Comparative Analysis of Dispersion Compensating Fiber (DCF) and Multiple Optical Phase Conjugation (OPC) modules used for Dispersion Compensation and Nonlinearity Mitigation

Aradhana Asiwal
PG Student, ECE Department, PEC University of Technology, Chandigarh, India
Email: annu.asiwal1991@gmail.com

Divya Dhawan
Assistant Professor, ECE Department, PEC University of Technology, Chandigarh, India
Email: divyadhawan@pec.ac.in

Abstract: Optical communication when used for long haul communication is characterized by dispersion and nonlinearities. Different techniques are used for the dispersion compensation and nonlinearity mitigation. Two of these techniques are Dispersion Compensating Fiber (DCF) and Optical Phase Conjugation (OPC). In this paper the performance of the system is analyzed by comparing various results at the receiver. A 10Gb/s NRZ signal is launched into a long Single Mode Fiber (SMF). Results in the terms of Q-factor (linear) and BER are observed by varying fiber length. Optical system consisting of one OPC and two OPC is also analyzed for different transmission distance. Simulation results show that, when compared with optical system consisting of one OPC, Q-factor improvement of 3.51 is achieved for the optical system consisting of two OPC. Nonlinearities are mitigated using DCF and OPC and on comparing with DCF, Q-factor improvement of 11.3 is achieved for OPC.

Keyword: *Dispersion Compensating Fiber (DCF); Optical Phase Conjugation (OPC); Single Mode Fiber (SMF).*

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1. INTRODUCTION

Due to demand of internet in daily life, there is a rapid growth in communication technologies like optical communication which have some promising advantages in terms of bandwidth, input power and losses in the channel over other communication forms. But in optical communication, dispersion and nonlinearities are two major problems faced by systems installed worldwide. The reliability of optical system is affected by broadening of pulse called dispersion which causes Inter-Symbol Interference (ISI) and it limits the length and capacity of the transmission system. Optical system performance degrades by chromatic dispersion (CD) with length of fiber more than 100kms. To compensate dispersion few techniques have been proposed for optical system[1], among them Optical phase conjugation, uses phase conjugated wave to compensate dispersion at the receiver which is innovative over other compensation techniques like DCF and Fiber Bragg Grating (FBG), etc.

2. DISPERSION COMPENSATING TECHNIQUES

2.1 Dispersion Compensating Fiber (DCF)

DCF is known to be a good technology for the compensation of dispersion. The positive dispersion of the conventional fiber is reduced by large negative dispersion coefficient of DCF. Proper length of DCF is required which can compensate the dispersion of conventional fiber.

Depending on the position of the DCF, Compensation is done by three different methods:

A) Pre-Compensation
B) Post-Compensation
C) Symmetrical-Compensation

A DCF must have small insertion loss, low optical nonlinearity, small polarization mode dispersion and it should also have large chromatic dispersion coefficient to decrease the size of DCF. Always a small size of the DCF is better. Net dispersion is reduced to zero if a DCF with negative dispersion is placed after a SMF with positive dispersion.

$$D_{SMF} \times L_{SMF} = - D_{DCF} \times L_{DCF} \quad \ldots\ldots(1)$$

Where D is the dispersion and L is length of each fiber respectively [2].

2.2 Optical Phase Conjugation (OPC)

Optical phase conjugation (OPC), also referred as Mid Span spectral inversion (MSSI), is a promising technology firstly proposed by Yariv et al. in 1979 to mitigate impairments in long-haul communication systems such as Kerr effect and chromatic dispersion [3][4]. OPC is placed at the mid of the fiber link so that the distorted signal after passing through the first fiber span get compensated after passing through OPC [5]. The principle of operation for OPC block is phase inversion according to:

$$\text{Ein}(t) = A(t)e^{j\phi(t)} \qquad (2)$$

$$\text{Eout}(t) = \eta A(t)\, e^{-j\phi(t)} e^{j\phi shift} \qquad (3)$$

Where η is device efficiency, ϕshift is a extra phase shift. Here ϕshift is equal to π/2 and η=1 [6].

In this paper, the use of DCF and OPC is proposed to

ISSN: 2321-8169
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compensate the CD and nonlinearities in 100 km long Single Mode Fiber (SMF). Then this length is varied by increasing fiber spans. Simulation results show that, when OPC is compared with DCF, improvement in Q-factor is achieved.

3. SIMULATION SETUP

Figures 1, 2 and 3 show the simulation setup of optical communication system. Simulation is carried out using Optsim Software to demonstrate the effect of various dispersion compensation and nonlinearity mitigation techniques and the results are being compared.

Simulation setup of an optical communication system is designed in which transmitter consists of a PRBS (Pseudo Random Bit Sequence) generator which transmits data at a bit rate of 10Gbps. PRBS transmit the data to Electrical Signal Generator which uses a NRZ modulation and a voltage signal. A continuous wave (CW) laser with external modulation at a wavelength of 1550nm is used as a source. Laser power used is 0dBm (1mW). Data from Electrical Signal Generator and continuous wave laser is transmitted to Electro absorption Modulator where it gets modulated using Mach Zehnder modulator. The modulated signal is transmitted through a transmission distance of 100 km. Transmission distance consist of single mode fiber (SMF) whose length is 80 km and Dispersion compensation fiber (DCF) whose length is 20 km. Loss in single mode fiber is 0.25dB/km and dispersion slope is 90 S/m^3 and loss in Dispersion compensating fiber is 0.5dB/Km and dispersion slope is -360 S/m^3. The positive dispersion of SMF is compensated by negative dispersion of DCF. Nonlinearity factor and diameter of SMF and DCF are 2.6$e^{-20}m^2/W$ and 8.2e^{-6} m respectively. Data is transmitted through the fiber and received at the receiver. Before receiver the data is passed through the optical power normalizer whose average output power is -22dBm. Receiver with low pass filter and 1 GHz bandwidth is used followed by a BER tester. Eye diagram analyzer is also used. Property Maps are used to observe the dispersion maps of Pre-, Post- and Symmetrical-DCF. Optical Phase Conjugation (OPC) is also used in place of DCF for dispersion compensation. It is used in the middle of the fiber link as shown in Fig. 4. The length of fiber before and after OPC is same to mitigate the dispersion and nonlinearities more effectively.

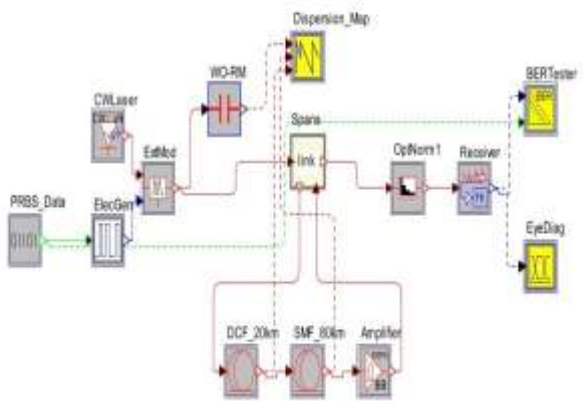

Figure 1 Simulation setup of an optical communication system consisting of DCF for dispersion compensation

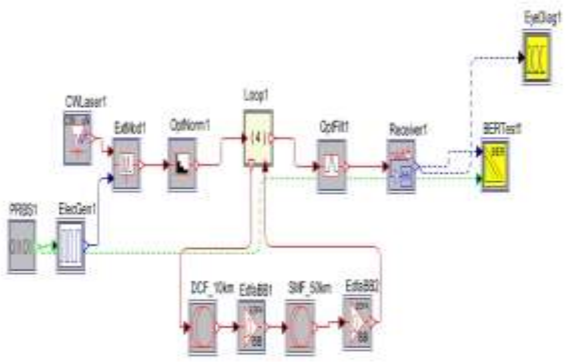

Figure 2 Simulation setup of an optical communication system consisting of DCF for nonlinearity mitigation

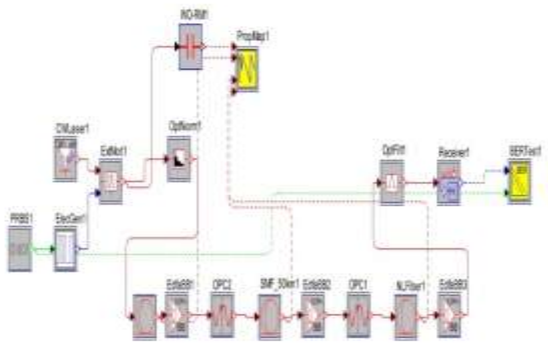

Figure 3 Simulation setup of an optical communication system consisting of two OPC

4. SIMULATION RESULTS AND DISCUSSION

The performance of the system is analyzed in terms of Q-factor and BER.

Figure 4 shows that Q-factor decreases and BER increases as the transmission reach increases. But using two OPC instead of one OPC is more beneficiary for an optical communication system. Distortion is very less and high Q-factor is achieved [7][8]. For a distance of 100 km, the Q-factor achieved for an optical communication system consisting of two OPC is 21.4 which is almost twice as that of system consisting of one OPC. High Q-factor and low BER i.e., 21.4 and 2.34e^{-102} are achieved respectively. At 120 km distance, the Q-factor for one OPC and two OPC are 4.12 and 9.06 respectively. Again, at 120 km Q-factor of optical communication system consisting of two OPC is more than twice as that of system consisting of one OPC. BER achieved for an optical communication system consisting of one OPC and two OPC are 1.86e^{-5} and 6.57e^{-20} respectively. The BER of an optical communication system consisting of two OPC is very less as compared to an optical communication system consisting of one OPC. For 140 km transmission distance, Q-factor for one OPC and two OPC are 0 and 3.51 respectively and BER values are 1 and 2.22e^{-4} respectively for one OPC and two OPC.

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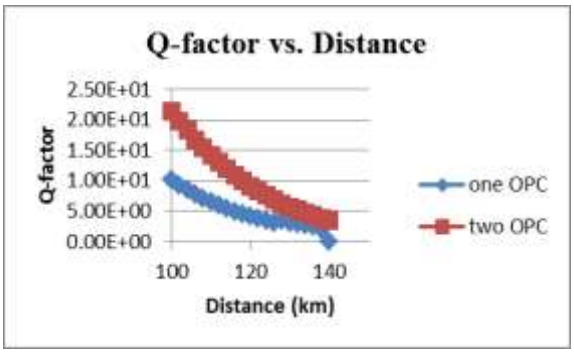

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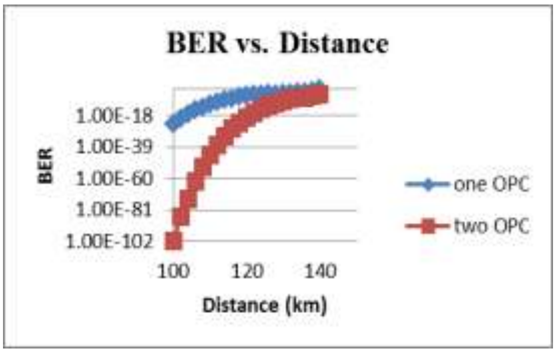
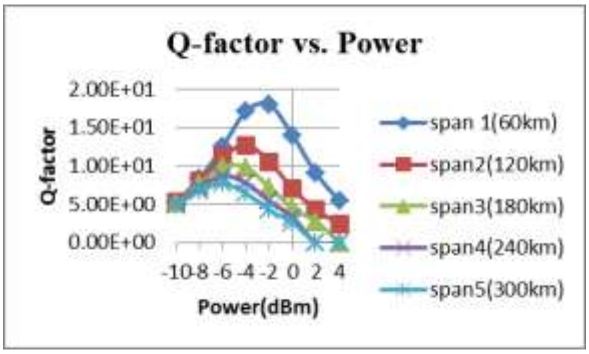


(b)

Figure 4 Comparison of an optical system consisting of One OPC and Two OPC (a) Q-factor vs. Distance and (b) BER vs. Distance



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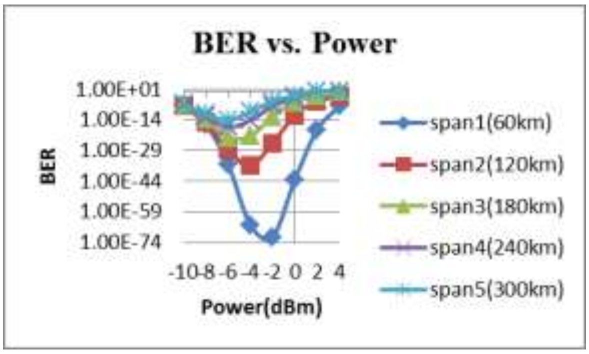
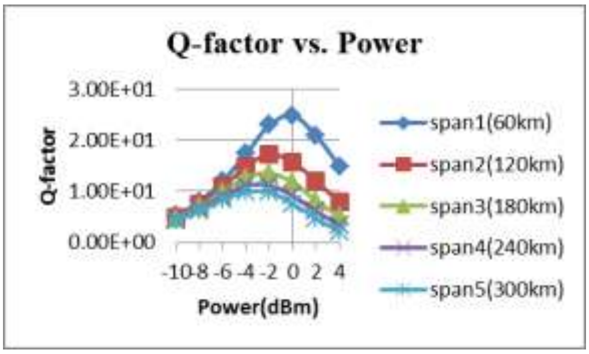


(b)

Figure 5 Performance of an optical system using Pre-DCF (a) Q-factor vs. Distance and (b) BER vs. Distance



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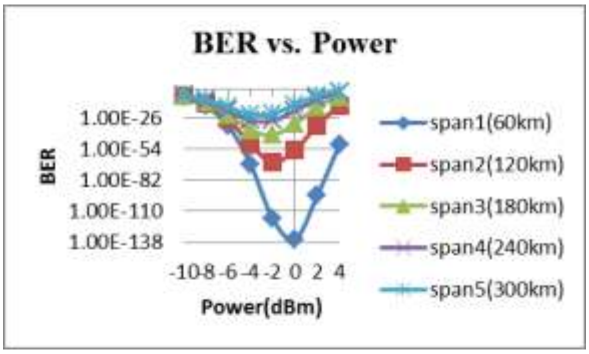
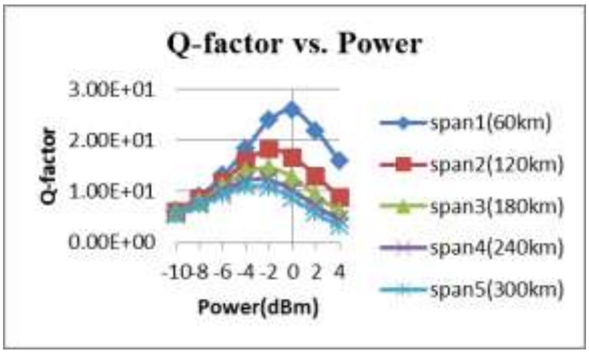


(b)

Figure 6 Performance of an optical system using Post-DCF (a) Q-factor vs. Distance and (b) BER vs. Distance



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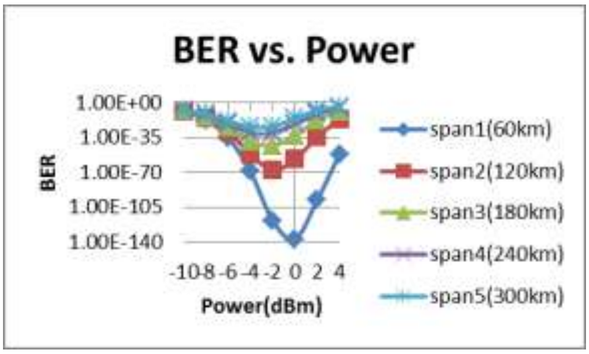
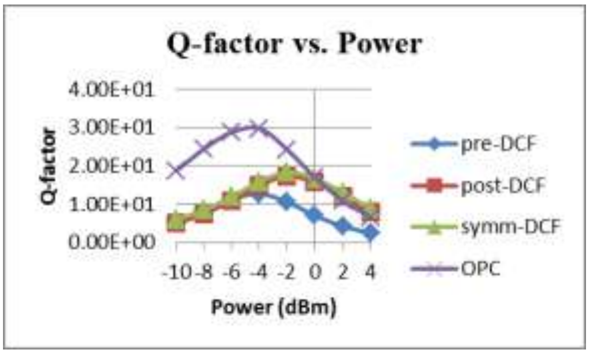


(b)

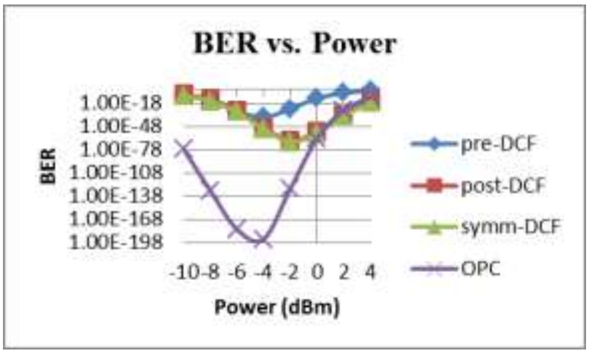
Figure 7 Performance of an optical system using Symmetrical-DCF (a) Q-factor vs. Distance and (b) BER vs. Distance

Figures 5, 6 and 7 show the Q-factor and BER performance of Pre-, Post-, Symmetrical-Compensation. Maximum nonlinearities are mitigated for 60 km transmission distance.

As the transmission distance increases, Q-factor decreases and BER increases. For the transmission distance of 60 km, the maximum and minimum value of Q-factor and BER are 17.934 and $3.22e^{-72}$ respectively at launch power of -2dBm. Maximum Q-factor and minimum BER for different transmission distance after mitigating nonlinearities using Post-DCF. Maximum nonlinearities are mitigated for 60 km transmission distance. As the transmission distance increases, the Q-factor decreases and BER increases. For the transmission distance of 60 km, the maximum and minimum value of Q-factor and BER are 24.811 and $3.41e^{-136}$ respectively at launch power 0dBm which are improved results than Pre-DCF. Maximum Q-factor and minimum BER for different transmission distance after mitigating nonlinearities using symmetrical-DCF. Maximum nonlinearities are mitigated for 60 km transmission distance. The values of Q-factor and BER observed for a transmission distance of 60 km are 25.811 and $3.41e^{-138}$ respectively at launch power 0dBm.



(a)



(b)

Figure 8 Comparison of DCF and OPC for 120km transmission distance (a) Q-factor vs. Distance and (b) BER vs. Distance

Performance of nonlinearity mitigation techniques i.e., DCF and OPC is observed for a transmission distance of 120 km. Results of nonlinearity mitigation are observed by varying launch power from -10dBm to 4dBm in terms of Q-factor and BER as shown in Figure 8. Nonlinearities are mitigated by using Pre-DCF at a distance of 120 km by varying launch power from -10dBm to 4dBm. The maximum and minimum values of Q-factor and BER are 12.7 and $3.18e^{-37}$ respectively at launch power -4dBm. Later on, nonlinearities are mitigated by using Post-DCF at same distance and same power. The maximum and minimum values of Q-factor and BER are 17.2dB and $7.01e^{-67}$ respectively at launch power -2dBm. Performance of Post-DCF is improved as compared to Pre-DCF. Now nonlinearities are mitigated using Symmetrical-DCF for the same distance and same power. The maximum and minimum values of Q-factor and BER are 18.4 and $7.01e^{-70}$ respectively at launch power -2dBm. Results of Symmetrical-DCF are almost similar to Post-DCF. There is very little increment in Q-factor. Finally, the nonlinearities are mitigated using Optical Phase Conjugation (OPC). The maximum and minimum values of Q-factor and BER are 29.7 and $1.87e^{-194}$ respectively at launch power -4dBm. The results of OPC are much improved as compared to DCF. High Q-factor and very small BER is achieved using this technique. The Q-Factor of OPC is better than that of DCF because OPC is implemented in the middle of the transmission link and the effect of dispersion is equalized [9][10].

5. CONCLUSION

Though DCF is a good technique for dispersion compensation but because of certain disadvantages like high insertion loss, bulkiness, limited input power, presence of residual dispersion, high order derivatives, high attenuation, low negative dispersion, etc., OPC is more suitable and reliable for the compensation. When OPC is used results in terms of Q-factor and BER are improved to a greater extent. Many studies are accepted in this perspective to reduce the effect of Dispersion to large extent by introducing new system design.

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Authors Biography

Aradhana Asiwal, is a PG Student, of Department of ECE in PEC University of Technology Chandigarh, India. She completed her B.Tech in department at SPSU, Udaipur, Rajasthan, India.

Mrs. Divya Dhawan is currently working as Asst. Professor in ECE Department of PEC University of Technology Chandigarh, India. She has a teaching experience of nearly 18 years. She is a member of IEEE, ISTE, and IEI. Her research interests include Optical Communication, Photonics Systems and Digital system design.