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MINIMIZATION OF SIGNAL DEGRADATION IN SINGLE MODE FIBRE OPTIC LINK

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Abstract- Single mode fiber optic transmissions and communications technologies are constantly growing and facing more challenges that limited its ability to transmit for long distances with great capacity (e.g.10Gbps and 40Gbps). One of these challenges is the degradation phenomenon that occurs when the optical signal passing through the fiber. There are three causes of this degradation, power attenuation, dispersion and nonlinear effects. Minimization of these effects will help the system to support long haul transmission distance with high capacity. In this paper, an optical communication link is constructed using Optisystem7.0. The degradation effect is studied and analyzed based on the BER and Eye Diagram obtained at the speed of 10 G bps and a distance ranging between 60 km to 100 km. The results show that the optical signal degrades when the transmission distance exceeds 60 km. An optical amplifier is introduced to eliminate the attenuation effect on the transmitted signal. It is found that at the speed of 40 Gbps the system performance limited to a distance of 5 km and this is due to the high dispersion effect. The results also show that Chromatic dispersion is the most significant affect of degradation phenomenon. The absence of nonlinear effect is also observed when the transmission power in the range of 1mw to 15mw.

Keywords - Fiber Optics, Attenuation, Dispersion, Nonlinear Effect, FBG, BER, Eye Diagram, Capacity.

1. INTRODUCTION

In optical communication systems**.** The signal degradation is one of the most importance properties of an optical fiber ,and it is the key distance limiting parameters in fiber optical transmission. Signal degradation includes power attenuation, pulse broadening, and fiber nonlinearities. Power attenuation is the loss of power introduced by the fiber, this loss is accumulated as the light propagated through the fiber strand, and it largely determines the maximum distance that optical links can be operated without amplification, Power attenuation is divided into three types ;that is scattering losses, material absorption and bending losses.

The second factor is the fiber dispersion (spreading of optical pulses as they travel down the fiber, it limits the system performance by broadening optical pulses as they propagate inside the fiber. The most significant types of dispersion in single mode optical fiber cable are chromatic dispersion (intramodal dispersion) and polarization mode dispersion (PMD). The third factor that affects the performance of single mode fiber is the nonlinearities effects associated with the nonlinear response of atoms and molecules to optical radiation fields (power). Nonlinearities in optical fiber include Stimulated Raman Scattering (SRS). Stimulated Brillouin Scattering (SBS), Self–Phase Modulation (SPM), Cross Phase Modulation (CPM), and Four Waves Mixing (FWM) [1-2].

All these factors limit the performance of a single mode fiber link communication. The signal degradation limits the information carrying capacity of a fiber in high speed transmission system; therefore minimizing these effects is the key for high bit rate and long haul transmission distance.

2. OPTICAL SIGNAL DEGRADATION

Optical signal degradation is caused by the following factors:

2.1 ATTENUATION LOSSES

Attenuation is a one of the important characteristic of an optical fiber, since it determines the repeater spacing in a fiber transmission system. The lower the attenuation, the greater will be the required repeater spacing and lower will be the cost of the system. Attenuation is defined as the loss of energy of the signal as it propagates through the fiber strands. The signal attenuation is expressed in the terms of power loss in dB/km of the optical fiber. It is very important to specify the attenuation because the number of repeaters required in an optical fiber communication is related to the amount of the attenuation. The maximum power received reliably at the other end of the fiber is related to its length and the absorption coefficient of the material as in equation1[3=7].

$$P_r = P_0\, e^{\alpha L} \quad (1)$$

Where, P_r: Maximum received power (w)
P_o: Incised power or input power (w)
α: Material absorption coefficient (dB).
L: Length of the fiber (Km).

The power attenuation through an optical fiber has three main causes: Scattering losses, Material absorption loss, and Geometric effects.

- **SCATTERING LOSSES**

Scattering is the result of the interaction of the traveling light wave through the fiber and the small variation in the material density composing the fiber (refractive index fluctuation). Scattering counts

for 85 percent of the attenuation Losses. Scattering is divided into two categories; Rayleigh scattering and Mie scattering.

Rayleigh scattering is the fundamental loss mechanism arising from local microscopic fluctuation in density. The signal attenuation loss is given by [3-7]:

$$L_{sc} = \frac{C}{\lambda^4} \quad (2)$$

Where:

Lsc: losses in dB (scattering losses).
C: constant in the range 0.7 – 0.9 (dB/ Km.µm).
λ : Wave length (λ = 1.55 um).

The contribution of ray light scattering can be reduced to below 0.01 dB/ km for the wave lengths longer than 3µm.

Mie scattering occurring because of the index in homogeneity on the scale longer than the optical wave length, is mainly forward direction, and in this source of scattering the ray escape out of the fibers [3-7].

- **MATERIAL ABSORPTION LOSSES**

Material absorption is the light interaction with the atomic structure of the fiber material and, also involves the conversion of optical power to heat. It can be divided into two categories.

- Intrinsic Absorption, responded to the absorption introduced by fused silica (material used to make fibers).
- Extrinsic Absorption is related to the losses caused by impurities within the silicon (Transition-metal ions and OH ions). The main source of extrinsic absorption in silica fiber is the presence of water vapors.

- **BENDING LOSSES**

Macro bending happens when the fiber is bent into large radius of curvature relative to the fiber diameter (large bends). These bends becomes a great source of power loss when the radius of curvature is less than several centimeters [3-4].

2.2 DISPERSION LOSSES

Dispersion is a phenomenon that occurs in all types of optical fibers after attenuation. It is the next limiting factor that determines how much and how far the information can be transmitted on a given fiber. Dispersion is expressed in P_S/(nm.Km) [3-4].

Dispersion is the broadening of light pulses as it propagates through the fiber. It increases with the length of the fiber. So it has a negative effect on the bandwidth of a fiber.

Dispersion also decreases the peak optical power of the pulse and therefore increases the effective attenuation of a fiber.

Dispersion may be classified into two categories depending on the cause. These are, Intermodal dispersion and Intramural dispersion (chromatic dispersion). Modal dispersions are dominant in the multimode fibers where the optical rays propagate in different modes.

This type of dispersion is absent in single – mode fiber (SMF), simply because the energy of injected pulse is transported by a single mode.

Single mode fibers are used in the fast optical networks and are subjected to two main dispersion phenomena named chromatic dispersion and Polarization Mode Dispersion that need to be taken into account. These two dispersion types are critical factors that limit both the bandwidth and the distance that the information can be transmitted. Chromatic dispersion (CD) causes a broadening of the pulses of light according to wavelength. This is shown in Figure1. On the other hand the Polarization Mode Dispersion (PMD) causes the pulse broadening according to polarization [3-8].

Figure1. The Chromatic Dispersion Phenomenon appeared in SMF Link [8].

- **CHROMATIC DISPERSION**

The Chromatic dispersion results from the combination of different wavelength of light being produced at the light source and different refractive indices in the transmission medium. Figure 2 shows the dispersion of a single mode Silica fiber. It lowest at 1310 nm; its attenuation is minimum at 1550 nm where dispersion is high [8].

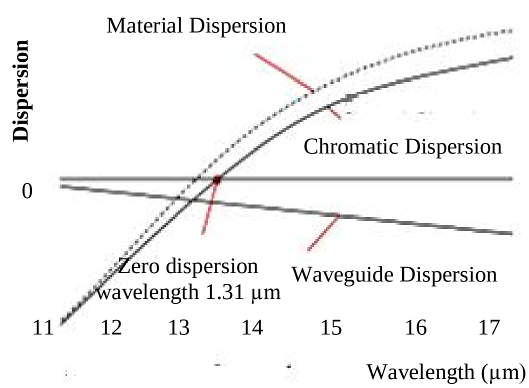


Figure 2 Chromatic Dispersion in a Standard SMF [8].

Material dispersion rises from the variation of the refractive index of the core material (silica) as a function of optical wavelength. The dispersion parameter is calculated using the following equations [3-8]

$$\Delta T = \frac{d}{d\lambda}\left(\frac{L}{V_g}\right)\Delta\lambda \qquad (3)$$

$$\Delta T = LD(\lambda)\,\Delta\lambda \qquad (4)$$

Where:

D(λ) : called the dispersion parameter and is expressed in units P_s/ (nm.Km).

B_2: GVD parameter.

λ: wavelength.

C: speed of light in vacuum, $c = 3*10^8$ m/s.

V_g: group velocity.

L: length of the fiber (nm).

Δλ: spectral width of the source

Waveguide dispersion is the most significant in SMF. It occurs since the SMF confined only about 80 percent of the optical power to the core. The Dispersion thus rises because the 20 percent of the light propagates in the cladding travels faster than the light confined to the core. The amount of the wave guide dispersion depends on the fiber design parameters (wavelength λ, and the core a). It is calculated by the following equation [3-8].

$$D_{wg}(\lambda) = \frac{N_2\Delta}{c\lambda}\left[\frac{c^2(Vb)}{dv^2}\right] \qquad (4)$$

Where:

D_{wg} (λ): waveguide dispersion

- **POLARIZATION MODE DISPERSION (PMD)**

Polarization Mode Dispersion is the type of dispersion occurs in single- mode systems and becomes of particular concern in long- haul, high-data rate. It broadens the optical signal width. When the input light travels along the fiber with E_x and E_y polarization having different group velocities and arrives at the output at different times as presented in Figure 3. If the group velocities of the two orthogonal polarization modes are V_{gx} and V_{gy}, the differential time delay is given by [3-8]:

$$\Delta T = \left[\frac{L}{V_{gx}} - \frac{L}{V_{gy}}\right] = L\left[B_{1X} - B_{1Y}\right] = L(\Delta B_1) \qquad (5)$$

This delay (ΔT) causes the pulse broadening phenomenon at the receiver output, which lead to symbol interference error .

PMD can be calculated according to the relationship.

$$\langle \Delta T \rangle \approx D_{PMD}\sqrt{L} \qquad (6)$$

Where: D_{PMD} measured in P_S / √km typical value of D_{PMD} range from 0.1 TO 1.0 P_S√Km

L: fiber length.

X and Y identically the two orthogonally polarization modes

The effect of the fiber birefringence on the polarization states of an optical signal are another source of pulse broadening. This is particularly critical for high rate long haul transmission links (e.g. 10 Gb/s over tens of kilometers), and this effect results from the intrinsic factors such as geometric irregularities of the fiber core or internal stresses and it leads to a periodic power exchange between the two polarization components, referred to as the beat length and is given by [3-8]:

$$L_B = \frac{\lambda}{B_m} \qquad (7)$$

Where:

λ: is the wavelength of the optical signal.

L_B: is the fiber length.

Typically, $B_m \sim 10^{-7}$, and $L_B \sim$ 10 m for $\lambda \sim$ 1μm. In most single mode fiber, birefringence changes randomly along the fiber in both magnitude and direction.

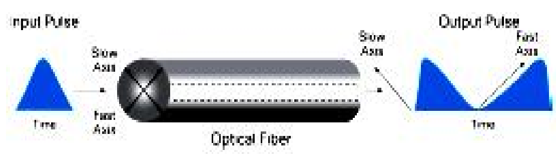


Figure3. Pulse Splitting Due to PMD in a Single-Mode Fiber

2.3 NONLINEAR OPTICAL EFFECTS

An optical effect is called nonlinear if its parameter depends on the intensity (power), these effects depend on the transmission length and there are two main nonlinear categories: Stimulated light Scattering and Nonlinear Phase Modulation [9-10].

- **STIMULATED BRILLOUIN SCATTERING**

Arises when light waves scatter from acoustic wave, the resultant scattered wave propagate principally in the backward direction in single-mode fibers, this back scattered light experience gain from the forward – propagating signals which lead to depletion of the signal power.

$$V_B = \frac{2nV_s}{\lambda} \qquad (8)$$

The optical power level at which stimulated Brillouin scattering becomes significant in a single mode fiber is given by the empirical formula below [9-12].

$$P_B = (17.6 * 10^{-3})\, a^2\lambda^2 \alpha\, \Delta V \qquad (9)$$

Where:

P_B: Stimulated Brillouin Scattering Optical Power Level Threshold in watts.

Δv : Light source line width (GHz).

The threshold power level for SBS is given by:

$$P_{th}\; g_B\; L_{eff}/A_{eff} \;\approx$$

Where

A_{eff}: is the effective core area. $A_{eff} = \pi w^2$, where w is the spot point.

L_{eff}: is the effective interaction length.

- **STIMULATED RAMAN SCATTERING (SRS)**

is caused by the vibrations of the crystal (or glass) lattice, SRS can occur in forward and backward directions in optical fibers, the scattering is predominately in the forward direction, and hence the power is not lost to the receiver. The SRS is calculated by the following formula:

$$P_R = (23.6 * 10^{-2}) a^2 \lambda\, \alpha \qquad (11)$$

Where:

P_R : Stimulated Raman Scattering Optical Power Level Threshold (Watt).

- **NONLINEAR PHASE MODULATION**

The phase modulation due to intensity dependent refractive index induces various nonlinear effects such as Self-Phase Modulation (XPM), Cross Phase Modulation (XPM) , and Four Wave Mixing(FWM).

- **SELF-PHASE MODULATION (SPM)**

It converts the optical power fluctuation in a propagating light wave to the phase fluctuations in the same wave. SPM increases the signal bandwidth considerably and limits the performance of the system. The nonlinear phase shift is given by.

$$\varphi_{NL} = \gamma P_{in} L_{eff} \qquad (12)$$

Where:

γ: $2\pi n_2/A_{eff}$.

N_2: is nonlinear- index coefficient.

P_{in}: input power.

L_{eff}: fiber losses.

. To reduce the impact of SPM in light wave system, it is necessary that $\varphi_{NL} << 1$.

- **CROSS PHASE MODULATION (XPM)**

It occurs when two or more optical channels are transmitted simultaneously inside an optical fiber using the WDM technique .XPM-induced phase shift can occur only when two pulses overlapped in time, all pulses overlapping is given by [5-112]:

$$\varphi_j^{NL} = \left(\frac{\gamma}{\alpha}\right)(2M - 1)P_j \qquad (13)$$

Where:

α: 0.2 db/km.

3. CHROMATIC DISPERSION COMPENSATION USING CHIRPED FBG AND OPTICAL CIRCULAR

The use of fiber gratings shown in Figure4 is to compensate for chromatic dispersion in an optical fiber. The grating serves as a selective optical delay line, which adjusts the transit times of different wavelengths in a pulse so they are approximately, equal [13].

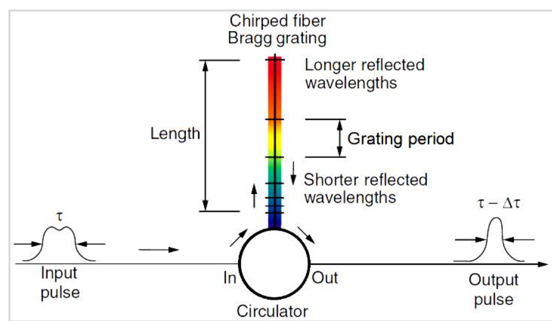


Figure 4 Layout of a Fiber Bragg Grating Based Dispersion Compensation Module [13].

Figures 5 and 6 show that the faster wave length entering the grating travels along, it almost to the end before being reflected, while slower wave lengths are travel a short distance, the waves can reach the detector (receiver) at the same time.

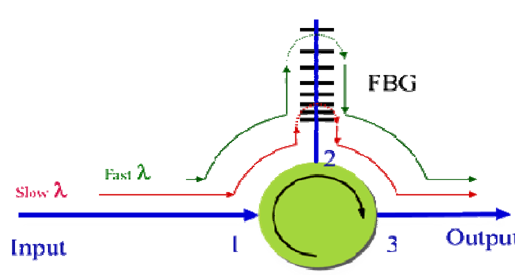


Figure5. Optical Circular Scheme [13].

The optical signal traveling inside the fiber degrades by dispersion phenomenon and is restored to its original shape by implementing FBG techniques shown in Figure6.

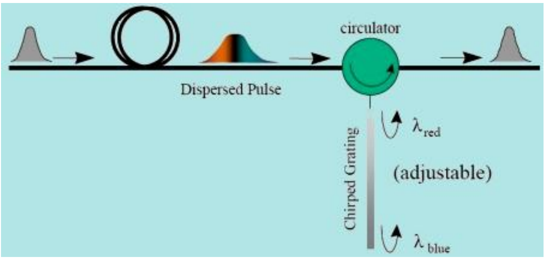
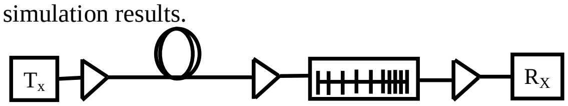


Figure 6 Chromatic Dispersion Compensation using FBD and Circular [11-13].

4. EXPERIMENTAL SETUP

In this paper an Optisystem7.0 software program is used to, design a complete fiber-optic transmission link shown in Figure6. The setup consists of the three basic elements common to all fiber optic communication systems: Electrical input is first coded into a signal by the modulator, using signal processing techniques. The transmitter coverts this electrical signal to an optical signal and launches it into the fiber. In the simulation setup, a single longitudinal mode semiconductor laser is directly modulated with a pseudo random bit sequence (PRBS). The optical pulses are transmitted over the fiber-optic channel, which in this case consists of one section of optical fiber, the signal experiences attenuation as it travels through the fiber, but it is amplified periodically by optical amplifiers. The transmitted pulse stream is converted back into the electrical domain by the optical receiver.

The proposed system consists of a photo detector followed by an electrical filter to enhance the signal quality. Time and frequency domain visualizes are used to evaluate the simulation results.



EDFA OF EDFA FBG Amplifier

Figure6. Fiber-optic Transmission link System Block Diagram

Initially the Polarization Mode Dispersion is reduced by minimizing the asymmetries index profile and stress; and by controlling the polarization mode coupling by fiber spinning. Table 1 shows the optical system parameters and the corresponding values used in the simulation.

In optical communication systems many types of signal power losses exist during transmission processing; these losses significantly degrade the system performance. In this paper the attenuation losses, chromatic dispersion losses and the non-linear effects losses were studied.

Table 4.1 Simulation Optical System Parameter

Parameter	Symbol	Value
Bit rate	B	10 Gbps,40Gbps
Transmission distance	L	(50 – 130) Km
Wave length	λ	1550 nm
Fiber attenuation coefficient	A	0.2 dB
Dispersion Coefficient	Dλ	16 s/m
Sample rate	Sr	32, 64
Optical laser power	P	1mw
Laser line width	Δλ	10 MHz
Dispersion slope	S λ	ps/(nm^2.Km)
Effective area	A_{eff}	80µm2

The launch power from the transmitter is set to 0dB.Then BER is detected with the BRE. The Estimation device while the received signal is observed by Eye Diagram. The input signal from the transmitter propagates through the single mode fiber. The simulation is conducted to observe the attenuation, distortion and nonlinear effects on the channel at 0Gbps and 40Gbps.The effects are observed at different transmission lengths and variables parameters.

In the first stage the data is transmitted at a rate of 10Gbps and the results shown in Figures 7 and 8 were observed at the distances of 60 km and 100 km. the results show the optical signal before propagates through the fiber strand.

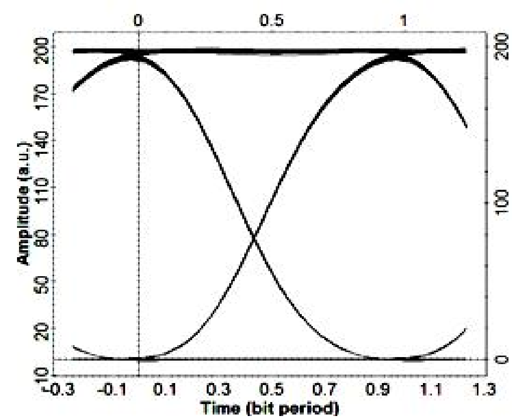


Figure 7 Eye diagram analyzer shows that the digital ‘1’ and ‘0’ levels of the received bids are easy to distinguish.

At 60 km of transmission distance the signal is detected at the output device, the eye is shown wide open indicating that the digits “1’ and “0” levels of the received bits are easy to distinguished. In this case received signal quality is very good and no degradation effect is observed.

Figures 8 and 9 represent the initial optical signal before propagates through the fiber strands. The received signals clearly show no sign of distortion or degradation. The Q-factor shows high value of about 157.227 and BER equals to 0.

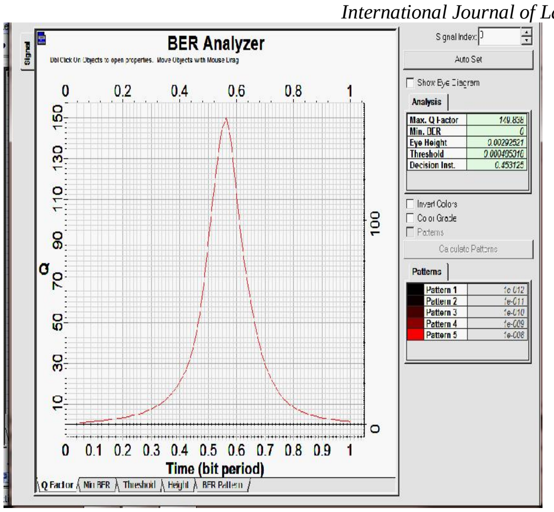


Figure8. Initial Optical Signal

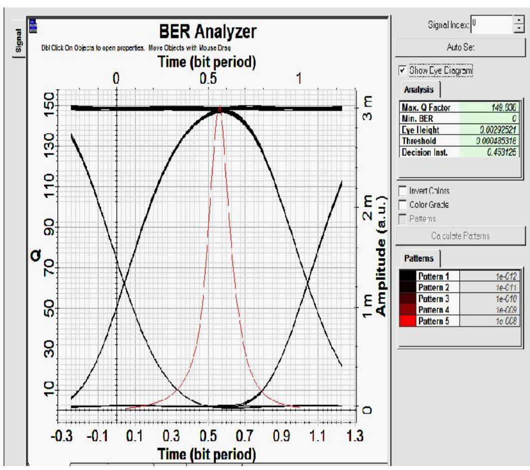


Figure 9. Initial Optical Signal Represented by the Eye Diagram

The signal is then sent through a 50 Km transmission distance, the output detected at the receiver side and the eye diagrams were obtained. The eye diagram shows “1” and “0” levels of the received bits and is very similar to that shown in Figure9. This indicates the good quality of received signal and no degradation occurs in the transmitted signal. The values of Q-factor and the BER obtained are 16.2 and $4x0^{-26}$ respectively.

The eye pattern can be viewed while making on-line adjustments to the system parameters.

It is observed that when the distance exceeds 60 km the received pulses are clearly distorted.

Figure 8 shows the eye diagram at the distance higher than 60 km. the distortion is due to optical attenuation.

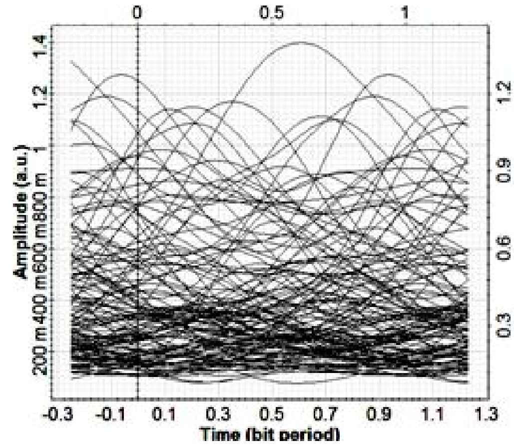


Figure 8 Eye diagram analyzer for the received signals ta distance grater than 60 km.

Optical amplifier can be used to amplify the attenuated signals at the receiver, however this process is not recommended since the amplifier causes signal degradation due to the noise introduced by the amplifiers themselves as well as the dispersion effects.

In this paper Fiber Bragg Grating is used to enhance the output signal sent at the distance exceeding 60 km. it succeeded to minimize the pulse broadening. Fiber Bragg Grating with the parameters shown in Table 2 is used.

Table 2. Fiber Bragg Grating Parameters

Parameter	Value
Frequency	193.1
Effective Index	1.45
Length	4mm , 3mm
Index of Modulation	0.0001
Linear Chirp	0.0001
Number of Segment	101
Maximum of number of Spectra Points	1000

Initially the received signal for the distance greater than 60 km is shown in Figure 10.

The maximum Q- factor and BER obtained are 6.4 and 0.01 respectively. the pulse width of the signal is 0.43 ps.

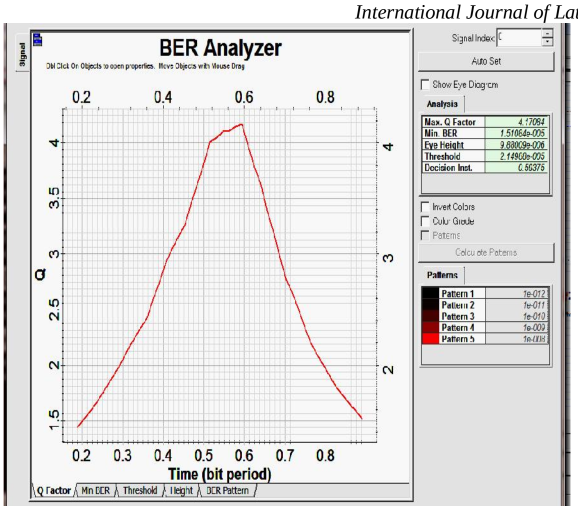


Figure10. Received Optical Signal at 100km

The signal received at the receiver is shown in Figure 10. The maximum q Factor is 6.4, the BER is 0.01 the pulse width is about 0.43 ps.

Also an amplifier is implemented to enhance the performance of the systems. The eye diagram obtained is shown in Figure11.

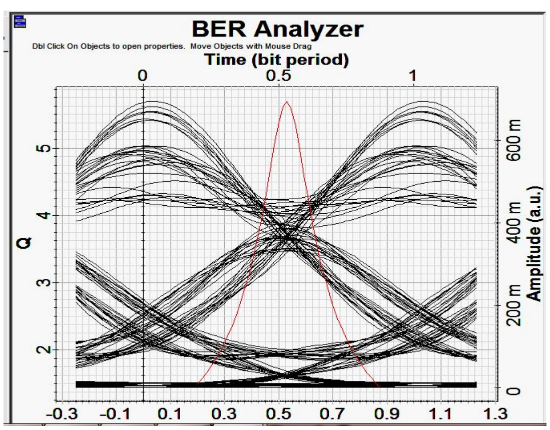


Figure11. Optical Output Signal eye diagram at distance 100km after applying the amplifier

In the next step the Fiber Bragg Grating mechanism is introduced to study the behavior of the transmitted signal. It is observed that the Q-factor increase to 7 and the BER becomes $2x10^{-6}$ while the pulse width reduces to 0.3 ps. This is shown in Figure 12.

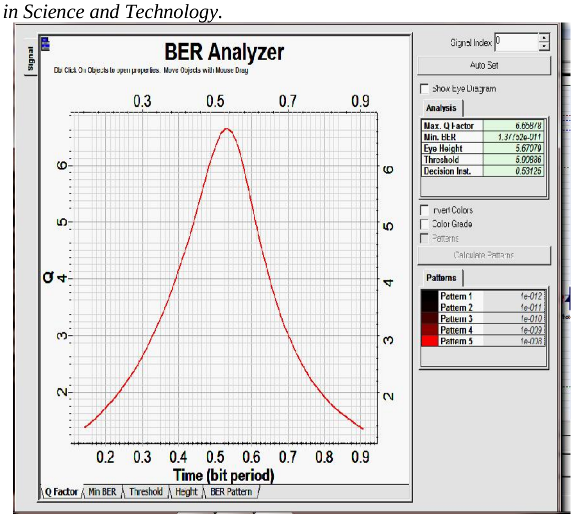


Figure 12. Output Optical Signal output at 100 km when FBG is used.

Similarly an optical signal is transmitted through 130 km cable length and the output is examined before and after implanting the FBG. Figures 13 and 14 show the output signal for both cases. The result shows that the received signal at the output clearly degrades because of the high desperation. The Q- factor is reduced 2.4 while the BER increases to 0.0076. The result obtained is shown in Figure 13.

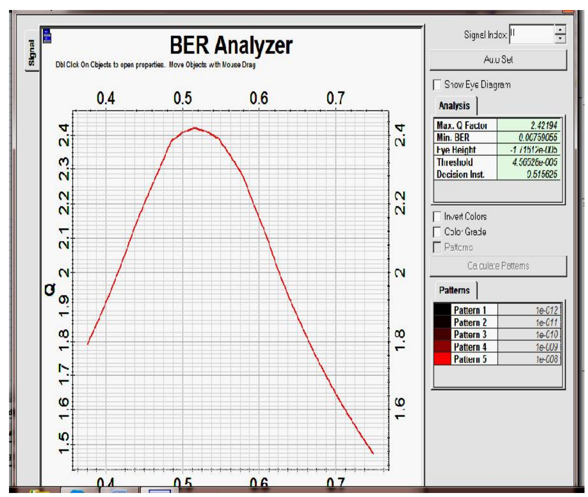


Figure13. Output Optical Signal at the Fiber length 130 km

The output optical signal after using Fiber Bragg Grating mechanism is shown in Figure 14.

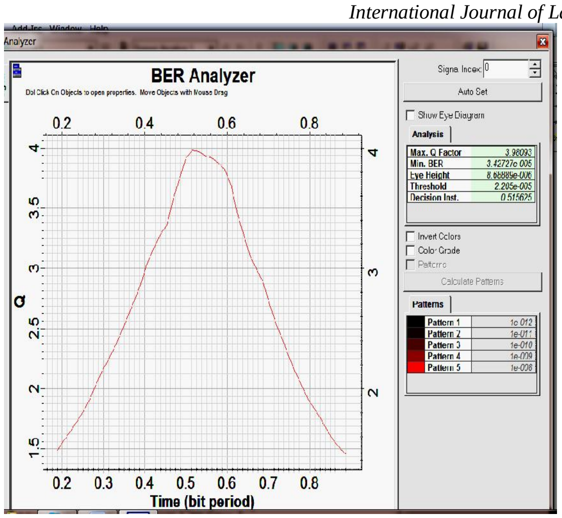


Figure14. Received Optical Signal of Fiber length 130 km after using FBG

It is clear from Figure 14 that the implantation of Fiber Bragg Grating mechanism even for long distance transmission (130 km) enhances the optical output signal at the receiver.

One more test is made in the proposed system by introducing the data rate of 40 Gbps. It is found that the received signal is significantly degrades as compared to the results obtained for the transmitted signals when the data rate is 10Gbps. It found that the 40Gbps data rate gives good results for only 5 km of the transmission distance. This means that the dispersion compensation has to be employed even for such short distance because high data rate has great influence in the dispersion phenomenon. It found that the channel with data rate of 40Gbps is sixteen times more sensitive to dispersion when compared to 10 Gbps and its very obvious that increasing of data rate lead to decrease the transmission distance. In both cases, the aim is to find out the maximum transmission distance of the optical data with less dispersion and degradation.

5. CONCLUSION

In this paper a single mode optical communication link is constructed and simulated using Optisystem7.0. The degradation effect in the optical signal at the receiver is studied and analyzed for the transmission speed of 10 Gbps and a distance of 60 km, 100 km and 130 km respectively. The results show that the optical signal degrades when the transmission distance exceeds 60 km. An optical amplifier is introduced to eliminate the attenuation effect on the transmitted signal. It is found that at the speed of 40 Gbps the system performance limited to a distance of 5 km and this is due to the high dispersion effect.

The results also show that Chromatic dispersion is the most significant affect of degradation phenomenon. The absence of nonlinear effect is also observed when the transmission power in the range of 1mw to 15mw. Fiber Bragg Grating is employed, to reduce the pulse spreading as well as the BER and to increase the Q- factor. The results indicate that nonlinear effect is negligible when the transmission power is in the range of 1mw to 15mw.

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