



Performance Analysis of Optical Networks Using Fiber Bragg Grating for Dispersion Compensation

Deepthy Prabha Sasidharan¹, Dr T. Vimala², Dr D. Sheela³, Dr. M. Anand⁴

¹Research Scholar, Department of ECE, Dr M.G.R Educational and Research Institute, Chennai, India deepthysist@gmail.com

²Professor, Department of ECE, Dr M.G.R Educational and Research Institute, Chennai, India

³Professor, Department of ECE, SIMATS School of Engineering, Thandalam, India

⁴Professor, Department of ECE, Dr M.G.R Educational and Research Institute, Chennai, India

ABSTRACT

Optical fiber communication enables high-speed data transmission from a transmitter to a receiver, where optical signals are converted into electrical signals. The increasing demand for bandwidth has led to the adoption of Wavelength Division Multiplexing (WDM), which transmits multiple signals simultaneously at different wavelengths. However, chromatic dispersion causes pulse broadening and degrades signal quality. This study investigates dispersion compensation techniques in a two-channel WDM optical network over transmission distances of up to 120 km. Fiber Bragg Grating (FBG) is employed for dispersion compensation. The system is modeled and simulated using OptiSystem software. The performance is evaluated using Q-factor and Bit Error Rate (BER). The simulation results indicate that mixed compensation using FBG provides better performance at longer transmission distances than pre-compensation.

Keywords—FBG, WDM, optical fiber, dispersion, optisystem.

1. Introduction

Achieving high data rates in optical fiber transmission is crucial. The data that is reliably transmitted over long distance depends on the fiber's transmission properties. These consist of elements like dispersion (signal spreading) and attenuation (signal loss). Three compensation techniques—pre, post, and symmetric—are used to obtain high data rates in optical transmission [1], [2] and [3]. Here, Fiber Bragg Grating is used in the system. With the 5 Gbps data rate, the NRZ encoding scheme is also applied. Both dispersion and signal loss in the transmitting line reduce the system's transmission capacity. When the pulse reaches the receiver in a long-distance transmission, its shape will be spread. Dispersion is the term used to describe this pulse spreading. Waveguide dispersion, material and chromatic are such numerous dispersion types.

In transmission through an optical fiber different wave length signals have different speeds. This leads to chromatic dispersion. As fiber's refractive index changes with the wavelength, material dispersion is happened. Through a material, light travels at different speeds with different wavelengths. The core and cladding of the optical fiber do not have the same refractive index, which causes waveguide dispersion. Fibers are characterized by a higher refractive index at their core, which causes light rays to travel at different speeds. Taking the insights from paper [4], [5] into consideration and for enhancing the transmission capacity, we have implemented a WDM system. Through optical fiber, many signals are combined and transmitted at different wavelengths in this approach. A single waveguide supports multiple channels, with each operating at a distinct wavelength, ensuring efficient utilization of the available bandwidth and increasing overall data transmission capacity.

Electronic Dispersion Compensation is a type of dispersion compensating method. This method was used by Jagjit Singh Malhotra, Manoj Kumar, et al. [6] to improve quality of a DWDM soliton link. Here a comparative analysis was conducted to evaluate the effectiveness of compensation in a 16-channel WDM system using EDFA as the amplifier.

Additionally, the work done by Hodzic, A., and Konrad [7] explored dispersion effects in a 40 Gbps WDM system with different modulation schemes. This paper aims to assess and compare these findings to understand the impact of dispersion on optical communication systems. By employing a return to zero modulation method they achieved higher bit rate optical transmission.

A study was conducted by Hoshida, T., Vassilieva, et al., [8]. Here they also compared NRZ and MDRZ.

Using a WDM network with 40 Gbps, CSRZ modulation was examined. Since single-mode fiber (SMF) exhibits less dispersion than multi-mode fiber, and hence it is used in our investigation. SMF has the least amount of loss at 1550 nm. Optical amplifiers must be used in the transmission link in order to receive strong high-quality signals at the receiver end with reduced distortion. Thus, the EDFA was employed. EDFA is compatible with WDM and has the ability to amplify several optical signals simultaneously. Fiber bragg grating technique (FBG) is the best sophisticated technologies for dispersion correction.

Optical fibers contain periodic structure called fiber Bragg gratings. Unlike the fiber's core around them, they

are made from parts that have a higher refractive index. A regular gap is created along the fiber for each of these parts. FBGs are created by modifying the refractive index of core through a process called photosensitivity. In order to generate periodic variations in the refractive index, UV light is used. These variations occur in a regular pattern, creating a periodic structure with a specific spacing, often in the micro meter range. FBGs are characterized by a specific wavelength of light they reflect, known as Bragg wavelengths. The Bragg wavelength (λ_B) is:

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

where:

n_{eff} : Fibre core effective refractive index,

Λ : Grating period (spacing between refractive index variations).

In FBG, light with Bragg wavelengths is reflected. A wavelength of light with another wavelength is not reflected. As a result, the FBG functions similar to a wavelength filter, reflecting a certain wavelength while permits others to travel through the fiber. Using a special fiber, the Dispersion Compensating Module reduces the effects of dispersion. A negative dispersion value is found for this fiber; -35 to -305 ps/(nm*km) is the ranges of it.

Tanvir Zaman Khan, Apurba Adhikary, and Md. Bipul Hossain conducted research on compensation of dispersion in communication systems. These days, this is one of the most important and researched subjects. Any dispersion could result in pulse spreading, which could deteriorate signals and produce interference from other signals. The first three models use dispersion compensation fiber, and the last three dispersion compensation models are designed using FBG, uniform type FBG. Each model is designed using an optical fiber length of 100 km, which are then simulated using an optical system software package [9].

Rajani, Raju Pal, and Vishal Sharma [10] used dispersion compensated fibers to compare compensation schemes at different optical power levels. A system that assesses the dispersion at different distances and input powers was proposed by Belen Melian, Manuel Laguna, et al. [11]. A DWDM was triggered at a modest data rate by Jagjit and Malhotra [6]. The employment of compensating fibers was the sole focus of the analysis.

One important element limiting the overall performance of optical systems is pulse broadening. DCF and FBGs are used to counteract the effects of pulse broadening. The pulse broadening issue requires a module that is both highly efficient and reasonably priced. This study examines and evaluates a number of approaches in order to find a cost-effective strategy with a notable reduction in pulse width. [12] – [14].

2.SYSTEM DESIGN

The primary performance constraint in optical fiber communication is dispersion. Dispersion has an impact on optical fiber communication performance. As an optical pulse propagates through a fiber, dispersion will cause the signal to widen. This leads to signal components to spread and overlap, which degrades system performance. Hence, improving performance in an optical fiber communication system requires effective dispersion reduction and compensation.

There are various dispersion compensating techniques like optical compensation and electronic compensation. The most effectively used compensating techniques for dispersion, are FBG and DCF. In our system architecture, we utilize mixed compensation and pre-compensation to achieve dispersion compensation using FBG. There are two FBGs used in the mixed compensation method. A first one goes before the Single Mode Fiber (SMF), and a second one is added after.

In our setup, pre-compensation analysis is performed by placing FBG before the WDM system. In this simulation setup, we have used a 2×1 WDM system, consisting of two identical transmitter sections. A modulator, a data source, laser source and NRZ driver included in each. 5 Gbps PRBS data created by the data source. In order to process the source output further, it is converted into an NRZ pulse by the modulator driver. 193.1 THz and 193.2 THz are the frequencies at which the laser source operates. A power of 10 dBm is set as the output power. There is a 30 dB extinction ratio on the modulator. The input is provided by a CW laser. Multiplexing occurs between the output and a 2×1 multiplexer (MUX). SMFs are used to combine the signals. A FBG is utilized to suppress dispersion over the transmission link. Here mix compensation method is used to further reduce dispersion. Electrical signals are converted into optical signals by photodiodes at the receiver. These photodiodes have a dark current of 10 nA. The main components which are used in the receiver system include a demultiplexer, a photo diode, a filter, and a 3R regenerator. Low-pass filtering is used to filter the electrical signal from the PIN diode. Following the 3R regenerator, a BER analyzer is used to check the performance of this generator. As a result of FBG, dispersion is fixed in the network. Mix compensation (as shown in Fig. 2) involves placing Fiber Bragg Gratings (FBGs) before and after the multiplexer to compensate for dispersion in the optical transmission system.

3.RESULT AND DISCUSSIONS

A Q-factor and Bit Error Rate are used in comparisons of compensation methods. System performance can be measured quantitatively and clearly with BER measurements.

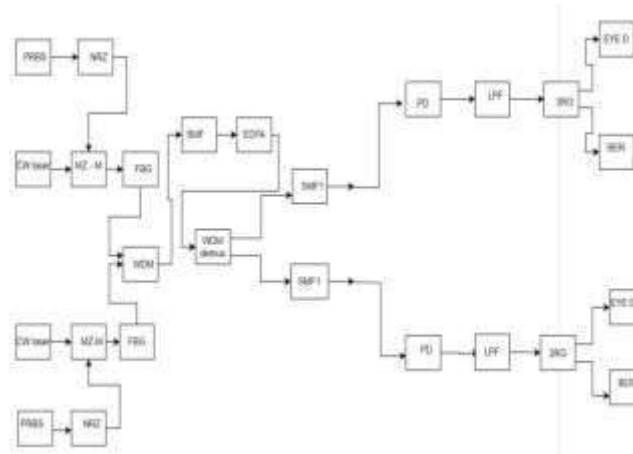


Fig. 1 Pre-compensation

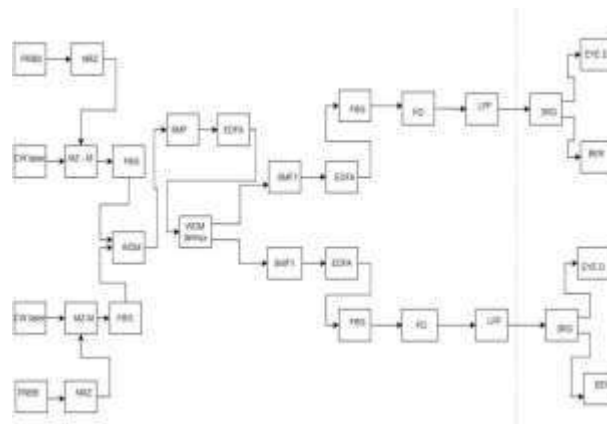


Fig. 2 Mix-compensation

3.1 Fiber Length and Bit Error Rate Investigation

Light travelling in an optical fiber losses power with distance. The power loss depends on wavelength and also fiber material used. Transmission of light through fiber is affected by absorption and back scattering. These factors lead to attenuation. Higher the data rate, shorter is the distance signal can travel before suffering modal dispersion. In practice, BER should be less than 10^{-9} . To maximize fiber length, we aim to use as much as possible. With 10 Gbps data rates, we must maintain BER below 10^{-9} . Transmission lengths are varied, keeping the signal power constant, and the impact on BER and Q-factor is measured. A 5 Gbps bit rate is used for measuring BER. 2.5 Gbps is the bit rate used for measuring Q-factor.

Our aim is to achieve maximum fiber length at maximum allowance value of BER, which is 10^{-9} . The data rate is set to 10 Gbps. Signal power is maintained by varying fiber lengths. Bit rates of 5 Gbps and 2.5 Gbps were measured to determine the BER and Q factor.

Table 1 Variation of Ber with Fiber Length (2.5GBPS)

SMF length (Km)	193.1Min BER	193.2Min BER
160	2.98E-07	7.38E-07
155	1.44E-09	7.70E-09
150	4.23E-12	5.70E-13
140	2.93E-21	5.34E-21
130	4.73E-30	1.30E-31
120	3.60E-56	9.73E-57

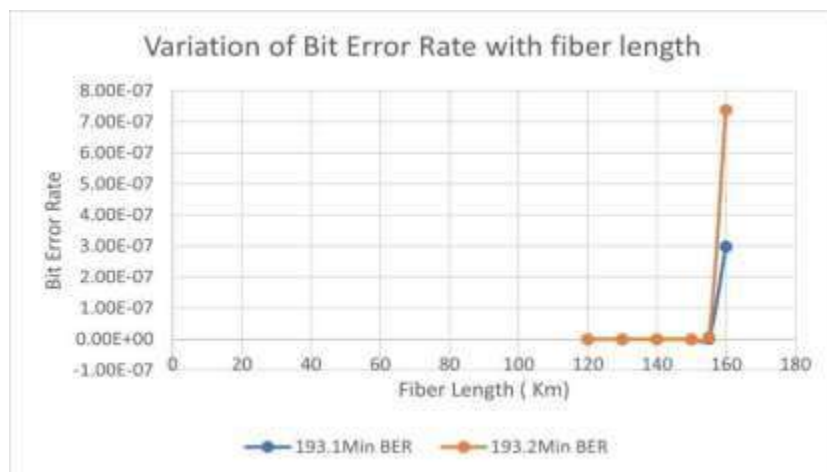


Fig. 3 Input parameter at a data rate of 2.5Gbps

Table 2 Variation of Ber with Fiber Length (5gbps)

SMF length (Km)	193.1Min BER	193.2Min BER
120	0.000351929	0.000131138
110	0.000591254	2.21E-05
100	5.94E-06	1.77E-05
90	5.44E-06	1.30E-05
80	3.83E-06	1.24E-06
70	2.08E-06	2.78E-06
60	9.70E-07	5.34E-07
50	6.56E-07	7.85E-07
40	2.00E-07	7.13E-07

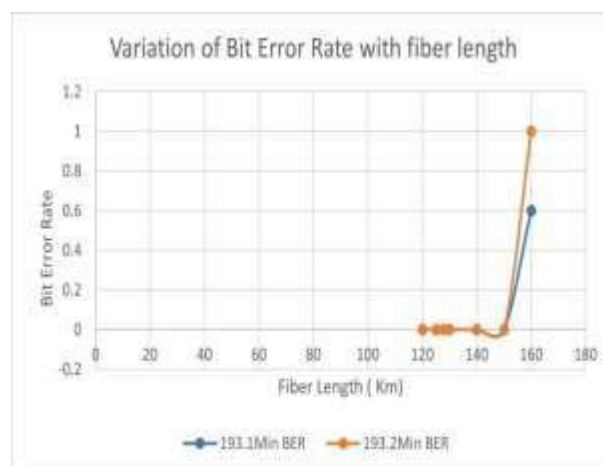


Fig. 4 Input parameter at a data rate of 5Gbps

Table 3 Variation of Ber with Fiber Length (10 Gbps)

SMF length (Km)	193.1Min BER	193.2Min BER
120	0.000351929	0.000131138
110	0.000591254	2.21E-05
100	5.94E-06	1.77E-05
90	5.44E-06	1.30E-05
80	3.83E-06	1.24E-06
70	2.08E-06	2.78E-06
60	9.70E-07	5.34E-07
50	6.56E-07	7.85E-07
40	2.00E-07	7.13E-07

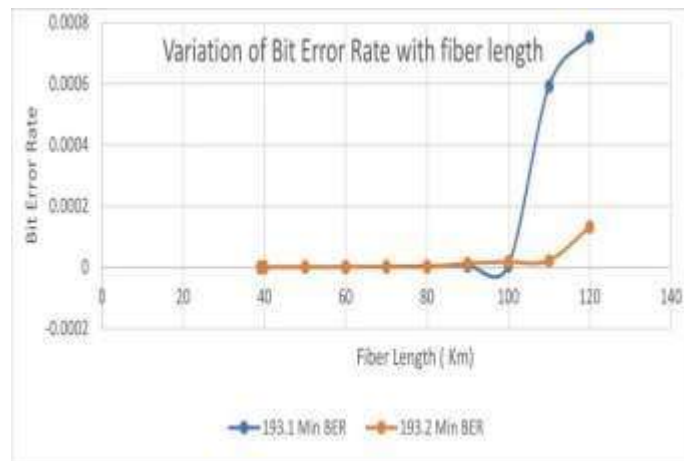


Fig. 5 Input parameter at a data rate of 10Gbps

3.2 Investigation on the Variation of Fiber Length on Q Factor

An optical system's Q-factor measures the quality of its digital signal. In the Q-factor, the signal power, the BER, and the noise power all play a role.

Q-factors above 6 are required for BERs beneath 10^{-9} . A Q-factor of more than 7 is needed for BERs below 10^{-12} .

Table 4 Fiber Length, Q Factor and Bandwidth (10 Gbps)

SMF length (Km)	193.1 Q factor	193.2 Q factor
120	3.35916	3.62755
110	3.19627	4.07229
100	4.37577	4.13149
90	4.39601	4.20282
80	4.47329	4.71001
70	4.60316	4.54256
60	4.7593	4.87767
50	4.83634	4.80132
40	5.06471	4.81997

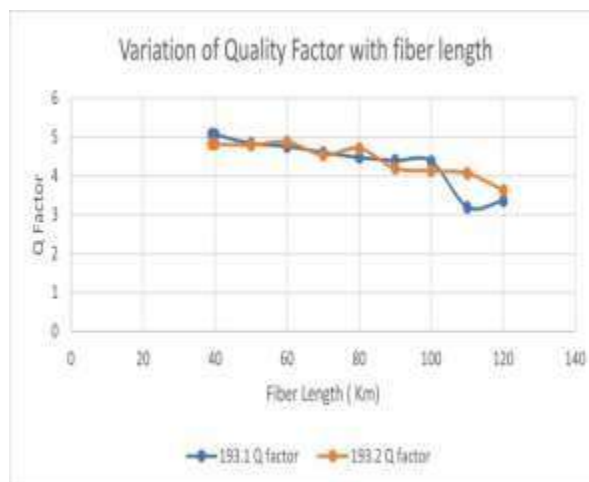
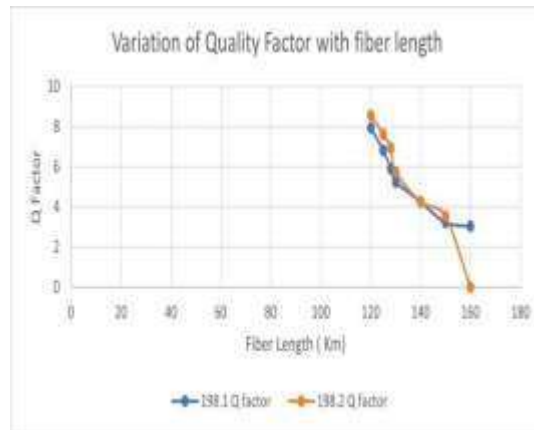


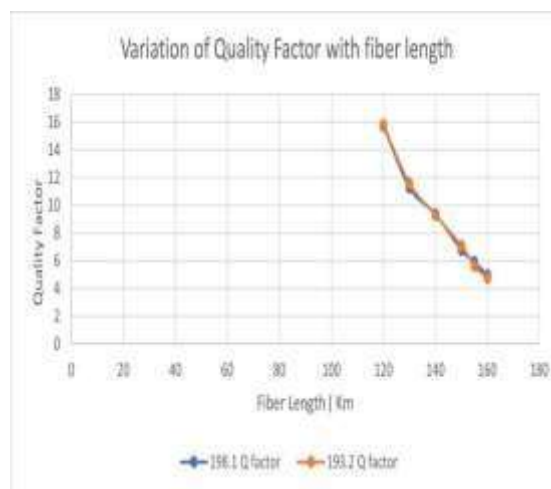
Fig. 6 At data rate 10 Gbps

Table 5 Variation of Q Factor with Fiber Length (5 Gbps)

SMF length	193.1 Q factor	193.2 Q factor
160	3.0358	0
150	3.2367	3.53045
140	4.2597	4.2432
130	5.2597	5.74332
128	5.90076	6.92765
125	6.81743	7.62981
120	7.93804	8.55754


Fig. 7 Input parameter at a data rate of 5Gbps
Table 6 Fiber Length and Q Factor (2.5 Gbps)

SMF length (Km)	193.1 Q factor	193.2 Q factor
160	4.9786	4.78671
155	5.91741	5.62882
150	6.80874	7.08898
140	9.37103	9.30749
130	11.306	11.6168
120	15.7268	15.8123


Fig. 8 At data rate 2.5Gbps

3.3 Comparison of Mix Compensation Vs Pre compensation.

The data rate is set to 5Gbps. For varying fiber length Minimum Ber and Q factor was measured for both mix compensation and pre compensation.

Table 7 Variation of Q Factor with Fiber

SMF Length (Km)	MIX COMPENSATION	PRECOMPENSATION
150	3.2367	3.0094
140	5.2597	4.57511
130	7.20026	6.70407
125	6.81741	6.807
120	7.93809	7.5778
110	9.75349	9

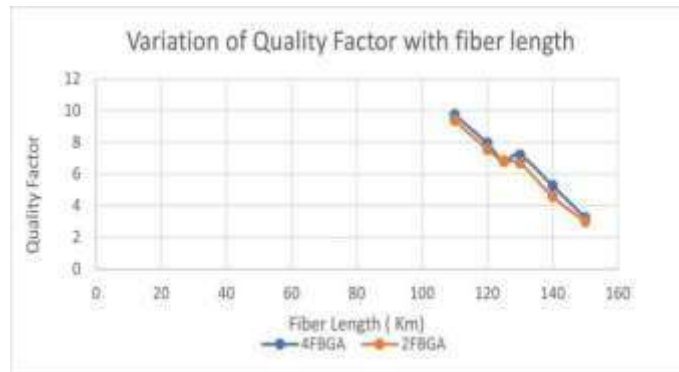


Fig. 9 Variation of Quality Factor with fiberlength

Table 8 Variation of Q Factor with Fiber Length (5 Gbps)

SMF Length (Km)	MIX COMPENSATION	PRECOMPENSATION
150	3.53045	3.35087
140	5.34332	4.273336
130	6.92765	6.54491
125	7.52981	7.28452
120	8.55754	7.86252
110	9.65715	9.07286

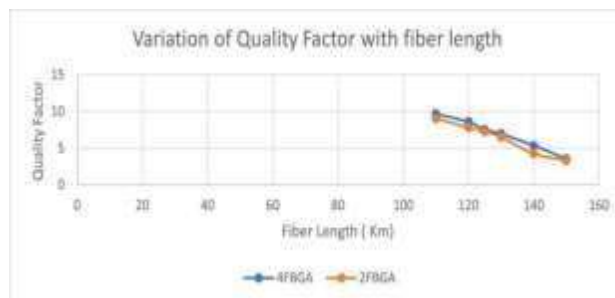


Fig. 10 Variation of Quality Factor with fiber length

3.4 Q Factor At 120km of Fiber Length for Data Rate in GBPS

120 kilometers of fiber were maintained. The data rates were varied in Gbps and for each data rate Q factor was measured.

Table 9 Data rate variation of Q Factor in Gbps

Data Rate in Gbps	193.1Q Factor	193.2 Q Factor
10	3.35916	3.62755
7.5	3.48105	3.55134
5	7.93804	8.55754
2.5	15.7268	15.8123



Fig. 11 . Variation of Q Factor with Data rate in Gbps

3.5 Investigation on the Variation of Fiber Loss on Q Factor

A fiber that is longer and a light wave that travels farther enables a weaker optical signal to be transmitted. In addition to fiber material, operating wavelength affects attenuation. Fiber attenuation is caused by absorption,

scattering, bending loss, loss caused by connectors and splicers. As the data rate remains constant at 2.5Gbps, the SMF attenuation is varied between 0.2dB/km to 0.3dB/Km and the Q factor is measured for varying fiber lengths in Km.

Table 10 With fiber attenuation, Q Factor varies

Attenuation dB/Km	193.1 Q factor	193.2 Q factor
0.2	16.3444	16.6691
0.22	14.0658	10.5126
0.24	7.94664	8.83504
0.26	7.3685	6.23863
0.28	4.3113	4.43017
0.3	2.82919	2.91027

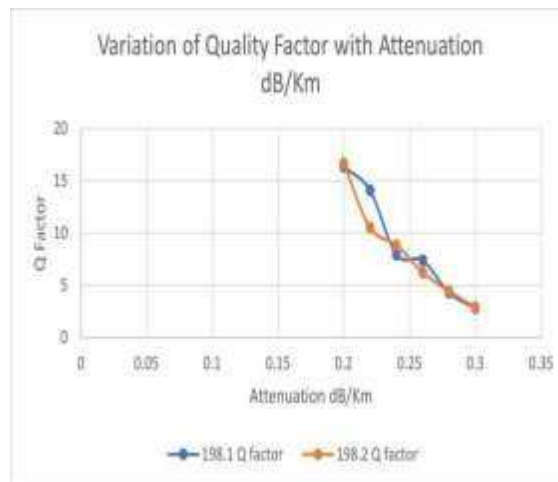


Fig. 12 Variation of Quality Factor with Attenuation dB/Km

4. CONCLUSION

Using FBG, this paper analyses the performance of pre and mix compensation schemes for dispersion compensation. According to the results, mix compensation provides the largest Q-factor and the least BER of all compensation methods when compared with pre compensation. With increasing fiber length, bit error rates (BER) were observed to increase exponentially. Additionally, fiber losses are observed to increase BER exponentially. The Quality Factor was found to be decreasingly with fiber length. The Quality Factor was found to be decreasing with increase in data rate.

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Competing Interest declaration: NO

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