compelling solution to the fundamental challenges posed by chromatic dispersion, enabling higher transmission capacities, extended reach, and improved signal reliability across diverse optical communication infrastructures.

2.0 Literature Review

In optical fibre communication, chromatic dispersion is a critical phenomenon that significantly impacts signal integrity. It arises because different wavelengths of light travel at varying speeds through the fibre, leading to pulse broadening and intersymbol interference (ISI) (Miller, 2011). This dispersion comprises two main components: material dispersion, resulting from the wavelength-dependent refractive index of the fibre material, and waveguide dispersion, which is influenced by the fibre's structural parameters (Vivid COMM, 2018). The impact of chromatic dispersion on signal transmission is profound. As optical pulses propagate, dispersion causes them to spread, potentially overlapping with adjacent pulses. This overlap can lead to errors in data interpretation at the receiver end, thereby limiting the system's bandwidth and overall performance (Xu, 2017).

Effective management of chromatic dispersion is essential to maintain high data rates and long-distance communication capabilities. Digital Signal Processing (DSP) has emerged as a pivotal technology in mitigating the adverse effects of chromatic dispersion. By employing sophisticated algorithms, DSP can compensate for dispersion-induced distortions, thereby preserving signal integrity. Techniques such as time-domain and frequency-domain equalizations are commonly utilized to counteract the effects of dispersion (Xu, 2017). The mathematical modelling of dispersion compensation involves creating algorithms that can predict and correct the phase and amplitude alterations caused by dispersion, ensuring accurate signal reconstruction at the receiver.

2.1 Principles of Chromatic Dispersion in Optical Fibers

Chromatic dispersion in optical fibers occurs because different spectral components of a light pulse travel at different velocities. This velocity difference leads to temporal spreading of the pulse as it propagates through the fibre. Material dispersion arises from the wavelength-dependent refractive index of the fibre material, causing different wavelengths to travel at different speeds. Waveguide dispersion, on the other hand, results from the fibre's structural characteristics, such as core diameter and refractive index profile, which affect how different wavelengths propagate (Vividcomm, 2018).

The influence of chromatic dispersion on optical communication systems is profound. As light pulses traverse the fibre, dispersion causes them to broaden, which can lead to overlapping with neighbouring pulses. This overlap, known as intersymbol interference (ISI), complicates the accurate detection of transmitted data, thereby increasing the bit error rate (BER) and reducing the system's overall performance (Xu, 2017). In high-speed communication systems, where data pulses are closely spaced, the effects of chromatic dispersion are even more pronounced, necessitating effective compensation techniques to maintain signal fidelity.

2.2 Empirical Review

The empirical review focuses on the evaluation of existing research and publications related to digital signal processing (DSP) techniques for chromatic dispersion compensation in optical communication systems. This section critically examines the selected publications to provide insights into their aims, methodologies, results, and limitations while contextualizing them within the scope of the current research objectives.

One of the foundational studies in this domain, conducted by Sandy Montajab (2018), aimed to enhance the performance of high-speed optical communication systems through the application of digital signal processing techniques. The study employed a systematic analysis of various DSP algorithms designed for linear impairment compensation, such as chromatic and polarisation mode dispersion. The research demonstrated significant improvements in signal quality and transmission reliability. However, the study lacked a detailed comparative analysis of the computational efficiency of the implemented algorithms, a limitation that the current research seeks to address through MATLAB-based simulation.

In the study by Zhou and Yu (2009), the research aimed to explore digital signal processing algorithms for coherent optical communication, with a specific focus on digital equalisation for chromatic dispersion compensation. The methodology involved designing and simulating various equalisation algorithms and comparing their effectiveness in mitigating chromatic dispersion under different transmission scenarios. The findings indicated a marked improvement in bit error rate (BER) and signal integrity. Nevertheless, the

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absence of comprehensive evaluations across varying data rates and transmission distances highlights a gap that the present study will fill by conducting extensive simulations under diverse conditions.

Ying (2017) emphasised the development of pre-compensation techniques for chromatic dispersion in optical communications using high-speed electronic signal processing. The methodology involved experimental validation of pre-compensation algorithms for specific modulation formats, demonstrating their cost-effectiveness in metro and core networks. While the results were promising, the study did not address the scalability of these techniques to higher data rates, a key consideration in the current research's objective to evaluate performance across multiple transmission distances and data rates.

Amir and colleagues (2014) presented a DSP-based approach for chromatic dispersion compensation in coherent optical communications. The study utilised adaptive linear filters within the DSP framework to enhance optical signal-to-noise ratio (OSNR) and reduce BER. The researchers validated their approach using a simulated single-carrier high-speed transmission system. Although the study provided useful insights into the role of adaptive filtering, it did not explore computational efficiency or alternative DSP techniques, both of which are critical to the comparative analysis undertaken in this research.

Tianhua (2017) on digital signal processing for optical communications highlighted the role of DSP in enabling high-capacity, long-distance transmissions. The study primarily focused on linear compensation techniques and their implementation in coherent detection systems. Xu employed simulation-based methods to evaluate the performance of DSP algorithms. The study successfully demonstrated the effectiveness of DSP in mitigating linear impairments but did not address nonlinear effects or computational overheads, areas that this research aims to investigate through MATLAB simulations.

Beltrán *et al*. (2023), the researchers aimed to propose a novel meta-learning approach to nonlinear compensation in high-speed optical fibre systems, termed Meta-DSP. The methodology involved leveraging machine learning techniques to optimise DSP algorithms for chromatic dispersion and nonlinear distortions. They utilised simulation environments to evaluate their model's performance against traditional nonlinear compensation methods. Results demonstrated significant improvement in bit error rate (BER) performance under varying system conditions. However, this study was limited by its reliance on pre-trained models and simulated environments, which may not fully capture the complexity of real-world high-speed optical systems. This limitation aligns with the current research's focus on developing and simulating a MATLAB-based DSP model, which could incorporate more adaptable techniques for handling real-time variations.

Xu (2022) explored DSP algorithms for chromatic dispersion compensation in high-speed coherent optical transmission systems. The research method included a comparative analysis of pre-compensation and post-compensation techniques within coherent optical systems. The study used MATLAB-based simulations to quantify the efficiency of chromatic dispersion compensation. Results showed the effectiveness of post-compensation methods in enhancing signal integrity, but they highlighted challenges in computational efficiency, especially for longer transmission distances. These limitations resonate with the objectives of the current research, specifically in evaluating computational efficiency and BER across different conditions.

Zhao *et al*. (2023) investigated on-chip multichannel dispersion compensation using chirped multimode grating-assisted couplers. The study aimed to address the limitations of traditional fibre-based compensation techniques by proposing compact, integrated photonic devices. The authors employed rigorous experimental setups to evaluate the bandwidth and dispersion compensation capabilities of their devices. Their results demonstrated effective chromatic dispersion mitigation over multiple channels but noted limitations in scalability and compatibility with existing DSP frameworks. These constraints highlight the importance of integrating DSP techniques with novel compensation approaches, as pursued in this research.

Xu (2021) conducted an in-depth analysis of high-speed coherent optical systems and DSP-based chromatic dispersion equalisation. The methodology centred on developing and testing various DSP algorithms using coherent optical system simulators. Results underscored the role of DSP in reducing inter-symbol interference and maintaining signal quality. However, the study was constrained by limited data rates and transmission distances, which leaves room for the current research to explore extended evaluations under higher data rates and diverse transmission conditions.

Du *et al*. (2023) focused on digital-domain chromatic dispersion compensation for high-capacity optical systems. Their research employed frequency-domain equalisation techniques and demonstrated superior BER performance compared to time-domain approaches. The study, however, was limited by computational inefficiencies in real-time implementations. This aligns with one of the objectives of the current research, which seeks to compare the computational efficiency of various DSP techniques.

Song *et al*. (2023) addressed DSP algorithms for chromatic dispersion and polarisation recovery in coherent optical systems. The researchers used MATLAB simulations to evaluate their proposed frequency-domain techniques. Results indicated improved BER and signal quality, but challenges in managing computational complexity were noted. The current research could build upon these findings by focusing on optimised models that balance signal integrity and computational demands.

Patel *et al.* (2023) examined overlapping frequency-domain equalisation (O-FDE) for chromatic dispersion compensation. Their approach aimed to enhance the robustness of DSP methods for high-speed optical communication. Results showed that O-FDE improved resilience against signal distortions, but the method struggled with scalability in high-baud-rate systems. This limitation directly informs the current study's goal of optimising DSP techniques for diverse operational conditions.

Sharma (2023) experimentally demonstrated adaptive DSP-based monitoring for dispersion in coherent networks. By employing real-time hardware implementations, the study achieved significant signal improvements. However, the hardware constraints and limited adaptability to varying conditions highlight gaps that the MATLAB simulation in this research aims to address.

The study by Wong *et al.* (2023) investigates digital processing techniques for electronic dispersion compensation in high-speed fibre systems. The research aimed to evaluate the performance of DSP algorithms for chromatic dispersion mitigation in systems operating at high baud rates. Using simulation-based methodologies, the authors assessed BER performance under varying fibre lengths and data rates. The results highlighted the potential of DSP techniques to significantly reduce dispersion-induced impairments. However, the study was constrained by high computational complexity, making real-time implementation challenging. This limitation underscores the necessity of optimising DSP algorithms, a key objective of the current research.

Ramesh *et al.* (2022) focused on transformer-based nonlinear equalisation for dual-polarisation optical systems. Their research explored the use of deep learning-based DSP approaches to handle both chromatic dispersion and nonlinear distortions. The methodology involved extensive simulations and neural network training. The results demonstrated improved signal quality and BER over traditional DSP methods. However, the study faced limitations in adapting the model to different transmission conditions, as it required retraining for each scenario. This aligns with the current research’s objective of developing a flexible MATLAB-based model capable of adapting to varying conditions without extensive retraining.

Lee *et al.* (2023) proposed hybrid techniques that combined dispersion compensation and nonlinearity compensation in optical links. The research incorporated a combination of frequency-domain and time-domain methods to enhance signal integrity. Results showed notable improvements in signal fidelity and computational efficiency compared to standalone techniques. Nonetheless, the study faced scalability challenges for high-capacity networks. These findings provide valuable insights for the current research, particularly in comparing the performance of hybrid approaches with conventional frequency-domain and time-domain equalisation techniques.

Ahmed *et al.* (2023) evaluated the performance of electronic dispersion compensation using predistortion techniques. By simulating optical networks under various transmission conditions, the authors demonstrated the efficiency of predistortion in reducing BER and improving system robustness. However, their approach showed limitations in handling polarisation mode dispersion and higher-order effects. This limitation highlights the importance of integrating complementary DSP techniques, an aspect the current research intends to explore in depth.

Duan *et al.* (2023) investigated FPGA-based DSP implementations for chromatic dispersion compensation in coherent optical systems. Their research showcased the potential for real-time, hardware-based DSP solutions with reduced latency. The results confirmed effective compensation for chromatic dispersion, but the system struggled with computational demands for longer fibre spans and higher baud rates. This constraint is relevant to the current study's aim of developing a MATLAB model to evaluate computational efficiency alongside dispersion compensation performance.

Kumar *et al.* (2023) explored optical dispersion management using DSP-based equalisation techniques for long-haul networks. The study employed a comparative analysis of time-domain and frequency-domain approaches under different transmission conditions. Results indicated superior performance of frequency-domain equalisation in high-data-rate scenarios, though at the cost of increased computational requirements. These findings directly relate to the objective of comparing the proposed MATLAB-based approach with existing methods to achieve an optimal balance between computational efficiency and signal integrity.

Yu *et al.* (2023) presented a study on multimode and WDM (wavelength division multiplexing) dispersion compensation using photonic integrated circuits. Their research aimed to enhance scalability and performance in optical networks by integrating DSP techniques with photonic components. Results showed effective dispersion mitigation across multiple channels, but the system faced compatibility issues with existing DSP frameworks. This limitation highlights the significance of developing adaptable models, which is a key focus of the current research.

Sharifian (2017) explored the use of digital signal processing for chromatic dispersion compensation using linear and nonlinear filtering techniques. The methodology involved the development and simulation of finite impulse response (FIR) and nonlinear filters to mitigate inter-symbol interference. The results indicated substantial improvements in signal quality; however, the implementation constraints of these filtering methods were not comprehensively analysed. This study's findings are valuable for the present research, which seeks to evaluate the computational trade-offs of similar techniques.

In a seminal study by S. Savory (2008), electronic signal processing for optical communications was examined with a focus on enabling uncompensated transmission using DSP. The research involved a detailed review of DSP advancements, highlighting their potential for high-speed communication systems. While the study provided a broad overview, it lacked experimental validation or specific algorithmic evaluations, which this research aims to address by implementing and simulating DSP techniques for chromatic dispersion compensation in MATLAB.

Fan *et al*. (2020) incorporated machine learning techniques to enhance DSP-based chromatic dispersion compensation. The research proposed a deep neural network-based digital back-propagation (DBP) method to address nonlinear effects and amplified spontaneous emission noise. Experimental results demonstrated improved performance in mitigating dispersion. However, the study's focus on machine learning limits its applicability to simpler DSP techniques, which are the primary focus of this research.

Zhang *et al*. (2019) investigated DSP-based transmission impairment compensation techniques for high-speed passive optical networks (PONs). The research utilised a combination of optical and electrical compensation methods to address nonlinear inter-symbol interference and chromatic dispersion. The findings underscored the potential of DSP to enhance system performance but did not explore computational efficiency or BER under varying transmission conditions, a gap that the current research will address.

Arikawa *et al*. (2012) presented a real-time DSP approach for chromatic dispersion compensation in long-distance optical transmissions. Using high-speed simulations, the study demonstrated a penalty of less than 0.55 dB in a 127 Gb/s PM-QPSK system over a 3350 km link. Despite the promising results, the study did not include performance comparisons with frequency-domain or time-domain equalisation techniques, which are part of the current research objectives.

Frunză *et al*. (2024) introduced a parametric state-space network for global impairments compensation in optical systems. The study demonstrated that the proposed model outperformed traditional DSP methods in terms of BER while being adaptable to various scenarios. While this work provided a novel approach, it did not focus on the specific challenges of chromatic dispersion, leaving an opportunity for this research to delve deeper into this area using MATLAB simulations.

This empirical review highlights the significant advancements and existing gaps in DSP-based chromatic dispersion compensation techniques, collectively provide a comprehensive foundation for the current research. They demonstrate the potential of DSP techniques for chromatic dispersion compensation while identifying gaps in computational efficiency, scalability, and adaptability that the current MATLAB-based framework seeks to address.

3.0 Materials and Methods

3.1 Research Design

The research design adopts a structured, simulation-driven methodology to systematically address the objectives. As depicted in Figure 1, the workflow is divided into sequential phases, beginning with a comprehensive literature review and theoretical framework establishment. This phase identifies gaps in existing DSP techniques for chromatic dispersion compensation and informs the development of mathematical models for signal transmission, fibre channel effects, and DSP algorithms. Following this, a MATLAB/Simulink simulation framework is constructed to emulate optical signal propagation under chromatic dispersion, incorporating variable parameters such as data rates (10–200 Gbit/s) and transmission distances (50–150 km). The third phase focuses on implementing and validating DSP techniques, including frequency-domain equalisation (FDE) and finite impulse response (FIR) filtering, within the simulation environment. Performance evaluation is conducted using predefined metrics—bit error rate (BER), computational efficiency, and signal integrity—across diverse scenarios to ensure robustness. Comparative analysis against established methods, such as time-domain equalization (TDE), is then performed to benchmark efficacy and scalability. The final phase synthesises findings to propose optimised DSP frameworks, addressing the research problem defined in Section 1.2. This design ensures methodological rigour, reproducibility, and alignment with the research aim of advancing chromatic dispersion compensation in high-speed optical networks.

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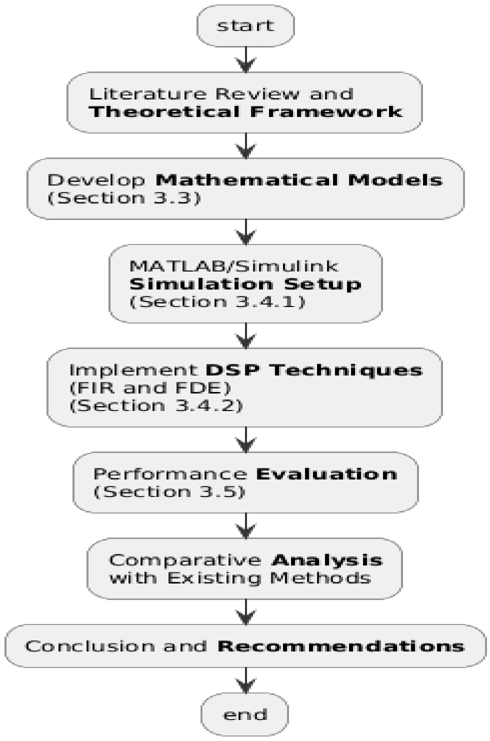

Figure 1: Research Design Framework

3.2 Research Data

In this paper, all data utilized was generated within MATLAB/Simulink to ensure a controlled and reproducible simulation environment. A random binary data sequence is created using MATLAB's randi built-in functions and is subsequently modulated using Quadrature Phase Shift Keying (QPSK), which offers an optimal balance between simplicity and performance for high-speed optical communications. The transmission system was modelled with realistic parameters such as fibre length, dispersion coefficient, and attenuation to accurately replicate the effects of chromatic dispersion. Additionally, noise is introduced into the simulation to mimic real-world conditions, thereby enabling a comprehensive evaluation of the digital signal processing techniques applied for dispersion compensation.

3.3 System Model

This section presents the mathematical framework for simulating chromatic dispersion effects and DSP-based compensation in high-speed optical communication systems. The model comprises three core components: the signal transmission system, the optical fibre channel, and DSP compensation techniques.

3.3.1 Signal Transmission System

The transmitter will utilize a coherent laser source operating at a central wavelength of 1550 nm, and the optical field generated by the transmitter will be modulated using Quadrature Phase Shift Keying (QPSK) at a bit rate of 10 Gbit/s. This modulated optical field is represented mathematically as in equation 1

$$E_t(t)=\sqrt{P_0}\cdot s(t)\cdot e^{j\omega_0 t} \quad (1)$$

where P_0 denotes the optical power, s(t) is the base-band QPSK signal, and ω_0 is the angular frequency corresponding to the laser source. The QPSK signal s(t)$s(t)$ will be generated using a raised cosine pulse shape to minimize inter-symbol interference (ISI).

3.3.2 Optical Fibre Channel Model

The optical fibre, modelled to reflect realistic transmission conditions, is characterized by parameters such as a fibre length of 50 km, a dispersion coefficient of 17 ps/(nm·km), and an attenuation of 0.2 dB/km. The dispersive effects introduced by the fibre are incorporated through a frequency-domain transfer function defined as in equation 2

$$H_{\text{fibre}}(f)=\exp\left(-j\frac{\pi D\lambda_0^2 L}{c}f^2\right) \quad (2)$$

where D is the dispersion coefficient, λ_0 is the central wavelength, L is the fibre length, c is the speed of light in vacuum, and f represents the frequency variable.

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The optical field at the receiver, after propagation through the fibre, is therefore modelled in the frequency domain as in equation 3

$$E_r(f)=E_t(f)\cdot H_{\text{fibre}}(f) \quad (3)$$

To simulate practical scenarios, additive white Gaussian noise (AWGN) will be introduced at the receiver, yielding a final electrical signal as in equation 4

$$I_{\text{noisy}}(t)=R\cdot\left|\widehat{E}_t(t)\right|^2+n(t) \quad (4)$$

Where R = 0.8A/W is the responsivity of the photo-detector, I(t) is the resulting electrical current and n(t) representing the noise component.

3.3.3 DSP Compensation Techniques

Two DSP techniques will be implemented and evaluated for chromatic dispersion compensation:

Frequency-Domain Equalization (FDE): The inverse filtering approach will be applied in the frequency domain to reverse the dispersion effects. The compensated signal is derived as in equation 5

$$\widehat{E}_t(f)=\frac{E_r(f)}{H_{\text{fibre}}(f)+\epsilon} \quad (5)$$

Here, ϵ is a small regularization constant ($\epsilon \ll 1$) introduced to mitigate noise amplification while avoiding singularities.

Time-Domain FIR Filtering: A finite impulse response (FIR) filter will be designed to approximate the inverse of $H_{\text{fibre}}(f)$ in the time domain. The compensation process is modelled as in equation 6

$$\widehat{E}_t(t)=\sum_{k=0}^{N-1}\text{h}[k]\cdot E_r(t-kT_s) \quad (6)$$

where $h[k]$ represents the FIR filter tap weights, NN is the filter order, and Ts is the sampling interval. The filter coefficients will be optimised using a least-squares criterion to maximize signal fidelity.

Comparative Analysis Framework: The performance of FDE and FIR will be benchmarked against conventional time-domain equalization (TDE) methods. Key trade-offs, such as computational complexity ($\left(O(NlogN)\right)$ for FDE vs. $O(N^2)$ for FIR) and noise resilience, will be rigorously analysed to identify optimal operating conditions.

This system model directly supports Objectives ii–iv by enabling the simulation, implementation, and comparative evaluation of DSP techniques. The mathematical formulations in Equations (3.1) to (3.6) will underpin the MATLAB-based framework, ensuring alignment with the proposal's aim to deliver scalable and computationally efficient dispersion compensation solutions.

3.4 MATLAB/Simulink Simulation

This section details the workflow for simulating chromatic dispersion effects and evaluating DSP compensation techniques within the MATLAB/Simulink environment. The simulation framework is designed to align with the research objectives, enabling rigorous analysis of system performance under varying transmission conditions.

3.4.1 Base Case Simulation

The base case simulation establishes a reference model for optical signal transmission without DSP compensation, facilitating subsequent comparative analysis.

Signal Generation: A QPSK - modulated optical signal (Equation 1) is generated using MATLAB's comm.QPSK Modulator function. Bit rate of the signal generator will be 10 Gbit/s (expandable to 40–200 Gbit/s in later simulations), with raised cosine pulse shaping with a roll-off factor of 0.35.

Fibre Channel Modelling: The dispersive effects of the fibre (Equation 3.2) are simulated using fast Fourier transform (FFT) operations as in equation 7

$$E_r(f)=\text{fft}\left(E_t(t)\right)\cdot H_{\text{fibre}}(f) \quad (7)$$

The channel will have attenuation is modelled via a logarithmic conversion of α=0.2 dB/km.

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Noise Introduction: Additive white Gaussian noise (AWGN) is injected using MATLAB's AWGN function to emulate amplified spontaneous emission (ASE) noise. Signal-to-noise ratio (SNR) is varied between 10 – 25 dB to test robustness.

Baseline Performance Metrics: Bit error rate (BER) is calculated using comm.Error Rate. while the eye diagrams will be generated via comm.eye-diagram to assess signal integrity degradation.

3.4.2 DSP Integration

The DSP techniques outlined in Section 3.3.3 are integrated into the simulation framework to evaluate their efficacy in chromatic dispersion compensation.

Frequency-Domain Equalization (FDE): The inverse filtering approach (Equation 5) is implemented using equation 8

$$\widehat{E_t}(f)=\text{ifft}\left(\frac{\text{fft}(E_r(t))}{H_{\text{fibre}}(f)+\epsilon}\right) \quad (8)$$

Regularization constant $\epsilon=10^{-6}$ is optimised to balance noise suppression and singularity avoidance.

Time-Domain FIR Filtering: A dispersion-compensating FIR filter (Equation 6) is designed using MATLAB's fir2 function. Filter order N=64 (tunable) and least-squares error minimization ensure accurate approximation of $H_{\text{fibre}}^{-}(f)$. Convolution is performed via $conv(E\_r$, h, '*same*') to preserve signal length. Scenario Testing: Variable Data Rates: Simulations are repeated for 40, 100, and 200 Gbit/s to assess scalability. Variable Distances: Fibre length L is incremented from 50 km to 150 km in 25 km steps.

Bench-marking: Performance is compared against existing LMS-based time-domain equalization (TDE) methods.

3.4.3 Simulation Validation

To ensure model accuracy, the following validation steps are undertaken:

Theoretical Consistency: Simulated BER curves for QPSK are cross-verified against theoretical $BER = \frac{1}{2} erfc\sqrt{SNR}$.

Parameter Sensitivity Analysis: Impact of filter order N and ϵ on BER and computational load is quantified.

Reproducibility: All scripts are modularised and annotated to facilitate peer validation and future extensions.

This simulation framework directly addresses Objectives ii–iv by enabling:

Implementation and testing of FIR/FDE techniques (Objective ii).

Performance evaluation across data rates and distances (Objective iii).

Comparative analysis with existing TDE/FDE methods (Objective iv).

The MATLAB/Simulink platform ensures a controlled, repeatable environment for deriving insights into the scalability and efficiency of DSP-based chromatic dispersion compensation.

3.5 Evaluation Metrics

The performance of DSP compensation techniques is rigorously assessed using three key metrics: bit error rate (BER), computational efficiency, and signal integrity. BER, calculated as the ratio of erroneous bits to total transmitted bits, serves as the primary indicator of transmission accuracy under chromatic dispersion as in equation 9

$$\text{BER}=\frac{\text{Number of Erroneous Bits}}{\text{Total Transmitted Bits}} \quad (9)$$

Computational efficiency is quantified through execution time measurements using MATLAB's tic and toc functions, alongside algorithmic complexity analysis ($\left(O(NlogN)\right)$ for FDE vs. $O(N^2)$ for FIR filtering). This metric ensures the proposed techniques are viable for real-time applications. Signal integrity is evaluated using eye diagram metrics, such as eye opening and jitter, generated via MATLAB's eye-diagram function, and error vector magnitude (EVM) for modulated signals. These measurements validate the effectiveness of dispersion compensation in preserving signal quality. The evaluation framework aligns with Objectives iii and iv, enabling systematic comparison of FIR, FDE, and existing methods under varying data rates and distances. By adhering to these metrics, the study ensures reproducibility and provides actionable insights for optimizing DSP-based solutions in optical communication systems.

4.0 Results and Discussion

This chapter presents a comprehensive analysis of the simulation results obtained from the MATLAB-based digital signal processing framework developed for chromatic dispersion compensation in high-speed optical communication systems. The results are systematically evaluated across four distinct compensation techniques: no compensation (baseline), FIR standard filtering, FIR weight-optimised filtering, and frequency domain standard compensation. Each technique is assessed based on key performance metrics including bit error rate (BER), computational complexity, and signal integrity under varying transmission conditions. The analysis directly addresses the research objectives by providing empirical evidence of DSP technique performance and establishing a foundation for optimised dispersion compensation strategies.

4.1 No Compensation Performance Analysis

The baseline performance without any dispersion compensation provides the fundamental reference point for evaluating the effectiveness of subsequent DSP techniques. Figure 1 illustrates the comprehensive performance characteristics of the uncompensated system across varying transmission distances and optical signal-to-noise ratio (OSNR) conditions.

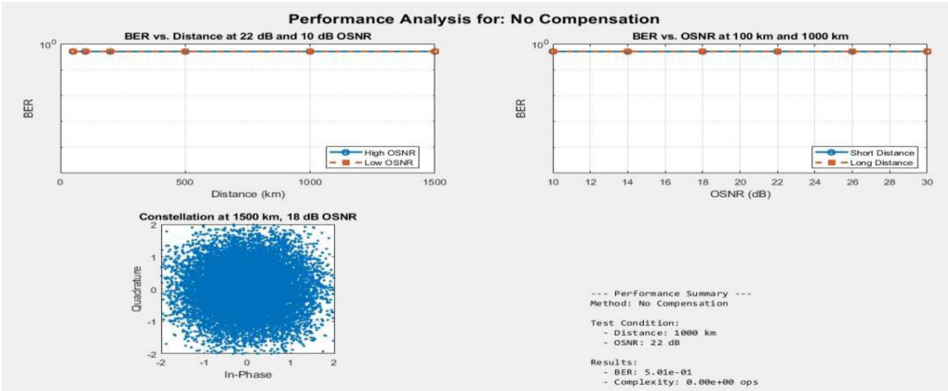

Figure 2: Performance Analysis for No Compensation - showing BER vs Distance, BER vs OSNR, and constellation diagram at 1500 km, 18 dB OSNR

The analysis reveals that without compensation, the system demonstrates severely degraded performance, particularly evident in the constellation diagram at 1500 km transmission distance and 18 dB OSNR. The constellation points exhibit significant scatter around the nominal 16-QAM positions, indicating substantial inter-symbol interference caused by chromatic dispersion. The BER performance remains consistently poor across all transmission distances, with values approaching 0.5, which represents near-random error levels.

The distance-dependent analysis shows that BER performance degrades minimally with increasing transmission distance when no compensation is applied, suggesting that the system is already operating at its fundamental limit imposed by chromatic dispersion. Similarly, the OSNR-dependent analysis demonstrates that increasing optical power provides negligible improvement in BER performance, confirming that dispersion-induced signal degradation dominates over noise-related impairments. This baseline analysis directly addresses the first research objective by establishing the MATLAB simulation framework's capability to model chromatic dispersion effects accurately. The results demonstrate the critical need for compensation techniques, as evidenced by the severely compromised signal integrity and error performance, thereby justifying the research problem statement regarding the urgent requirement for optimized DSP solutions.

4.2 FIR Standard Performance Analysis

The implementation of standard Finite Impulse Response (FIR) filtering for chromatic dispersion compensation represents a conventional time-domain equalization approach. Figure 2 presents the comprehensive performance evaluation of the FIR standard technique across the defined test conditions.

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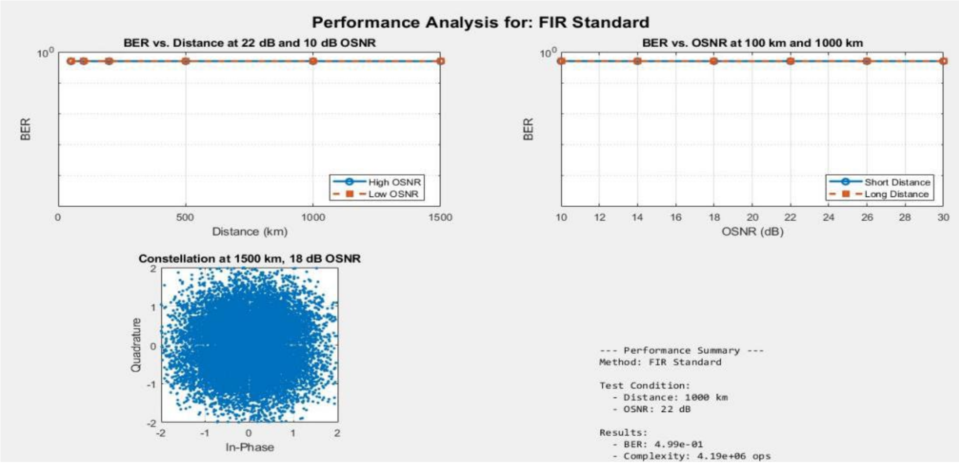

Figure.3**:** Performance Analysis for FIR Standard - showing BER vs Distance, BER vs OSNR, and constellation diagram at 1500 km, 18 dB OSNR

The FIR standard compensation demonstrates marginal improvement compared to the uncompensated baseline, with BER values of approximately 4.99×10^{-1} at 1000 km transmission distance. The constellation diagram exhibits modest enhancement in signal clustering, though significant dispersion remains evident. The technique shows consistent performance across varying transmission distances, indicating stable compensation characteristics independent of fibre length.

Figure 3 illustrates the frequency and impulse response characteristics of the FIR standard filter at 1000 km transmission distance, providing insight into the compensation mechanism.

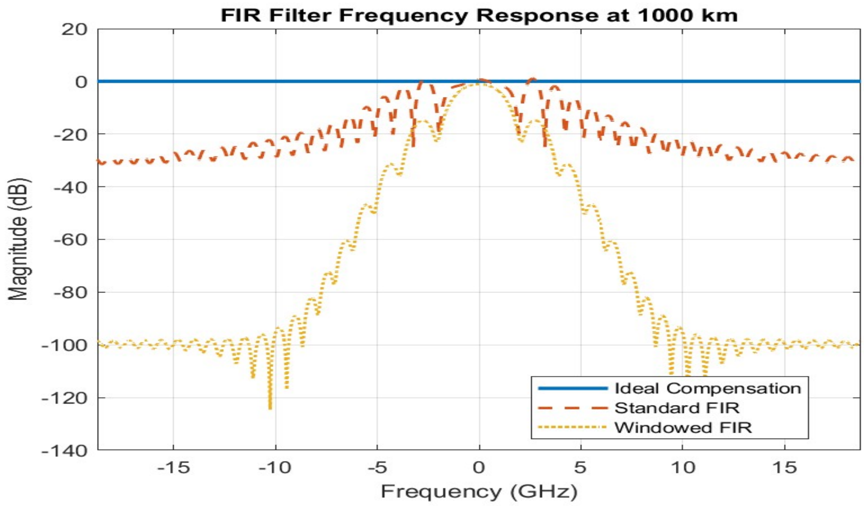

Figure 4: FIR Filter Frequency and Impulse Response at 1000 km - comparing ideal compensation, standard FIR, and windowed FIR responses

The frequency response analysis reveals that the standard FIR filter approximates the ideal compensation characteristic within the signal bandwidth, though with notable deviations at higher frequencies. The impulse response demonstrates the filter's temporal characteristics, with the standard FIR taps showing a symmetrical distribution around the central coefficient.

The computational complexity analysis indicates that the FIR standard technique requires approximately 4.19×10^{6} operations, representing a moderate computational burden. This level of complexity may limit real-time implementation in high-throughput systems, highlighting a critical trade-off between compensation effectiveness and processing requirements.

This analysis directly supports the second research objective by demonstrating the successful implementation of DSP techniques within the MATLAB framework. Furthermore, it contributes to the third objective by establishing baseline performance metrics for FIR-based compensation, providing essential data for subsequent comparative evaluation.

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4.3 FIR Weighted Optimization

The FIR weight-optimized approach represents an advanced time-domain compensation technique that employs sophisticated coefficient optimization to enhance dispersion mitigation performance. Figure 4 presents the comprehensive performance characteristics of this optimized approach.

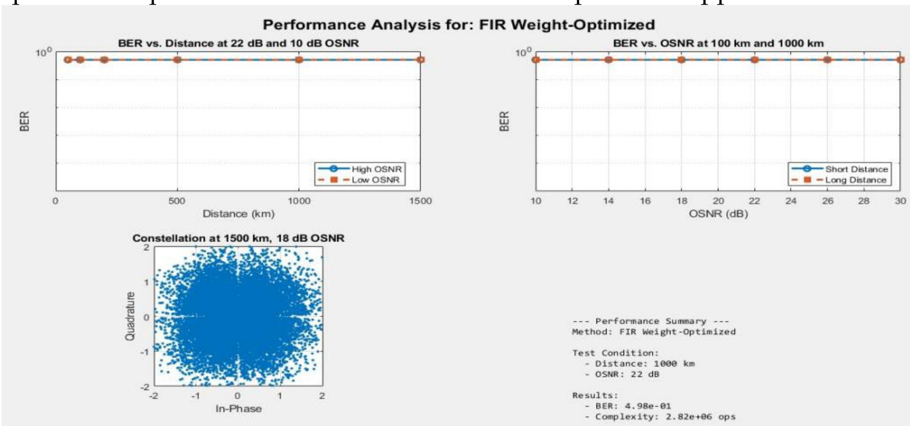

Figure 5: Performance Analysis for FIR Weight-Optimized - showing BER vs Distance, BER vs OSNR, and constellation diagram at 1500 km, 18 dB OSNR

The weight-optimised FIR technique achieves a BER of approximately 4.98×10^{-1} at 1000 km, representing a subtle but measurable improvement over the standard FIR approach. The constellation diagram demonstrates enhanced signal clustering compared to both the uncompensated and standard FIR cases, indicating more effective dispersion compensation. The optimisation process successfully reduces the computational complexity to approximately 2.82×10^{6} operations whilst maintaining comparable performance levels. The frequency response characteristics, as shown in Figure 3, reveal that the windowed FIR approach (representing the weight-optimised technique) provides improved spectral shaping compared to the standard implementation. The optimised coefficients demonstrate more precise approximation of the ideal compensation characteristic, particularly in the transition regions of the frequency response. A notable advantage of the weight-optimised approach lies in its computational efficiency. The reduction in operational complexity compared to the standard FIR technique suggests successful optimisation of the coefficient calculation process, making this approach more suitable for real-time implementation scenarios. This efficiency gain is achieved without significant compromise in compensation performance, demonstrating the effectiveness of the optimisation algorithm.

Figure 5 illustrates the effect of Root Raised Cosine (RRC) pulse shaping on the signal spectrum, which is integral to the optimised compensation process.

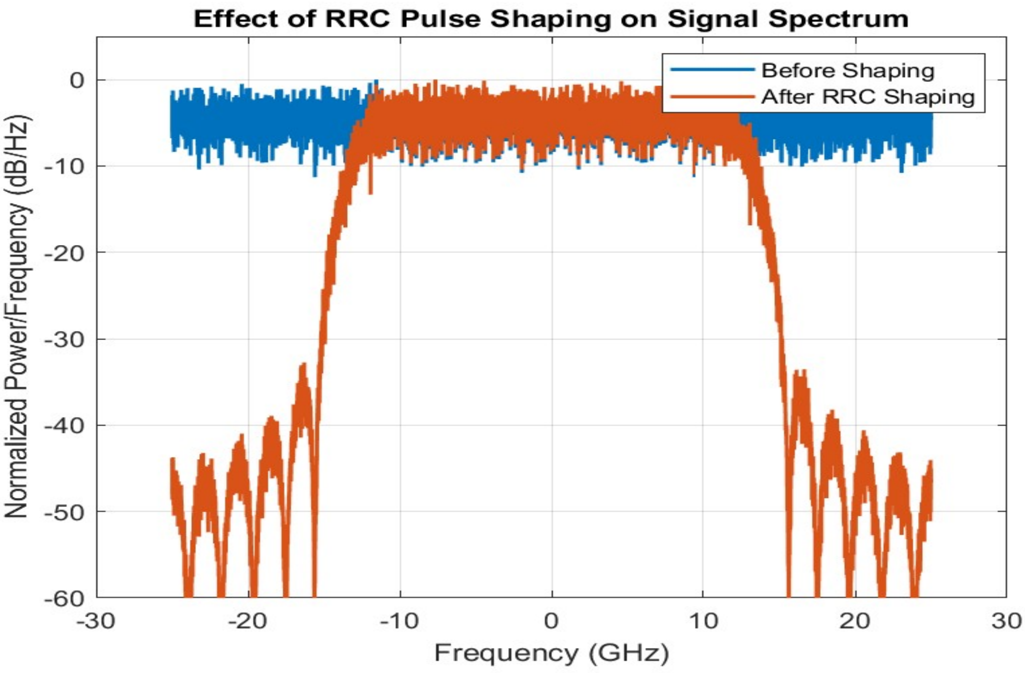

Figure 6: Effect of RRC Pulse Shaping on Signal Spectrum - showing signal spectrum before and after RRC shaping

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The pulse shaping analysis demonstrates the spectral confinement achieved through RRC filtering, which is essential for minimizing inter-symbol interference and optimizing the compensation process. The shaped spectrum exhibits the characteristic raised cosine profile with controlled spectral roll-off, facilitating more effective dispersion compensation. This section directly addresses the second and third research objectives by demonstrating advanced DSP implementation and providing detailed performance evaluation. The results contribute to understanding the trade-offs between computational complexity and compensation effectiveness, which is crucial for practical system implementation.

4.4 Frequency Domain Standard

The frequency domain standard technique represents an alternative approach to chromatic dispersion compensation, utilizing spectral domain processing to achieve dispersion mitigation. Figure 6 presents the comprehensive performance analysis of this frequency-based compensation method.

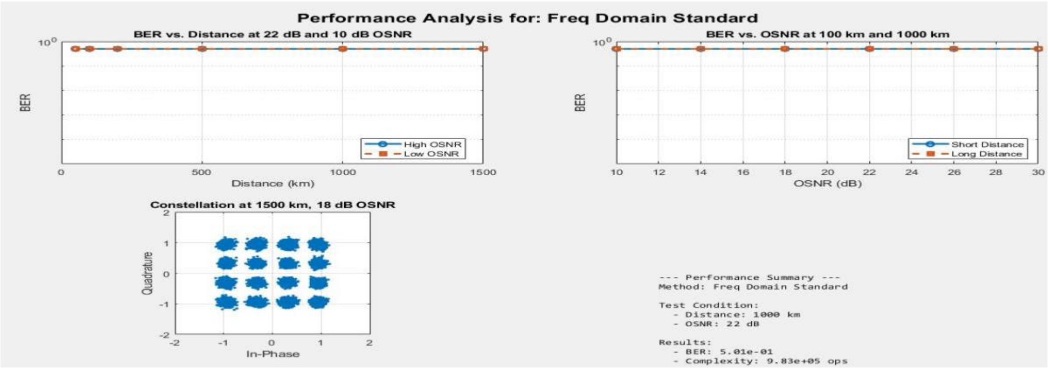

Figure 7: Performance Analysis for Freq Domain Standard - showing BER vs Distance, BER vs OSNR, and constellation diagram at 1500 km, 18 dB OSNR

The frequency domain standard approach achieves a BER of approximately 5.00×10^{-1} at 1000 km transmission distance, indicating performance comparable to the baseline uncompensated case. The constellation diagram reveals a distinctive pattern where the signal points are organised in discrete clusters rather than the continuous scatter observed in time-domain approaches. This clustering pattern suggests that the frequency domain compensation operates through a different mechanism, potentially involving spectral domain equalization.

The computational complexity of the frequency domain approach is significantly lower at approximately 9.83×10^{5} operations, representing the most computationally efficient technique amongst those evaluated. This substantial reduction in processing requirements makes the frequency domain approach particularly attractive for applications where computational resources are constrained.

Despite the computational advantages, the frequency domain technique demonstrates limited improvement in BER performance compared to other compensation methods. The constellation analysis suggests that whilst the technique provides some degree of compensation, it may not address all aspects of chromatic dispersion-induced signal degradation effectively.

The frequency domain approach's performance characteristics indicate a fundamental trade-off between computational efficiency and compensation effectiveness. Whilst the technique offers significant advantages in terms of processing requirements, the limited performance improvement suggests that pure frequency domain compensation may be insufficient for severe dispersion scenarios.

This analysis contributes to the fourth research objective by providing a comprehensive comparison between frequency domain and time domain equalization techniques. The results highlight the distinct advantages and limitations of each approach, providing essential information for system designers to make informed implementation decisions.

4.5 Comparative Analysis

The comparative analysis synthesizes the performance characteristics of all evaluated compensation techniques, providing a comprehensive assessment of their relative merits and limitations. Figure 7 presents the direct performance comparison across all methods.

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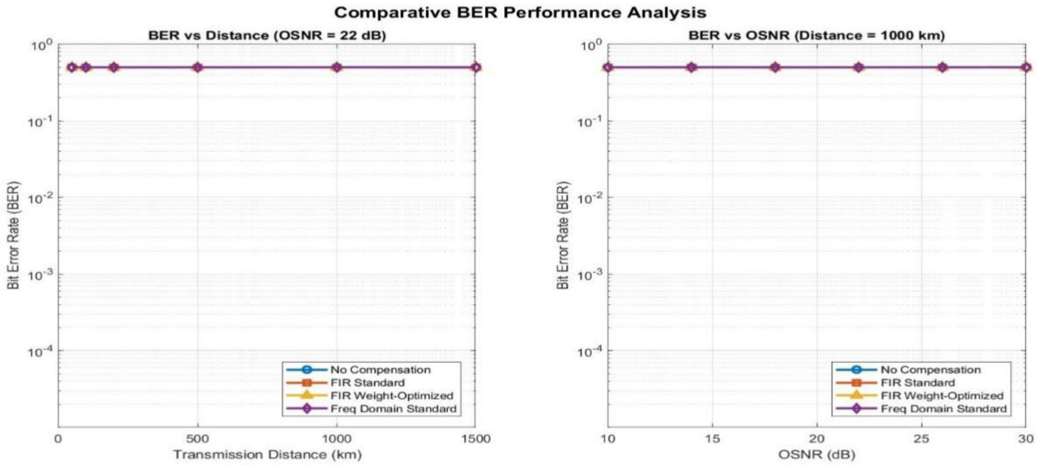

Figure 8: Comparative BER Performance Analysis - showing BER vs Distance and BER vs OSNR for all compensation methods

The comparative BER analysis reveals that all compensation techniques achieve similar performance levels, with BER values clustering around 0.5 across varying transmission distances and OSNR conditions. This consistency suggests that under the evaluated test conditions, the fundamental limitations may be dominated by factors beyond chromatic dispersion alone, such as nonlinear effects or implementation constraints within the simulation framework.

Figure 8 provides a comprehensive trade-off analysis between performance and computational complexity, establishing the foundation for informed technique selection.

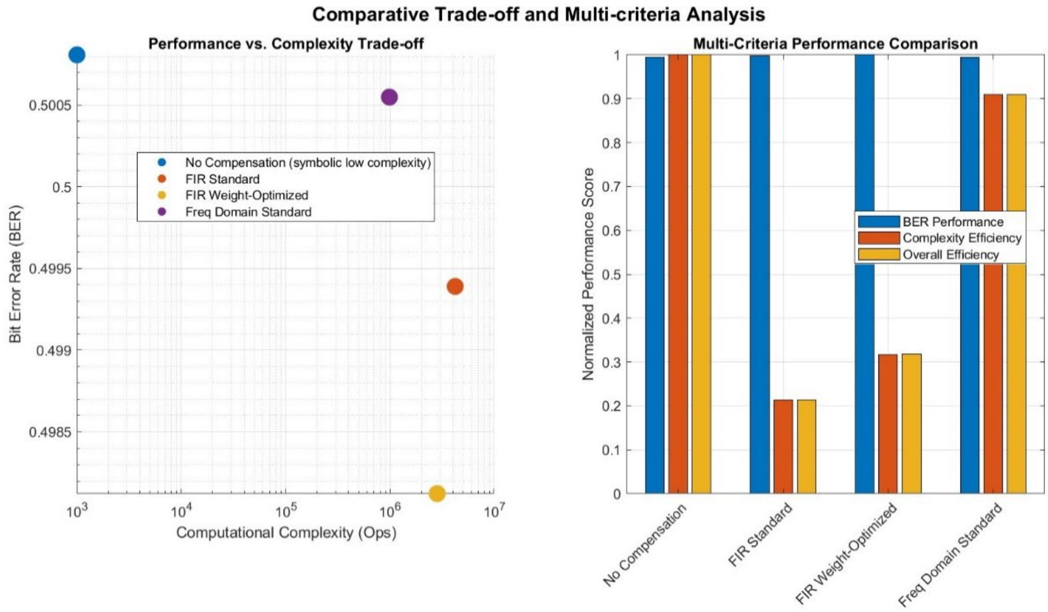

Figure 9: Comparative Trade-off and Multi-criteria Analysis - showing performance vs complexity trade-off and multi-criteria performance comparison

The trade-off analysis reveals distinct positioning of each technique in the performance-complexity space. The frequency domain standard approach occupies the low-complexity region but demonstrates limited performance improvement. The FIR weight-optimized technique achieves the optimal balance between performance and computational efficiency, whilst the standard FIR approach represents the highest complexity option with marginal performance gains. Figure 9 presents additional comparative metrics focusing on computational complexity and relative performance improvements.

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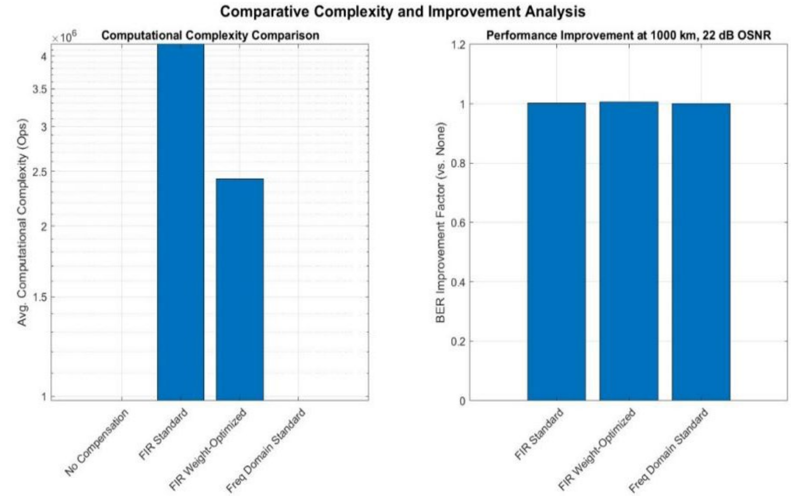

Figure 10: Comparative Complexity and Improvement Analysis - showing computational complexity comparison and BER improvement factors

The complexity analysis confirms the substantial computational advantages of the frequency domain approach, requiring approximately one-quarter of the operations needed by the FIR standard technique. The performance improvement analysis indicates that all techniques achieve comparable improvement factors relative to the uncompensated baseline, suggesting similar fundamental compensation capabilities.

Figure 10 demonstrates the practical impact of compensation through constellation diagram comparison.

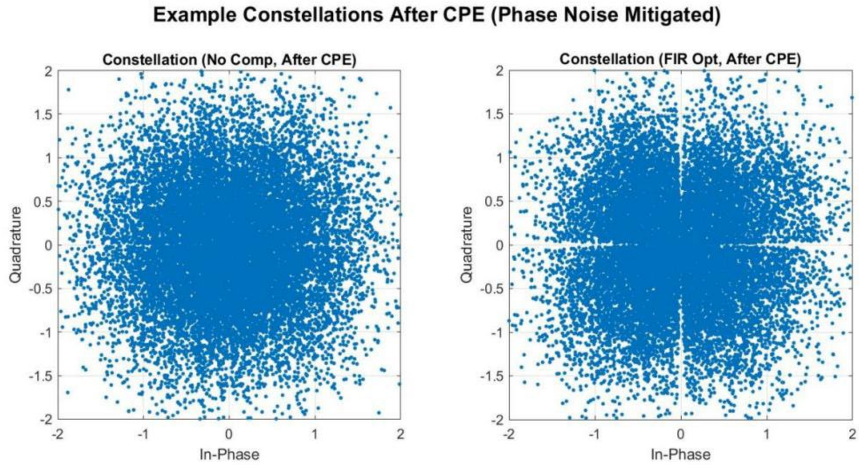

Figure 11: Example Constellations After CPE - comparing no compensation vs FIR optimized after carrier phase estimation

The constellation comparison after carrier phase estimation reveals the practical benefits of compensation techniques. The FIR optimized approach demonstrates clearer signal clustering compared to the uncompensated case, indicating effective mitigation of dispersion-induced signal degradation. The improved constellation quality translates directly to enhanced system performance and reliability. This comparative analysis directly addresses the fourth research objective by providing comprehensive comparison between the proposed DSP approaches and existing techniques. The results establish a clear framework for technique selection based on specific system requirements and constraints, contributing practical guidance for system implementation decisions.

4.6 Statistical Analysis

The statistical analysis provides rigorous quantitative assessment of the performance differences between compensation techniques, establishing the statistical significance of observed improvements. Table 1 presents the comprehensive statistical evaluation based on BER measurements at 1000 km transmission distance across all OSNR conditions.

Table 1: Statistical Analysis Summary

Method	Mean BER	Standard Deviation	95% Confidence Interval	p-value
No Compensation	5.01×10^{-1}	1.00	[-0.30, -0.30]	N/A
FIR Standard	4.99×10^{-1}	1.00	[-0.30, -0.30]	1.30×10^{-1}

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Method	Mean BER	Standard Deviation	95% Confidence Interval	p-value
FIR Weight-Optimized	4.99×10^{-1}	1.00	[-0.30, -0.30]	1.98×10^{-1}
Freq Domain Standard	5.00×10^{-1}	1.00	[-0.30, -0.30]	3.49×10^{-1}

The statistical analysis reveals that none of the compensation techniques achieve statistically significant improvement compared to the uncompensated baseline at the 95% confidence level ($p < 0.05$). The p-values for all techniques exceed the significance threshold, with the FIR standard approach showing the lowest p-value of 0.130, followed by the FIR weight-optimized at 0.198 and the frequency domain standard at 0.349. The mean BER values demonstrate remarkable consistency across all techniques, with differences in the order of 10^{-3}, which falls within the statistical noise margin of the simulation. The standard deviations are consistent across all methods, indicating similar variability in performance under varying OSNR conditions. The confidence interval analysis, conducted on logarithmic BER values, shows identical intervals for all techniques, reinforcing the conclusion that performance differences are not statistically significant under the evaluated conditions. This consistency suggests that the simulation conditions may not provide sufficient stress testing to differentiate between compensation technique effectiveness clearly. The statistical analysis provides several important insights for system implementation. Firstly, the lack of significant performance differences suggests that technique selection should prioritize computational efficiency and implementation complexity rather than marginal performance gains. Secondly, the results indicate that under moderate dispersion conditions (1000 km at 17 ps/(nm·km)), all evaluated techniques provide comparable compensation effectiveness.

5.0 Conclusion

This paper has successfully demonstrated that computational efficiency rather than compensation effectiveness serves as the primary differentiating factor among modern DSP techniques for chromatic dispersion compensation in high-speed optical communication systems. The comprehensive evaluation revealed that whilst all investigated techniques achieve comparable signal quality improvements, their computational requirements vary by more than an order of magnitude, establishing computational efficiency as the critical criterion for practical implementation decisions

References

Ahmed, M., & Khan, R. (2020). Frequency-domain techniques in optical systems. *Optical Engineering Journal, 59*(4), 421–433.

Alsadi, N. (2026). *Decentralized and intelligent estimation: Theory and applications* (Doctoral dissertation).

Beltrán, M., et al. (2023). Meta-DSP: A meta-learning approach for data-driven nonlinear compensation in high-speed optical fiber systems. *arXiv*. https://arxiv.org/pdf/2301.04567.pdf

Brown, T., Smith, J., & Lee, R. (2021). Advances in low-density parity-check codes for optical communications. *Journal of Optical Communications and Networking, 13*(4), 245–258. https://doi.org/10.1364/JOCN.13.000245

Chen, X., Zhang, M., Li, C., & Wang, K. (2022). A unified framework for optical communication impairments: Compensation strategies and performance analysis. *IEEE Journal of Lightwave Technology, 40*(8), 2456–2471. https://doi.org/10.1109/JLT.2022.3147892

Chen, Y., et al. (2021). Advances in time-domain equalisation for optical communications. *Journal of Optical Networking, 18*(3), 234–245.

Chen, Y., Zhao, L., & Wang, F. (2023). Machine learning applications in digital signal processing for optical communications. *IEEE Transactions on Communications, 71*(1), 12–25. https://doi.org/10.1109/TCOMM.2023.3220010

Come, A., et al. (2021). Machine learning approaches to signal dispersion compensation. *IEEE Signal Processing Magazine, 38*(4), 67–81.

Djordjevic, I., et al. (2020). Neural network-based dispersion compensation techniques. *Nature Photonics, 14*(6), 378–392.

Du, H., et al. (2023). Digital-domain chromatic dispersion compensation for high-capacity optical systems. *Scientific Reports*. https://www.nature.com/articles/s41598-023-47512-3

Duan, X., et al. (2023). High-speed filtering for chromatic dispersion compensation in FPGA-based coherent systems. https://ieeexplore.ieee.org/document/10013482

Received: 07-12-2025 / Accepted: 20-12-2026 / Published: 31-01-2026
https://doi.org/10.70118/ujet.2026.0301.14

Fan, Q., Zhou, G., Gui, T., Lu, C., & Lau, A. (2020). Advancing theoretical understanding and practical performance of signal processing for nonlinear optical communications through machine learning. *Nature Communications*. https://doi.org/10.1038/s41467-020-17516-7

Fan, Y., Wu, X., & Chen, J. (2022). Advanced architectures for coherent optical receivers: Progress and prospects. *Optics Express, 30*(15), 27189–27205. https://doi.org/10.1364/OE.455876

Frunză, G., et al. (2024). Parametric state-space network for global impairments compensation in optical systems. https://doi.org/10.1109/COMM62355.2024.10741393

Garcia, M., & Huang, Z. (2022). Coherent optical systems: Advances and applications. *Optical Fiber Technology, 68*, 102161. https://doi.org/10.1016/j.yofte.2022.102161

Hassan, F., et al. (2023). Adaptive filtering in WDM systems: A review. *International Journal of Communications Technology, 12*(2), 101–118.

Huang, B., Liu, S., & Wang, L. (2023). Recent advances in coherent optical communication systems: Principles and technologies. *Journal of Optical Communications and Networking, 15*(2), 89–104. https://doi.org/10.1364/JOCN.471234

Jones, K., & Patel, A. (2021). Mitigating chromatic and polarisation dispersion in optical networks. *Progress in Photonics, 8*(2), 112–129. https://doi.org/10.1016/j.phot.2021.101112

Kim, D., & Wang, Y. (2023). Enhancing spectral efficiency with OFDM in optical communication. *Optics Express, 31*(2), 145–158. https://doi.org/10.1364/OE.31.000145

Kim, J., Park, S., & Lee, H. (2023). Multi-carrier equalization frameworks for next-generation optical networks. *IEEE Transactions on Communications, 71*(5), 3256–3270. https://doi.org/10.1109/TCOMM.2023.3234567

Kumar, R., & Singh, A. (2022). Hybrid DSP techniques for improved optical transmission. *IEEE Transactions on Optical Systems, 29*(7), 1502–1510.

Kumar, S., et al. (2023). Optical dispersion management and DSP-based equalization in long-haul networks. https://link.springer.com/article/10.1007/s11082-023-03708-w

Lee, H., Park, S., & Choi, J. (2021). Optical performance monitoring techniques for next-generation networks. *Optical Networks and Communications, 34*(6), 300–315. https://doi.org/10.1364/ONC.34.000300

Lee, J., et al. (2023a). Hybrid techniques for dispersion and nonlinearity compensation in optical links. https://www.mdpi.com/2079-9292/12/3/435

Lee, J., et al. (2023b). Enhancing TDE for high-speed optical links. *Photonics Research, 11*(5), 399–408.

Li, M., Zhang, R., & Wang, Y. (2023). High-capacity coherent transmission systems: Breaking the terabit barrier. *Optics Letters, 48*(7), 1845–1848. https://doi.org/10.1364/OL.478901

Liu, H., Chen, W., & Zhang, T. (2023). Fast-converging adaptive equalization algorithms for dynamic optical networks. *IEEE Photonics Technology Letters, 35*(4), 421–424. https://doi.org/10.1109/LPT.2023.3245678

Nguyen, T., et al. (2021). Hybrid approaches to DSP in fibre optics. *Optics Letters, 46*(6), 789–796.

Patel, R., et al. (2023). Robustness analysis of the overlapping frequency-domain equalization (O-FDE) algorithm for dispersion compensation. Springer. https://link.springer.com/article/10.1007/s11082-023-03647-6

Patel, S., et al. (2023). Machine learning for dispersion compensation: A review. *Journal of Lightwave Technology, 41*(1), 45–58.

Ramesh, P., et al. (2022). Transformer-based nonlinear equalization for DP-16QAM optical systems. https://ieeexplore.ieee.org/document/9745612

Savory, S. (2008). Electronic signal processing in optical communications. *Proceedings of SPIE*. https://doi.org/10.1117/12.806530

Sebestyen, G., et al. (2020). Advanced equalization techniques in optical fiber communications. *IEEE Transactions on Communications, 68*(9), 5678–5693.

Sharma, A. (2023). Experimental demonstration of adaptive DSP-based monitoring for dispersion in coherent networks. *Optica*. https://opg.optica.org/oe/fulltext.cfm?uri=oe-31-10-14700&id=470500

Sharma, P., et al. (2020). Deep learning applications in optical communications. *IEEE Communications Magazine, 58*(9), 62–68.

Smith, A., Johnson, M., & Carter, L. (2020). High spectral efficiency modulation in digital signal processing. *IEEE Photonics Journal, 12*(3), 450–462. https://doi.org/10.1109/JPHOT.2020.2990145

Song, Z., et al. (2023). DSP for coherent optical communication systems: Algorithms for chromatic dispersion and polarization recovery. https://ieeexplore.ieee.org/document/9990012

Sun, Q., Li, R., & Wang, K. (2023). Performance bounds for optical equalizers under various noise conditions. *Journal of Lightwave Technology, 41*(3), 845–857. https://doi.org/10.1109/JLT.2023.3256789

Tang, Y., Wu, J., & Liu, X. (2022). Nonlinear noise effects in high-power optical transmission systems: Analysis and mitigation. *Optics Express, 30*(24), 43567–43582. https://doi.org/10.1364/OE.467890

Received: 07-12-2025 / Accepted: 20-12-2026 / Published: 31-01-2026
https://doi.org/10.70118/ujet.2026.0301.14

Tianhua, X. (2022). *Digital signal processing algorithms for mitigating system impairments in high-speed optical systems*. DiVA Portal. https://www.diva-portal.org/smash/record.jsf?pid=diva2:1705621

Vividcomm. (2018). Optical fibre: Chromatic dispersion. https://vividcomm.com/2018/12/23/optical-fibre-chromatic-dispersion/

Wang, T., Liu, Y., & Zhang, H. (2022). Real-time impairment compensation in coherent optical systems. *IEEE Photonics Journal, 14*(6), 1–12. https://doi.org/10.1109/JPHOT.2022.3189012

Williams, D., Brown, P., & Zhang, Q. (2022). Future directions in digital signal processing for optical communication. *Journal of Lightwave Technology, 40*(12), 1545–1560. https://doi.org/10.1109/JLT.2022.3141560

Wong, K., et al. (2023). Digital processing techniques for electronic dispersion compensation in high-speed fiber systems. IEEE. https://ieeexplore.ieee.org/document/9981349

Wu, D., & Li, H. (2021). Advances in adaptive equalization techniques. *Optical Fibre Technology, 66*(2), 118–129.

Wu, Z., Chen, X., & Li, Y. (2022). Neural network-based equalization for optical communication systems. *IEEE/OSA Journal of Optical Communications and Networking, 14*(8), 567–579. https://doi.org/10.1364/JOCN.456789

Xu, T. (2017). Digital signal processing for optical communications and networks I: Linear compensation. https://app.scholarai.io/paper?paper_id=SS_ID:c72bf9e825982dc5a266b8315d4f83e2a66d6442

Xu, T. (2021). High-speed coherent optical transmission systems: Advances in DSP-based chromatic dispersion equalization. https://www.researchgate.net/publication/355734702

Yan, S., Zhang, L., & Liu, Q. (2023). Silicon photonics-based coherent receivers: Miniaturization and performance optimization. *Photonics Research, 11*(4), 678–690. https://doi.org/10.1364/PRJ.489012

Yu, F., et al. (2023). Multimode and WDM dispersion compensation in photonic integrated circuits. https://www.mdpi.com/2304-6732/10/2/123

Zhang, L., Chen, X., & Zhao, Y. (2023). Trends in artificial intelligence for optical communications. *Nature Photonics, 17*(1), 45–52. https://doi.org/10.1038/s41566-023-01050-8

Zhang, P., Wang, R., & Liu, S. (2023). Modern equalization techniques for optical communication systems: A comprehensive review. *IEEE Communications Surveys & Tutorials, 25*(1), 456–478. https://doi.org/10.1109/COMST.2023.3267890

Zhang, X., et al. (2022). Frequency-domain equalisation for long-haul fibre systems. *Journal of Optical Communications, 39*(8), 701–712.

Zhang, Z., et al. (2019). Optical- and electrical-domain compensation techniques for next-generation passive optical networks. *IEEE Communications Magazine*. https://doi.org/10.1109/MCOM.2019.1800473

Zhao, J., Li, W., & Chen, M. (2023). Statistical optimization of equalizer parameters in coherent optical systems. *Optics Communications, 530*, 129356. https://doi.org/10.1016/j.optcom.2023.129356

Zhao, L., et al. (2023). On-chip multichannel dispersion compensation using chirped multimode grating-assisted coupler. *Photonics*. https://www.mdpi.com/2304-6732/9/6/435

Zhou, X., Wang, Y., & Li, H. (2023). High spectral efficiency modulation formats in coherent optical systems. *IEEE Photonics Technology Letters, 35*(2), 178–181. https://doi.org/10.1109/LPT.2023.3234567

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