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Optimal Analysis of 40 Gbps Dispersion Compensated Optical Fiber System †

Murad Hassan * and **Arslan Arif**

Department of Electrical Engineering, University of Gujrat, Gujrat 50700, Pakistan; arslan.arif@uog.edu.pk
* Correspondence: murad.hassan@uog.edu.pk
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Abstract: Dispersion is one of the main factors that limit the development of optical fiber communication systems regarding data rate and long distance transmission of the signal. This is because of increases in dispersion with the increase in data rate and distance, resulting in signal degradation. In this work, we propose an optimal dispersion compensated optical fiber system, which is designed on the basis of Q-factor, eye height, and bit error rate. The system operates at a bit rate of 40 Gbps and a distance of 100 km. According to the optimization scheme, the system is simulated using the modulation format Non Return to Zero (NRZ) with uniform and Linear Chirped Apodized Fiber Bragg Grating (LCAFBG) as dispersion compensator. After deciding the Fiber Bragg Grating (FBG) structure, other key parameters are simulated to meet the requirements. The simulation results show that using NRZ modulation format with a LCAFBG Tanh profile gives better performance.

Keywords: dispersion; optimal; chirped; apodized; fiber bragg grating (FBG); non return to zero (NRZ); linear chirped apodized fiber bragg grating (LCAFBG)

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1. Introduction

Recent economic, technological, and population increases have substantially increased communication data utilization globally. During the past decade, the rise in cloud computing, Internet of Things (IOT), and 5G communication has increased bandwidth requirements. Keeping in view the COVID-19 pandemic, the paradigm shifts from physical work to online have increased the bandwidth utilization and quest for more communication resources to meet the global challenges. The enhancement of optical fiber communication has been evolving rapidly in the last decade to deliver high-speed and large-bandwidth data transmission resources. The increase in distance causes degradation in signal with numerous losses including attenuation, tap losses, and splice losses in an optical fiber communication link [1]. The signal strength is weakened by these losses, which makes it difficult to detect the signal at receiver end. Signal transmission over fiber for long distances requires compensating all limitations affecting signal strength. In the optical domain, optical amplifiers, and Single Mode Fiber (SMF) are employed for amplifying and lowering dispersion in signals, providing a new way for research to flourish in technologies allowing transmission over longer distances with high bit rates. This work analyzes the performance of an optical communication link for 40 Gbps data rate over the distance of 100 km using 1520 nm wavelength. Erbium-Doped Fiber Amplifier (EFDA) is used as an optical amplifier because of its ability to link a large number of signal channels, enhancing capacity and gain [2]. A Fiber Bragg Grating (FBG) filter is utilized as a dispersion compensator to minimize Bit Error Rate (BER) and to increase bandwidth capacity. The performance matrices are based on FBG apodization functions (Uniform, Gaussian, and Tanh) comparing two modulation techniques, i.e., Return to Zero (RZ) and Non Return to Zero (NRZ). The results are compared on the basis of input power, apodization length, BER, and Q-Factor [3].

A severe limitation faced by engineers is the fiber chromatic dispersion in long-distance optical transmission systems. The fiber chromatic dispersion is directly proportional to the fiber transmission length, resulting in an unendurable amount of distortion that eventually leads to errors. Therefore, it is compulsory to use dispersion compensator devices to reduce unwanted distortion [4]. The simple optical communication system comprises transmitters, optical fibers, and receivers.

Optical amplifiers are used to transmit terabits of data over long distances by overcoming the fiber loss limitation to longer distances. The deployment of a Wavelength Division Multiplexing (WDM) system boosts the capacity, which requires an EDFA optical amplifier [5]. The core concept in EDFA technology is the use of silica fiber doped with erbium. Another element used to compensate dispersion is a Fiber Bragg Grating (FBG) filter device. FBG is applied for removing dispersion and used as an economical filter for wavelength selection [6]. The FBG is able to reflect specific wavelengths because of recurring variations in Refractive Index (RI) of fiber core.

The major factors that determines the quality of the communication system depends on formatting of codes and modulation of the signal. The modulated signal is added with an external electrical signal; for this purpose, the two most used RZ and NRZ modulation techniques are used [7]. The modulated signal is transmitted to the receiver through single-mode fiber SMF.

2. Methodology

This work proposes an optimal analysis of maximum data rate of 40 Gbps using distances up to 100 km. The simulation was performed using software OPTISYSTEM 7. An optical channel was made using different devices to work on an optical link with least dispersion and high Q factor. The technique used for simulation is based on the NRZ modulation format. The apodization profile of FBG is tanh, Gauss, and uniform is used to make the optical link. According to this scheme, the simulations are carried out for a continuous wave CW laser with different values of power inputs. EDFA optical amplifiers are used to transmit high bit data in the optical communication link.

As shown in Figure 1, the optical communication link was designed using OPTISYSTEM 7 software. The optical system in the figure contains a bit sequence generator from which we can change the data rate. This defined bit sequence is fed into the pulse generator, where NRZ modulation format is used to compare the Q factor. The generated electrical signal is the input of Mach Zehnder modulator that combines the modulated pulse with the CW laser. Apodization parameters tanh, Gauss, and uniform are used for finding the optimal Q factor. The resulting signal of the MZ modulator then travels from two single-mode fibers (SMFs) of 50 km separated with optical amplifiers of EDFA with a gain of 20 dB. Forty gigabytes per second of bit data, after travelling 100 km, are fed into fiber Bragg grating, which reduces the unwanted dispersion in the signal. A low-pass Bessel filter is used to limit the noise power. The results are measured using a BER and eye diagram analyzer.

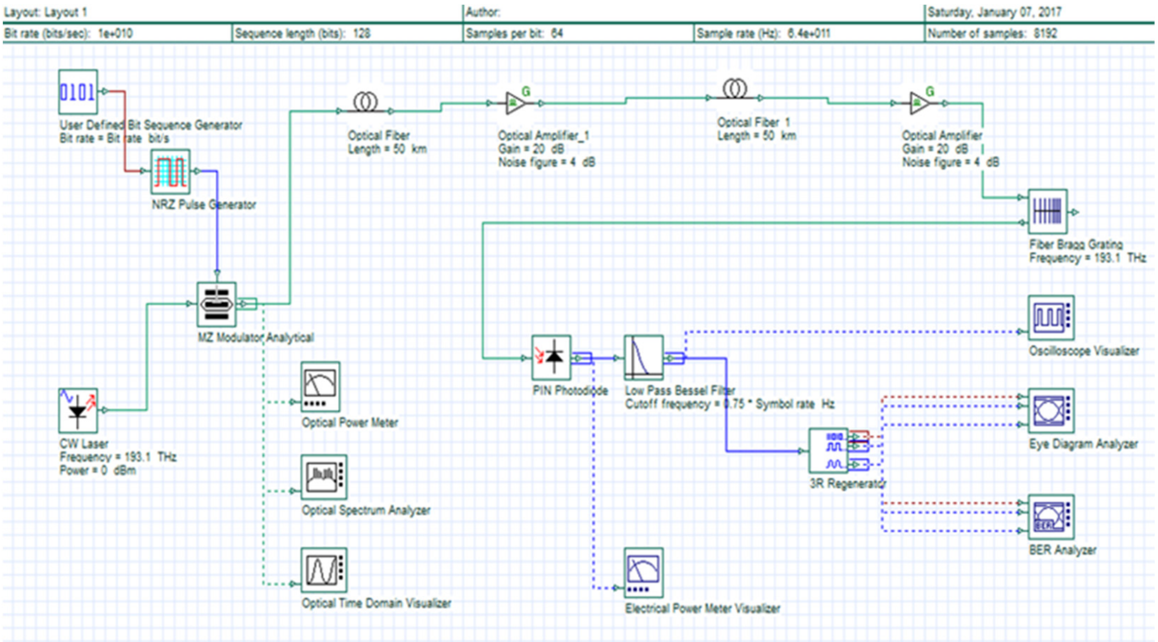


Figure 1. Design system layout for simulation.

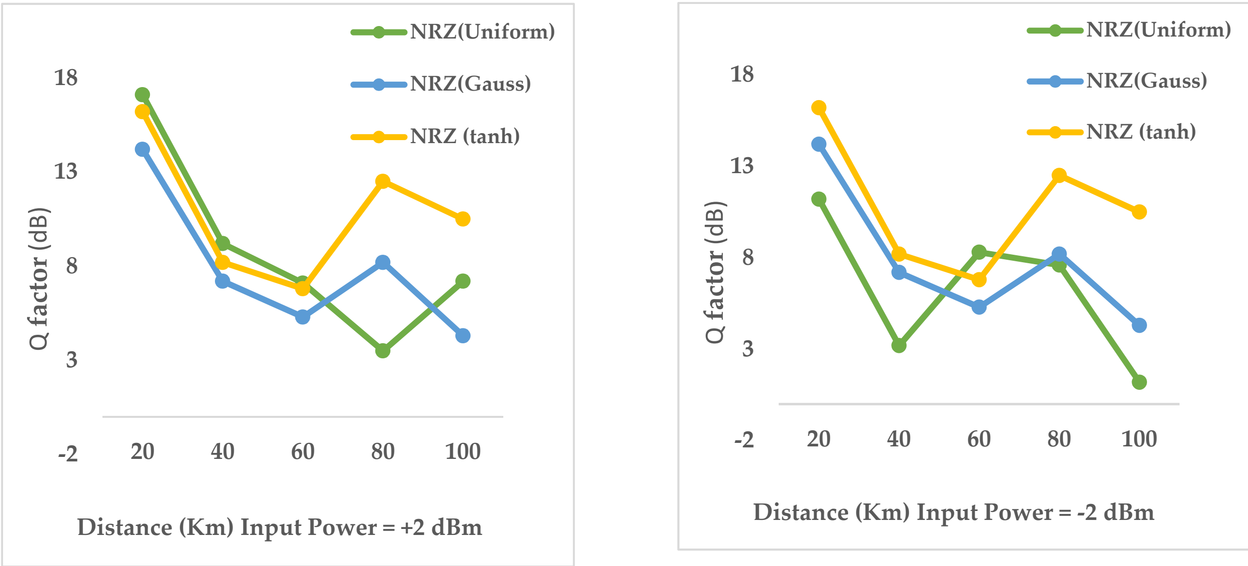
3. Results

The designed optical communication link is evaluated using OPTISYSTEM software" (Optiwave Systems Inc., Nepean, ON, Canada). Based on different qualitative parameters used in the simulation, which are shown in the Table 1 below.

Table 1. Parameter values used for simulation setup.

Parameters	Values
Input power CW laser P_i	−10 to +15 dBm
Laser frequency	1480 nm, 1550 nm
Modulation Format	NRZ
Fiber length	100 km
Bessel filter cutoff frequency	0.75 Bit symbol rate Hz
Gain of EDFA	20 dBm
Noise	4 dBm
MZ apodization parameter	Tanh, Gauss, Uniform

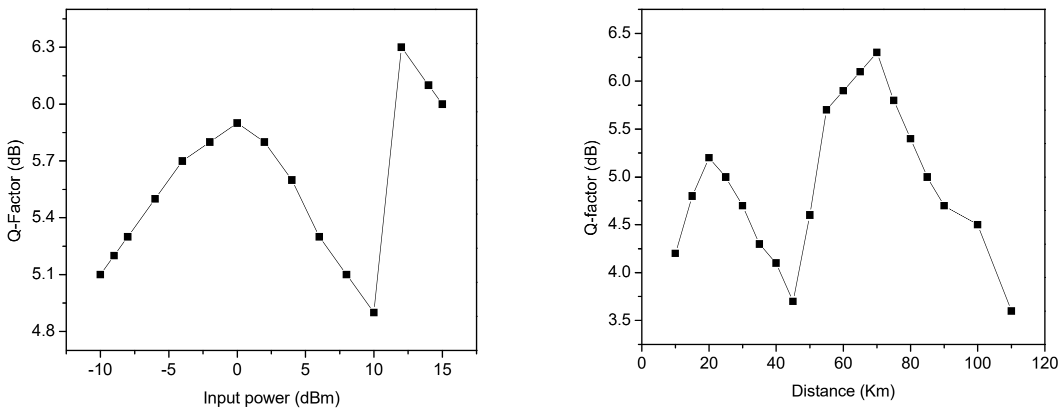
For optimal FBG structure, the simulation is carried for different input values of CW with laser changes from −2 dBm to +2 dBm. Figure 2 below shows the results using NRZ modulation format, and Tanh Apodized FBG profile gives the better Q factor as compared to Gauss and uniform for 100 km fiber length.



(**a**) (**b**)

Figure 2. Performance of FBG for different input values (**a**) Pi = +2 dBm, (**b**) Pi = −2 dBm.

The next phase is to define the optimal input power for communication link that gives maximum Q factor. CW laser input power varies within a range of −10 dBm to +15 dBm. Power less then −10 dBm is not chosen because of low OSNR, and the power chosen must not be greater than +15, as this causes nonlinear effects to the system. The following Figure 3a shows that simulation result of input power of CW laser. The graph shows that the optimal value of input power is +12 dBm, which gives the high Q factor to the designed optical system. After finding the optimal values of FBG performance and input power of CW laser, the next parameter is an amplifier span length (L_a). This is the distance at which the optical amplifier would be placed from the transmitter end. EDFA with the gain of 20 dBm and noise of 4 dBm is used for this simulation.

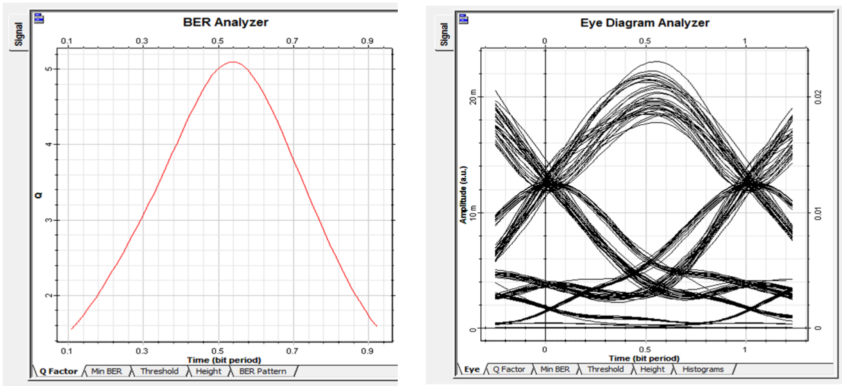


(**a**) (**b**)

Figure 3. Optimal analysis for Q factor, (**a**) CW laser input power, (**b**) OF distance.

Figure 3b above shows the optimal value of amplifier span length at which the maximum Q factor occurs. It may be seen that the length of span is 70 km where this designed optical link gives the maximum Q factor.

All the optimal values of parameters found above are then fed into the system as input in Figure 1. The final simulation values are shown Figure 4b below. The results show a Q factor of 9.58 dB, BER of 4.34×10^{-10}, and Eye Height of 1.61.



(**a**) (**b**)

Figure 4. Simulation results (**a**) Bit Error Rate (BER) analyzer, (**b**) eye diagram analyzer.

Conflicts of Interest: The authors declare no conflict of interest.

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