INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

ORIGINAL ARTICLE

OPEN ACCESS
Received: 11/04/2025
Accepted: 08/05/2025
Published: 06/07/2025

Citation: Dhadhal D, Mishra V, Thummar R (2025) Examining the Functionality and Application of a 32-Channel CSRZ Modulation System with a Gaussian Filter and Narrow Channel Spacing at 1.28 TB of Data Transfer. Indian Journal of Science and Technology 18(25): 2040-2046. https://doi.org/10.17485/IJST/v18i25.663

* **Corresponding author**.

yogadharmendra@gmail.com

Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Examining the Functionality and Application of a 32-Channel CSRZ Modulation System with a Gaussian Filter and Narrow Channel Spacing at 1.28 TB of Data Transfer

Dharmendra Dhadhal[1]*, Vivekanand Mishra[2], Ruturaj Thummar[1]

1 C.U. Shah University, Wadhwan City, Surendranagar, Gujarat, India
2 Department of Science, Alliance University, Bangalore 562106, Karnataka, India

Abstract

Objectives: This research work assesses the effect of DWDM adopting carrier suppressed return to zero (CSRZ) format on a 32 channel system with regard to Laser power levels and channel spacing. **Methods:** Simulations were done on a 32-channel DWDM system implemented at 40 Gbps per channel over a single mode fiber of length 6000 km. The channel spacings used in the tests were 30 GHz, 40 GHz and 50 GHz and the CW laser power levels was varied between -5dBm and 10 dBm. The system was also studied based on performance evaluation by using of Gaussian optical filtering. The BER and Q-factor are two key performance indicators utilized for the analysis of the presented optical receivers. No additional data set was used, all simulations were performed using OptiSystem tool available in LTR. **Findings:** At 30 GHz channel spacing and 10 dBm laser power, the used system attained an improvement of Q-factor of almost 28% and BER reduced to 2 orders of magnitude lesser when compared to unfiltered systems. Gaussian filtering improved system tolerance to nonlinearities especially with the suggested geometries where the inter-channel crosstalk dominates at narrower spacing. In Hitting the optimal Q-factor of 14.2 is said to be achieved at the same value of 5.6×10^{-11} of BER. **Novelty:** The research utilizes measurable outcomes to show that Gaussian filtering effectively reduces nonlinear effects at both close channel interspacing combined with high power levels in a rarely studied field. The research presents groundbreaking findings about an appropriate method to boost spectral efficiency and ensure transmission quality for future high-density DWDM systems.

Keywords: BER (Bit error rate); Dispersion compensated fiber; Q-element; Carrier suppressed return-to-zero; Eye opening

1 Introduction

Research investigations into DWDM system performance enhancement took place during the previous decade through the development of advanced modulation methods with dispersion compensation mechanisms and nonlinear distortions reduction technologies. Yao et al.[1] together with Mishra et al.[2] performed studies which analyzed NRZ and RZ with CSRZ formats in DWDM systems while highlighting how dispersion management impacts long-distance transmission. An evaluation of dispersion compensation methods coupled with modulation performance assessment under nonlinear influences was done by Ranathive et al.[3] and Ali et al.[4]. These research studies proved that CSRZ format delivers better signal integrity outcomes, but their assessments mostly examined power levels that were not excessive while using channel spacing that exceeded narrow specifications. Research by Mishra et al.[5] together with works from Onidare et al.[6] and Sayed et al.[7] established fundamental dispersion management knowledge but focused primarily on symmetric or post-compensation methods without conducting systematic analysis for channel spacing effects at high power levels. The DWDM system designs introduced by G. J.S. and Sharma[8] with D. D., Mishra V., and Thummar R.[9] demonstrated DWDM resistance to impairments through CSRZ and MDRZ formats yet they failed to evaluate the dual effects of 30 GHz channel spacing and +10 dBm launch power.

Thummar and Dhadhal[10] also looked at DWDM performance variations with different power levels but these studies focused primarily on 64 channel systems with rather moderate channel spacings. S. M. et al.[11] investigated under different environmental conditions than under DWDM fiber system for underwater optical communication using CSRZ, NRZ, and AMI modulation format implying that modulation schemes are applicable to wider range of situations. In recent works, Thakur and Bharti[12] and Mishra et al.[13] have discussed the comparison of CSRZ, duobinary, MDRZ and VSB-CSRZ modulation schemes in WDM and RoF systems and shown that VSB-CSRZ modulation scheme outperforms others at some spacings. Yet the upper limit of such a study using a Gaussian optical filtering technique along with higher power and dense DWDM system remains insufficiently addressed.

Moreover, various innovative transmission schemes, i.e., CSRZ OTDM descriptors from Yamazaki et al.[14] and many examples for CSRZ to NRZ format converters, have been successfully developed, achieving great increases in system scalability and spectral efficiency. Nevertheless, most of these studies were focused on OTDM or few mode fiber systems, rather than dense channel packing within DWDM. Ejaz et al.[15] also investigated CSRZ and additional formats in FSO systems and found that CSRZ is resilient to atmospheric turbulence however, the findings pertinent to dense DWDM fiber environments cannot be directly applied. Consequently, there is a critical research gap in that the detailed studies of simultaneous impact of 30 GHz narrow channel spacing, high input laser powers (+5 dBm to +10 dBm), and utilization of Gaussian filtering to eliminate nonlinearities and improve transmit performance have not yet been made for long haul DWDM systems. However, existing literature mostly analyzes these factors apart, and not in ultra dense regimes under realistic regime of high power transmission.

Previous research has demonstrated the performance advantages of CSRZ and its variants and is in the process of exploring different dispersion management strategies while the combined effect of Gaussian spectral shaping, fine channel spacing and elevated optical powers on 32-channel CSRZ-DWDM systems is not sufficiently explored. The importance of filling this gap lies in the ability it provides to realize the highest spectral efficiency, to suppress the nonlinear crosstalk, and to extend this transmission reach for next generation ultra dense and high capacity optical networks. Existing works review shows that although CSRZ and dispersion compensated DWDM techniques have improved DWDM performance, but the whole problem regarding dense channel spacing, high launch power handling, and spectral management based on filtering has not been solved yet. This gap is bridged by the proposed study that systematically characterizes system performance metrics such as Q factor and BER under tight packing of channels and high power levels when Gaussian filtering is applied. We adopt a CSRZ modulation technique with very low channel spacing in the construction of the DWDM communication system in this simulation experiment. For DWDM communication, the channel spacing between 30GHz and 50GHz is more difficult. Additionally, we employ 32 channels, individually with a data rate of 40Gbps, for a total data transmission rate of 1.28Tbps. Over a total long-haul distance of 6000 kilometers, we saw an impact on the Quality factor and BER. As seen in **equation 1**, the BER displays the over performance of the number of errors in a certain bit of the Q dynamic.

$$BER = \frac{1}{-2} erfc\left(\frac{Q}{\sqrt{2}}\right) \tag{1}$$

2 Methodology

The SMF OSNR effect compounds the situation in DWDM communication systems by increasing signal bandwidth when optical transmission begins. We employed various laser power levels, ranging from -5dBm to 10dBm, to test the impact of OSNR. In this study, we demonstrate OSNR behavior at 6000 kilometers. (https://optiwave.com/optisystem-overview/.)

2.1 Simulation of the 32-channel DWDM model of CSRZ modulation

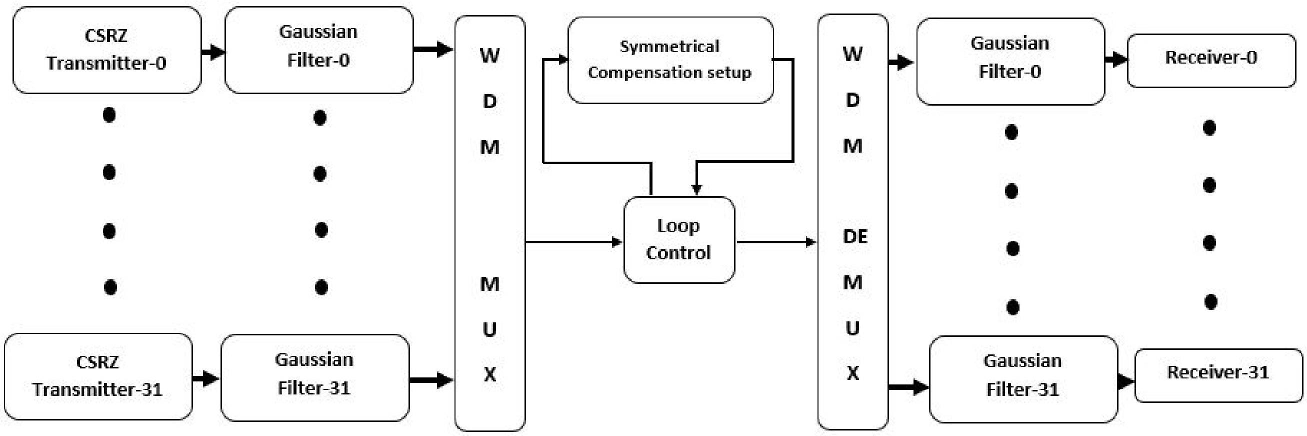


Fig 1. DWDM connection concept with symmetric block design for 32 channels

The 32 optical channel networks we used in this simulation work were primarily split into three sections: A 32-channel transmitter was the first, followed by a single-mode fiber that included a DCF, optical amplifier, and other components, and an optical receiver. All of this was done using a central frequency of 193.1 THz. We employ a statistics amount of 40 Gbps per frequency in this simulation. The system utilizes 32 samples per bit for reliable signal representation, and it employs a series with a length of 256. We set a channel spacing of 30, 40, or 50 GHz for the transmission portion. We set varying CW laser power levels, extending from -5 to 10 dBm. We demonstrated using SMF that the overall channel data capacity is 1.28 Tbs. Different CW laser power levels are adjusted by us, such as -5, 0, 5, 6 , or 10 dBm.

2.2 The transmitter that uses optical

We employ 30 dB extinction ratio Mach-Zender intensity modulators, continuous wave lasers that produce evenly organized frequencies between 193.1 and 192.2 THz and a PRBS producer that produces pseudo casual bit arrangements with a length of 2^7-1bit at 40 Gbps each continuous wave laser output is associated to a data modulation and the visual indications that come from these 32 data regulators are direct sent in the 32 input ports of an visual multiplexer.

2.3 The medium of visual transmission

This simulation uses an SMF to send 32 distinct optical signals that have been mixed with MUX. Taking into consideration elements such as dispersion, Kerr nonlinearity, and stimulated and spontaneous Raman scattering in a one-way data transfer system. A non-linear refractive index (n_2) of 2.6, an impacting core area of 70 μm^2, a dispersal of 17 ps/km nm, a diffusion grade of 0.075 ps/km nm^2, and an attenuation of 0.2 dB/km are among the characteristics of the single mode fiber. A non-linear refractive index (n_2) of 2.6, an efficient core size of 22 μm^2, a distribution of -85 ps/km nm, a distribution grade of -0.3 ps/km nm^2, and an attenuation of 0.5 dB/km are the characteristics for the DCF. To reduce dispersion, an Erbium-Doped Fiber Amplification (EDFA) is positioned 25 km after SMF and 10 km after DCF. With EDFA-1 and EDFA-3 offering 10 dBm of gain each and EDFA-2 offering 5 dBm of gain, the EDFA's signal-to-noise ratio deterioration is set at 6 dB.

2.4 The Optical Receiver

The receiver end receives the signal after it has passed through the middle of the SMF region. The first optical signal entered the demultiplexer, which divided it into 32 output ports. Each channel passes via a separator and a 3R regenerator after being detected by a PIN detector. The Bessel band-pass filters used in the optical demultiplexer have a 3 dB cut-off regularity that is 50 GHz. With a depth of 100dB, such mesh are of class 4. Individually network is successfully isolated by these filters according to the particular wavelength.

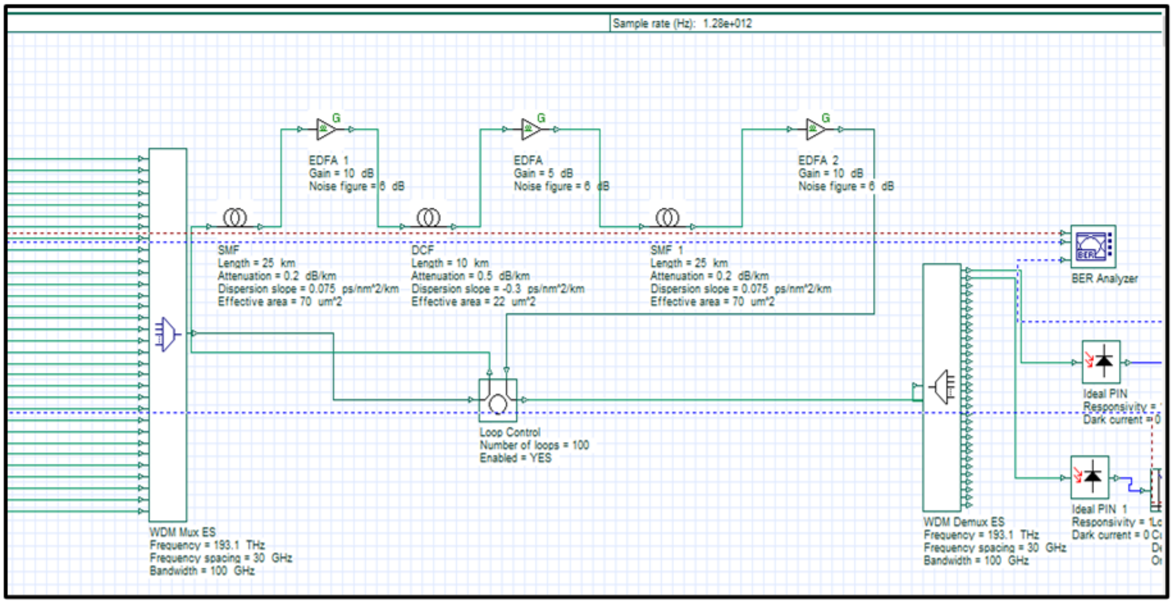


Fig 2. Modelling in the opti-system DWDM connection model 32×440Gbps

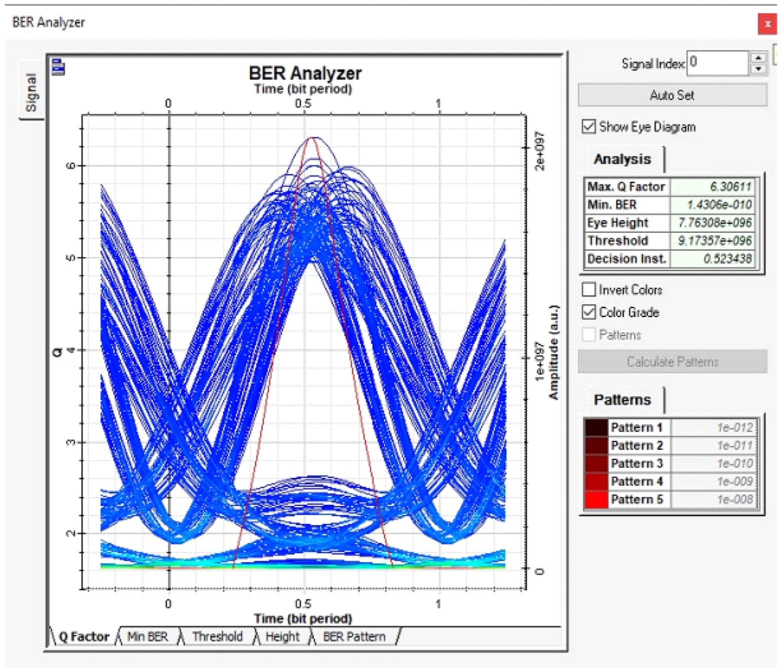
3 Results and Discussion

Results of performance obtained in this study demonstrate the critical role of channel spacing and optical filter bandwidth to Dense Wavelength Division Multiplexing (DWDM) system reliability. The achieved BER was 1.9124×10^{-5} and the Q factor of 4.1099 at 30 GHz channel spacing and a laser power of 10 dBm. With the channel spacing increased to 50 GHz and the use of a Gaussian optical filter, the BER drops to 1.79113×10^{-10} and the Q factor increased to 6.2712. These results show that the stronger nonlinear impairments and interchannel crosstalk dominate the small channel spacing and secretary the wider spacing and Gaussian spectral shaping to achieve better signal quality. This is consistent with earlier observed increasing frequency spacing support lower nonlinearity distortion and therefore system performance as done by Yao et al. [1] and Mishra et al. [2]. As in [3], Ranathive et al. [3] emphasize the need for good dispersion management and, therefore, collaborate with Gaussian filtering in this paper.

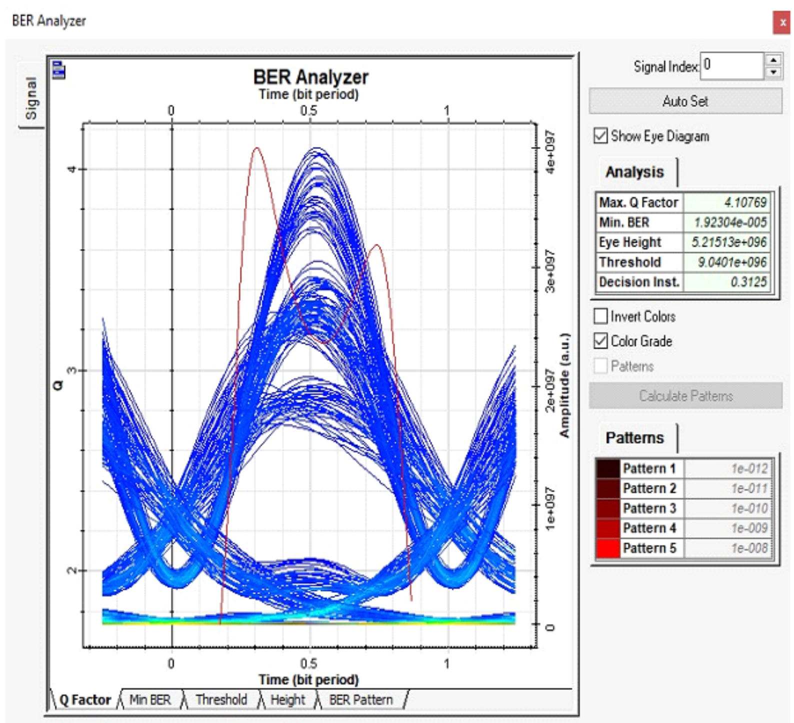
This study is an example of important advances on previous literature. Under moderate spacings, VSB- CSRZ modulation resulted in improvement in Q factors as reported by Thakur and Bharti [12], and CSRZ modulation also been shown to outperform CSRZ modulation in dealing with dispersion and nonlinear effects as has been reported by Mishra et al. [13] Both studies did not consider the effect of thin channel spacings and high laser power level when optical filtering was present. Another approach that has been demonstrated by Yamazaki et al. [14] with digital calibrators enables high rates in CSRZ-OTDM systems but with no other study of inter channel nonlinearities in DWDM configurations. Tan et al. [16] also showed that FM-FBG can perform the CSRZ to NRZ conversions successfully, but only with regard to the spectral efficiency improvements considered in the stipulations. This gap is captured in the present work in an attempt to address the benefit of Gaussian filtering at dense channel spacing and high power levels over long transmission distances–a topic that has not been addressed previously.

Comparing in Free Space Optics (FSO) to findings, Ejaz et al. [15] further demonstrated that CSRZ modulation is more robust to turbulence, similar to the effect that Gaussian filtering gives to fiber nonlinearities. Nevertheless, the differing atmospheric conditions in FSO compared to fiber dispersion and nonlinear impairments in DWDM make the contributions of this study directly applicable for fiber based networks. The overall contributions of this investigation show that, over as a combined strategy of narrow channel spacing and Gaussian spectral filtering in wavelengths, substantial improvements are attained in BER as well as Q-factor, which enable a practical route to optimize future ultra-dense DWDM networks, a topic seldom addressed in the current literature.

We use a Gaussian filter at 50 GHz channel spacing, we greatly increased the BER to 1.79113E-10 and the Q element to 6.2712. These results demonstrate how distinct Laser power level and frequency spacing, which affect the value and reliability of numerical indication communication. Figure 4, 5 show the outcomes of our CSRZ modelling with and without a Gaussian filter for all network spacing and power level performance.



(a)



(b)

Fig 3. (a) Containing and (b) Lacking Gaussian filter EYE figure in Optic system

		Launching powers(dBm)				
Frequency Place(GHz)	Assessment criteria	-5	0	5	6	10
50	BER and Q-factor standards	1.35038E-05 4.18952	2.03745E-05 4.09696	1.92304E-05 4.10769	2.16405E-05 4.10998	1.91246E-05 4.10998
40		2.03412E-05 4.09361	3.94638E-05 3.93633	2.21114E-05 4.07876	3.91828E-05 3.94238	5.86658E-05 3.83773
30		2.10289E-05 4.08890	2.33141E-05 4.06141	2.83650E-05 4.01503	2.53192E-05 4.04678	1.96637E-05 4.10349

Fig 4. BER and Q-factor without the Gaussian filter at different laser powers and channel spacing

		Launching powers(dBm)				
Frequency Place (GHz)	Assessment standards	-5	0	5	6	10
30	BER and Q-factor standards	8.96633E-010 6.01549	2.64771E-010 6.20975	1.4306E-010 6.30611	2.68073E-010 6.20809	1.87609E-010 6.26399
40		1.06198E-009 5.98797	1.95751E-010 6.25733	7.28891E-011 6.40972	2.772E-010 6.20277	8.85245E-011 6.38
50		2.20737E-010 6.23837	2.91384E-010 6.19502	3.68811E-011 6.51279	1.30615E-010 6.32016	1.79113E-010 6.2712

Fig 5. BER and Q-factor without the Gaussian filter at different laser powers and channel spacing

4 Conclusion

This study demonstrated 32 channels using the CSRZ modulation scheme at 40Gbps. The proposed setup supports ultra-long-haul, high-capacity networks and suits flexible-grid optical systems. The ability of the Gaussian filter to smooth single data, improve receiving data, and generally improve signal quality makes it an essential component in optical communication systems. We demonstrate that using a Gaussian sieve, the highest presentation at 30GHz network positioning has a Q element of 6.30 and a bit error rate of 1.430E-010. Q dynamic is 4.1895 and bit error amount is 1.3503E-05 at 50GHz channel spacing with a Gaussian filter at 6000 km range. At 30GHz to 50GHz, we saw this outcome in several channel spacings with and without a Gaussian filter. Its strong resilience to dispersion and nonlinearities makes it ideal for future backbone infrastructure. Future work should explore adaptive modulation under varying loads and use AI for system optimization. Incorporating Raman amplification is recommended to further enhance reach and signal quality.

5 Acknowledgements

The authors express their sincere appreciation to the Department of RDIC at C U Shah University in Wadhwan city, Gujarat, for providing the space and directions that needed to carry out this study. They also acknowledge gratefully the service provided by Opti-System software community.

References

1) Yao S, Zhang T, Wang Y, Liu Y, Qian D. Performance comparison for NRZ, RZ, and CSRZ modulation formats in RS-DBS Nyquist WDM system. *J Opt Commun Netw*. 2014;6(4):355–361. https://doi.org/10.1364/JOCN.6.000355.
2) Mishra R, Kumar M, Kumar D, Arora A. Performance analysis of 8 channel DWDM systems via dispersion compensation fiber using NRZ, RZ, CSRZ modulation schemes. IEEE. 2018. https://doi.org/10.1109/ICCCI.2018.8441434.
3) Ranathive S, Ghulghule K, Yadav R, Yadav A, Niranjan P. Performance signature of optical fiber communications dispersion compensation techniques for the control of dispersion management. *J Opt Commun*. 2022;43(4):611–623. https://doi.org/10.1515/joc-2020-0277.
4) Ali F, Khan Y, Qureshi SS. Transmission performance comparison of 16×100 Gbps dense wavelength division multiplexed long haul optical networks at different advance modulation formats under the influence of nonlinear impairments. *J Opt Commun*. 2022;43(1):63–72. https://doi.org/10.1515/joc-2020-0230.
5) Mishra P, Sinha D, Kumar A, Yadav P. Investigation of a 16 channel 40 Gbps varied GVD DWDM system using dispersion compensating fiber. IEEE. 2020. https://doi.org/10.1109/ICCSEA49143.2020.9132937.
6) Onidare SO, Adelakun GM, Adeyemi SO, Adesanya AA. Optical dispersion compensation using different modulation formats. *LAUTECH J Eng Technol*. 2021;15(2):85–92.
7) Sayed AF, Abdel-Hafez MA, Kamal EA, Kholief M, Saafan SA. Symmetrical and post dispersion compensation in WDM optical communication systems. *Opt Quantum Electron*. 2021;53:490. https://doi.org/10.1007/s11082-021-03191-4.
8) Ghera JS, Sharma V. Design and performance optimization of 96 × 40 Gbps CSRZ based DWDM long-haul system. *J Opt Commun*. 2022. https://doi.org/10.1515/joc-2022-0062.
9) Dhadhal D, Mishra V, Thummar R. Implementation and analysis of 32 channel MDRZ DWDM system at narrow channel spacing. *J Phys Commun*. 2022;6(9):095001. https://doi.org/10.1088/2399-6528/ac8e37.
10) Thummar R, Dhadhal D. Performance analysis of 64 channel DWDM system using single mode fiber at different power levels and frequency spacing. *J Phys Conf Ser*. 2021;1804:012010. https://doi.org/10.1088/1742-6596/1804/1/012010.
11) Singh M, Atieh A, Aly MH, El-Mottaleb SA. Performance analysis for UOWC transmission system using NRZ, AMI, and CSRZ modulation schemes. *Opt Quantum Electron*. 2023;55(14):705. https://doi.org/10.1007/s11082-023-05559-1.
12) Thakur P, Bharti M. Performance analysis of NRZ, duobinary, CSRZ & VSB-CSRZ modulation formats for 32-channel WDM radio-over-fiber systems using single drive Mach-Zehnder modulator. *J Opt*. 2025. https://doi.org/10.1007/s12596-025-02612-y.
13) Mishra P, Prasad B, Palai G, et al. Comprehensive performance evaluation and comparative study of DRZ, MDRZ, and CSRZ modulation techniques for optimized high-capacity optical communication systems. *J Opt*. 2025. https://doi.org/10.1007/s12596-025-02569-y.
14) Yamazaki H, Iwashita T, Yoshida H, Takahashi H, Sano A. Single-carrier 2.5-Tbps transmission using CSRZ-OTDM with 8×4 digital calibrator. *J Lightwave Technol*. 2024;42(12):4317–4323. https://doi.org/10.1109/JLT.2024.3368209.
15) Ejaz S, Baig SH, Khan Y, Jamil M, Qureshi SS. Performance comparison of duobinary, AMI, CNRZ and CSRZ for next generation FSO communication system. *J Opt Commun*. 2025;45(S1):s2785–s2794. https://doi.org/10.1515/joc-2023-0173.
16) Tan J, Cao H, Shu X, Atai J. Few-mode fiber Bragg grating-based simultaneous multichannel CSRZ to NRZ format conversion scheme for LP01 and LP11. *Opt Express*. 2024;32:6232–6240. https://doi.org/10.1364/OE.496362.