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SPM limited long haul optical transmission in RZ-DPSK for varying input launch power with SMF, Monte Carlo Simulation

Devendra Kumar Tripathi* , H.K.Dixit, N.K.Shukla

J.K.Institute of Applied Physics and Technology University of Allahabad- (INDIA).
*E-mail:dekt@rediffmail.com

Abstract

In this paper 10Gbps and 20Gb/s optical systems have been studied for return to zero differential phase shift keying. Observations are based on numerical simulations of dispersion compensated transmission link, for the range of optical signal power -2.5 to +2.5,-5 to +5,-10 to +10,-20 to +20dBm.Transmission over distances of four thousands of kilometers has been shown with amplified spontaneous emission (ASE) noise of the inline erbium doped fiber amplifier.

Key words: DWDM, OSNR, ASE, RZ, DPSK

1. Introduction

Tremendous increase in bandwidth demanding applications in the sectors of television, telephony and internet requires the backbone of all data communications, the long-haul transmission systems, to increase their bandwidth as well. Long-haul optical transmission systems spectral capacity of have been increasing at a rate exceeding the Moore's Law and demand for higher bandwidth has been enhancing even faster. Optical capacity of fiber can be increased by minimizing fiber loss, or increasing the OSNR, reducing the channel spacing, increasing the low loss window to fit more WDM channels, or making better use of the existing window by employing higher order modulation formats [3]. All of these choices face several technical issues, and a common underlying limitation is fiber nonlinearity. Hence both research and product development of scaling optical transmission systems to such line rates has received a lot of attention during the last decade. There are several ways to realize an increase of the line rate per wavelength channel [1].However with the continuous evolution in technology the modulation format considered to be the most suitable for long haul transmission has shifted as well [2].

Bit rate-distance product is a figure-of-merit of light wave systems. To increase the capacity of light wave systems, or bit rate-distance product, high speed data rate per channel and tighter channel spacing in DWDM systems are the possible solutions. In such high speed DWDM systems, linear and nonlinear impairments become severe. Those linear impairments include chromatic dispersion (CD), and first order polarization mode dispersion (PMD); nonlinear impairments include self-phase modulation (SPM), cross-phase modulation (XPM) and four-wave mixing (FWM). Self-phase modulation (SPM) is a nonlinear optical effect of light-matter interaction. An ultra short pulse of light, when travelling in a medium, will induce a varying refractive index of the medium due to the optical Kerr effect. This variation in refractive index will produce a phase shift in the pulse, leading to a change of the pulse's frequency spectrum .Now to combat both the linear and the nonlinear impairments over the transmission fiber; an optimal modulation format is desired. A modulation format with narrow optical spectrum can enable closer channel spacing and tolerate more CD distortion. A modulation format with constant optical power can be less susceptible to SPM and XPM. A modulation format with multiple signal levels will be more efficient than binary signals and its longer symbol duration will reduce the distortion induced by CD and PMD. In addition, in an optical repetitive amplified light wave system, amplified spontaneous emission (ASE) noise is another concern which requires modulation formats more tolerant to additive ASE noise.

There have been many optical modulation formats in the scope of this researching area. Because of its easy to modulate and demodulate, most of them are binary signaling, e.g. duobinay, VSB/SSB, RZ, phase-shift-keying (PSK) etc. While, others are multi-level signaling, e.g. differential-quadrature-phase-shift-keying (DQPSK), and M-PAM etc. Return-to-zero differential phase shift keying (RZ-DPSK) modulation format is effective to improve the transmission performance of the long-haul optical fiber communication system, and several experimental reports prove this [4–6].Earlier bit-rate dependent performance degradation was observed in the long-haul RZ-DPSK system using the block type dispersion map. The performance was degraded near the system zero dispersion wavelength, and it showed a spectral performance hole near the zero dispersion wavelength [7].

Long-haul optical fiber communication system is an important infrastructure to support the latest broadband communication in the world. It is important to study a technology to improve the performance of such system, and the Return-to-Zero Differential Phase Shift Keying (RZ-DPSK) modulation attracts much attention because of its improved long distance transmission performance.In this paper, the performance of the long-haul RZ-DPSK system is studied as a function of the launch power. The results showed that there exists the launch power dependent performance enhancement and degradation. The degradation is independent to the input launch power, but it is minimum near around 7-8db of power for and for 20Gbps bit-rate of more than about 10Gbit/s.

2. Theory

In order to improve system tolerance to nonlinear distortion and to achieve a longer transmission distance, return-to-zero DPSK (RZ-DPSK) has been proposed. Similar to NRZ-DPSK modulation format, the binary data encoded as either a “0” or a “π” phase shift between adjacent bits. But the width of the optical pulses is narrower than the bit slot and therefore, the signal optical power returns to zero at the edge of each bit slot. In order to generate the RZ-DPSK optical signal, one more intensity modulator has to be used compared to the generation of NRZ-DPSK. The general block diagram of a RZ-DPSK transmitter is shown in Fig.1. First, an electro-optic phase modulator generates a conventional NRZ-DPSK optical signal, and then, this NRZ-DPSK optical signal is modulated by a clock signal with same data rate as the electrical signal through an electro-optic intensity modulator. Sometimes RZ-DPSK is also referred to as intensity modulated DPSK (IM-DPSK) because of its additional bit-synchronized intensity modulation. In this modulation format, the signal optical power is no longer constant; this will probably introduce the sensitivity to power-related nonlinearity like SPM.Due to the narrow optical signal pulse width, the optical spectrum of RZ-DPSK is wider than a conventional NRZ-DPSK. Intuitively, this wide optical spectrum would make the system more susceptible to chromatic dispersion. However, similar to RZ-OOK, RZ-DPSK is more tolerant to data-pattern dependent SPM-GVD effect with optimal dispersion compensation because of its regular RZ waveform.

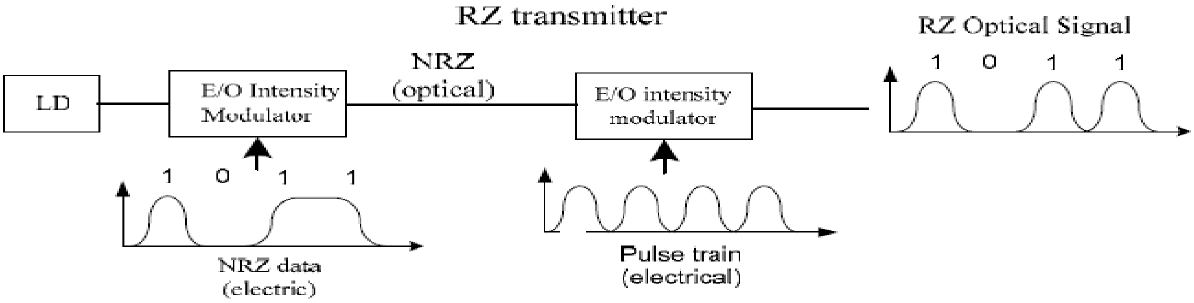

Figure1.Block diagram of RZ Transmitter

RZ means ‘return-to-zero’, so the width of optical signal is smaller than its bit period. Usually a clock signal with the same data rate as electrical signal is used to generate RZ shape of optical signals. RZ transmitter. First, NRZ optical signal is generated by an external intensity modulator then, it is modulated by a synchronized pulse train with the same data rate as the electrical signal using another intensity modulator. RZ optical signal has been found to be more tolerant to nonlinearity than NRZ optical signal. The reason for its superior resistance to nonlinearity than NRZ is probably due to its regular data pattern of optical signal. Because of characteristic of ‘return-to-zero’ of RZ optical signals, an isolated digital bit ‘1’ and continuous digital “1”s would require the same amount of optimal dispersion compensation for the best eye opening. So with the optimal dispersion compensation in the system, RZ format shows better tolerance to nonlinearity than NRZ. The spectrum of RZ is shown in Fig. 1. Compared to NRZ, it has a wider spectrum because of its narrower pulse width. This would lead to less spectrum efficiency for RZ in a WDM system.

3. Simulation Modeling

In simulation model transmitter uses a T Flip-Flop which encodes PRBS binary signal. This encoded signal is then used to generate the transmitted 1550-nm 33% RZ-DPSK optical signal. The signal then propagates over fiber spans; each span consists of 80 km of single-mode fiber (SMF) with a dispersion of 21.42 ps/nm/km, approximately 20.5 km of dispersion-compensating fiber with a dispersion of –83.3ps/nm/km and an EDFA for compensating the fiber loss. A noise adder after the fiber spans merges the optical signal and ASE noise (in both polarizations). A 25-GHz first-order Gaussian optical filter is used, along with a 7.5-GHz 3rd-order Bessel low-pass electrical filter. Estimator for determining the linear noise in the received DPSK signal. Finally, the MC DPSK BER Estimator is connected to the original PRBS bit stream, the DPSK receiver, and the single-ended receiver in order to calculate the link BER.

4. Results and Discussion

Return to zero differential phase shift keying simulation has been carried for over four thousands kilometers for the varying input launch power and bit rates. Figure shows the results of numerical simulations for various data formats. Maximum Q value as a function of number of fiber spans has been obtained for the 10Gb/s system with Pin 8dBm.It is observed that with the increase in the number of fiber spans the Q value decreases. Since only a single channel has been considered in the system, no nonlinear crosstalk is involved, and the signal degradation is mainly attributed to the SPM nonlinearity at such low power. Significant reduction in Q value atthe20Gb/s data rate is observed as compared to10Gb/s for all the formats. Intuitively, optical phase modulation-based RZ-DPSK light wave systems significantly reduce the effect of SPM because the optical power is not modulated. For the RZ-DPSK format, since the optical pulses spread quickly and overlap with adjacent pulses before they reach the effective length of the fiber, the effect of the noise will decrease and it gives the best performance. Also the balanced detection of RZ-DPSK is responsible for its enhanced performance. The RZ-DPSK modulation format gives the best performance for linear ASE noise but, which is consistent with the SPM-induced nonlinear waveform distortion is the dominant effect.

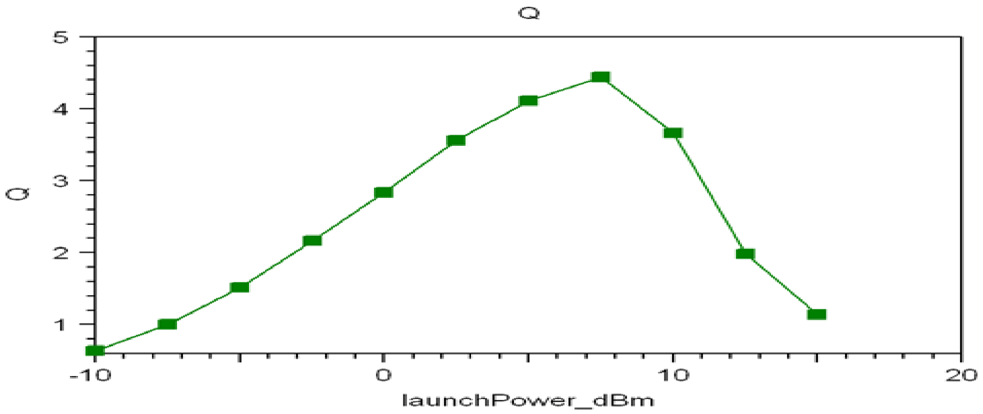

Figure2. MC DPSK Q versus launch power for 10Gbps.

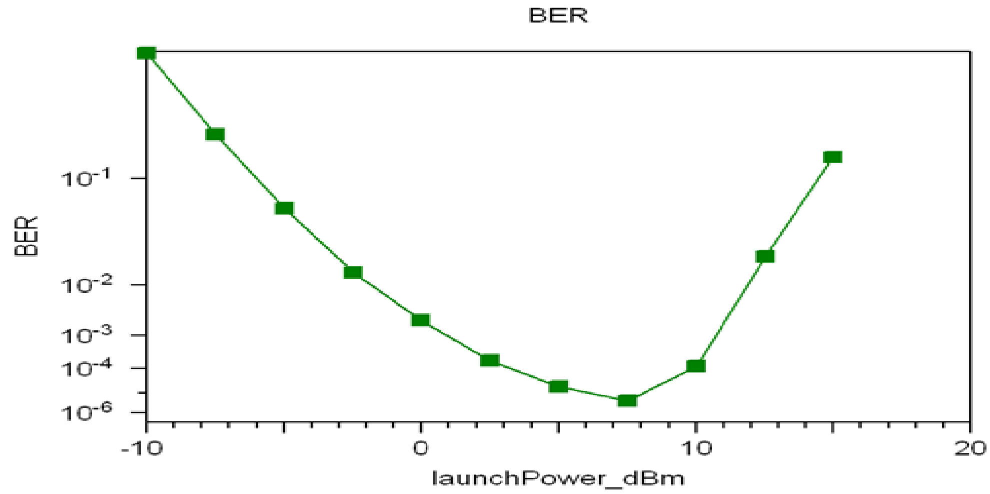

Figure3. MC DPSK BER versus launch power for 10Gbps.

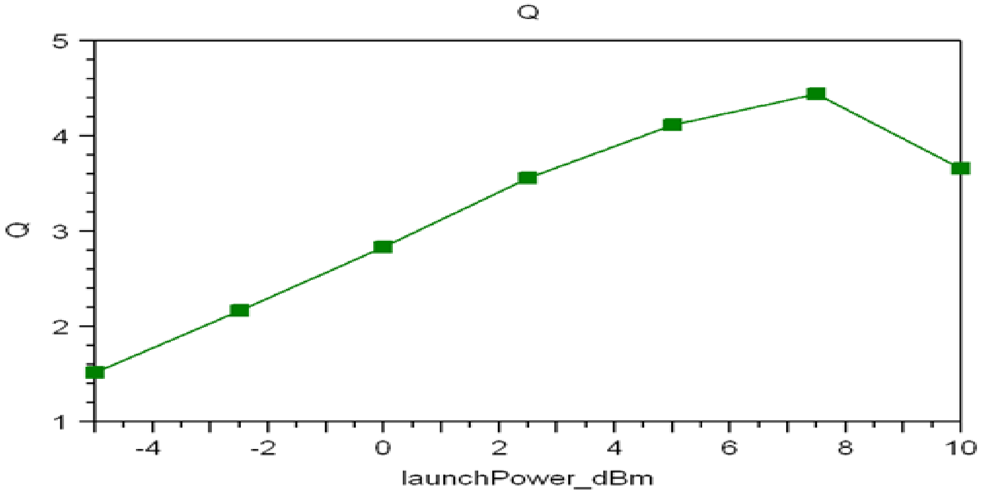

Figure4. MC DPSK Q versus launch power for 10Gbps.

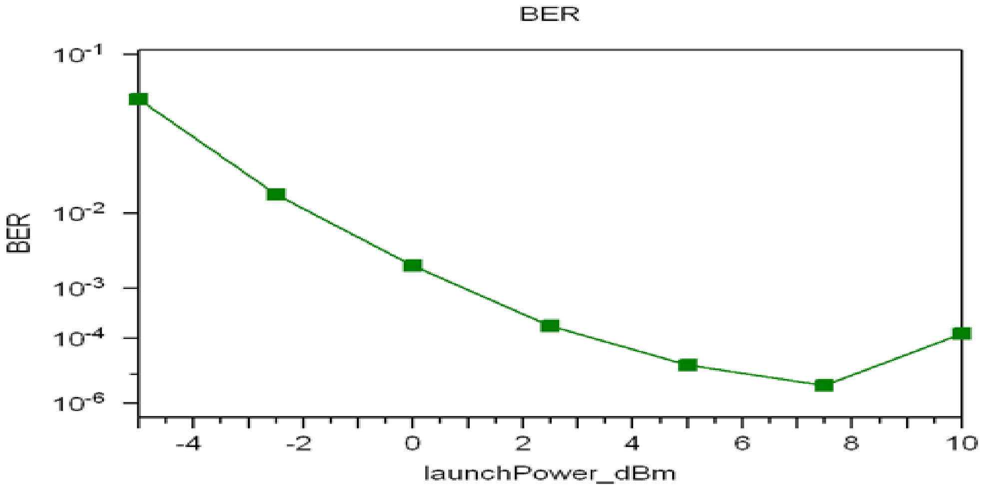

Figure5. MC DPSK BER versus launch power for 10Gbps.

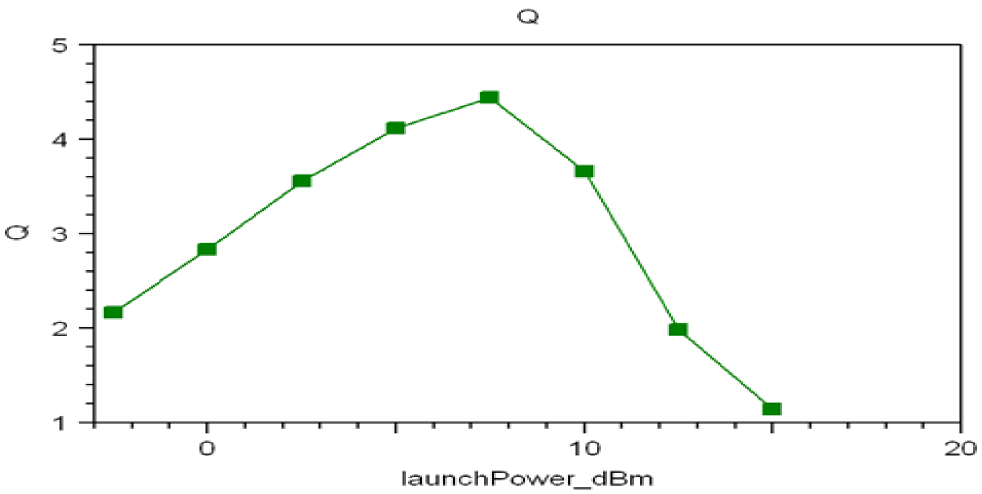

Figure6. MC DPSK Q versus launch power for 10Gbps.

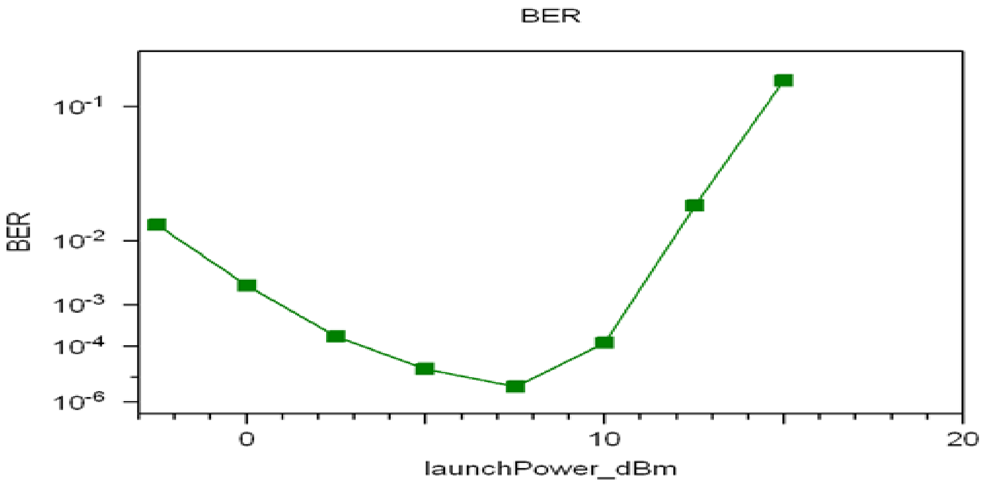

Figure7. MC DPSK BER versus launch power for 10Gbps.

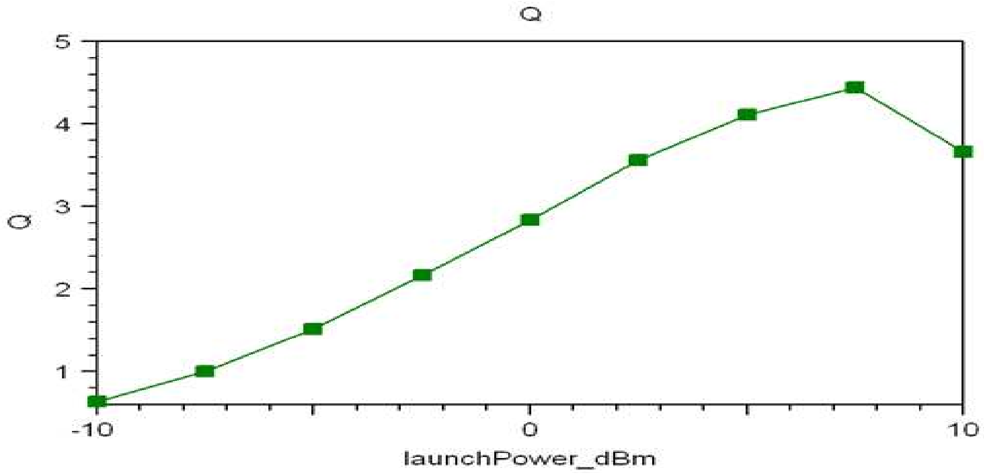

Figure8. MC DPSK Q versus launch power for 10Gbps.

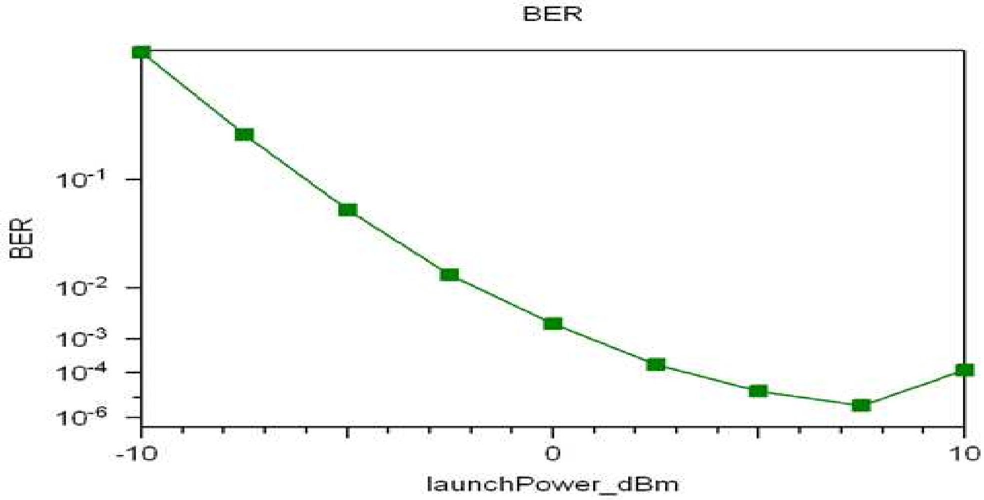

Figure9. MC DPSK BER versus launch power for 10Gbps.

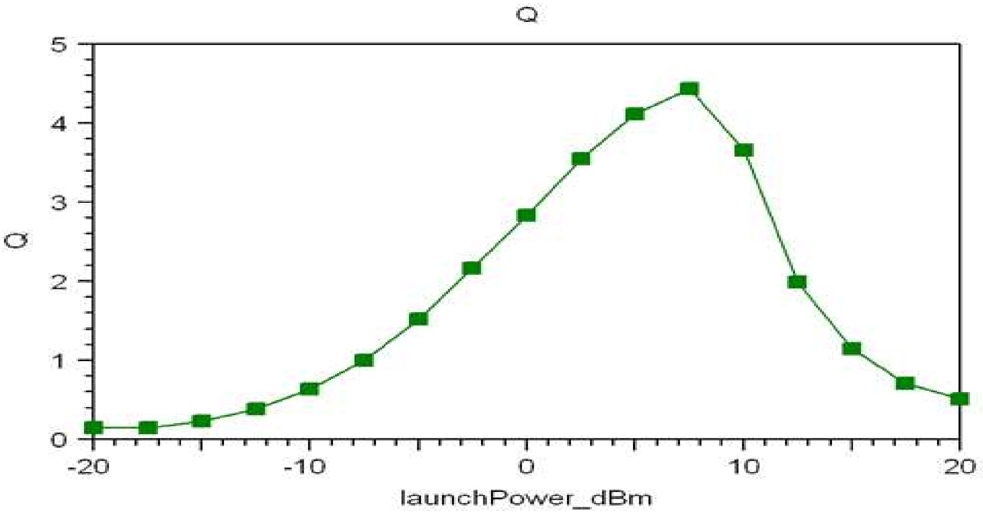

Figure10. MC DPSK Q versus launch power for 10Gbps.

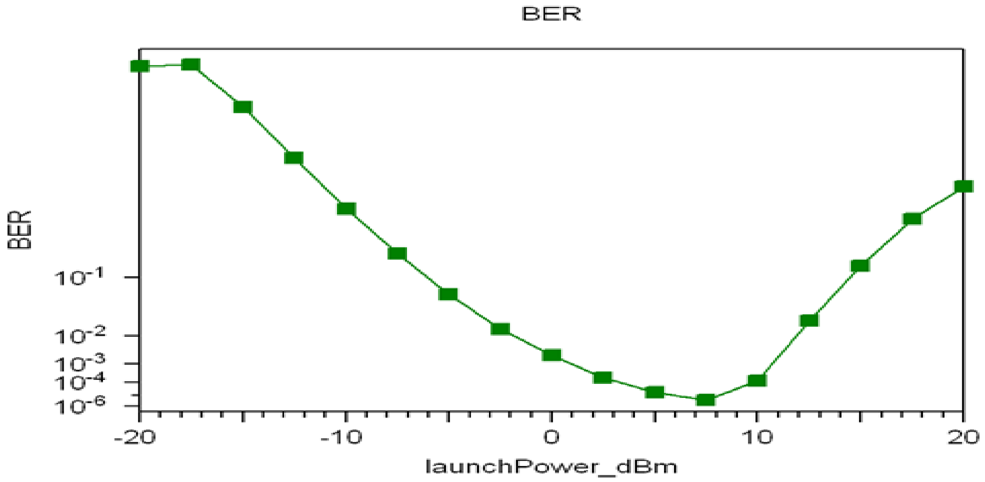

Figure11. MC DPSK BER versus launch power for 10Gbps.

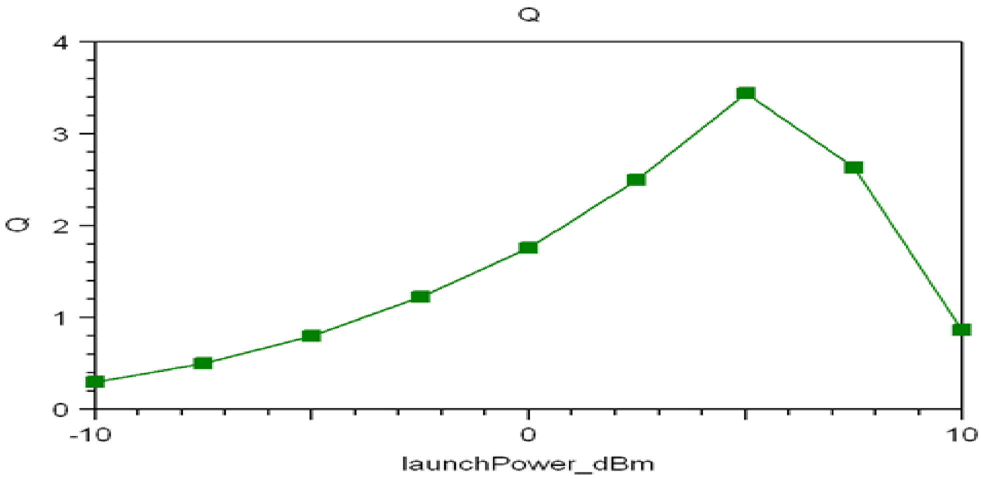

Figure12. MC DPSK Q versus launch power for 20Gbps.

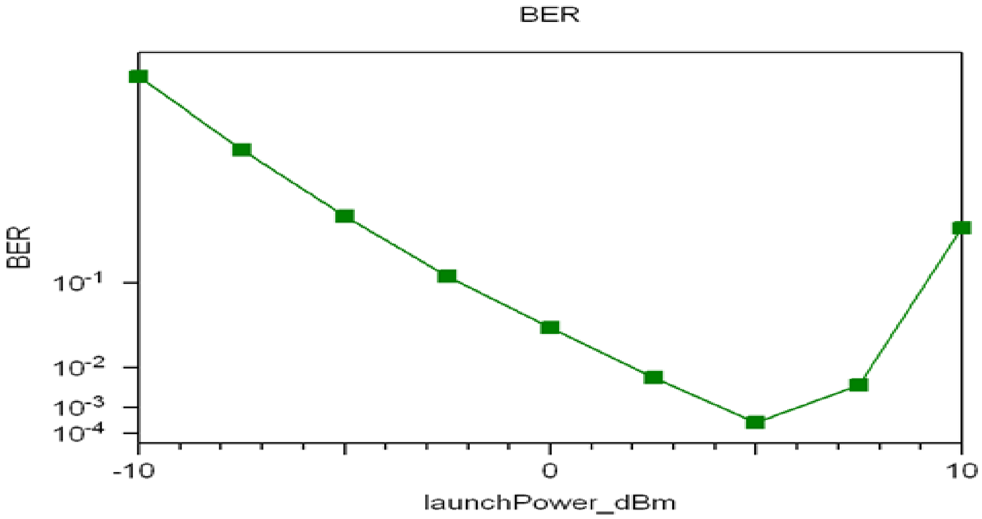

Figure13. MC DPSK BER versus launch power for 20Gbps.

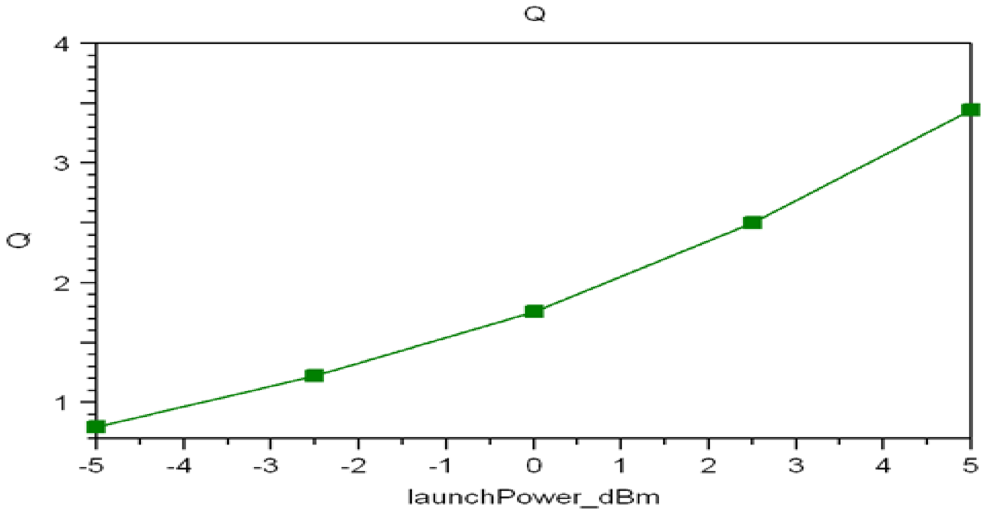

Figure14. MC DPSK Q versus launch power for 20Gbps.

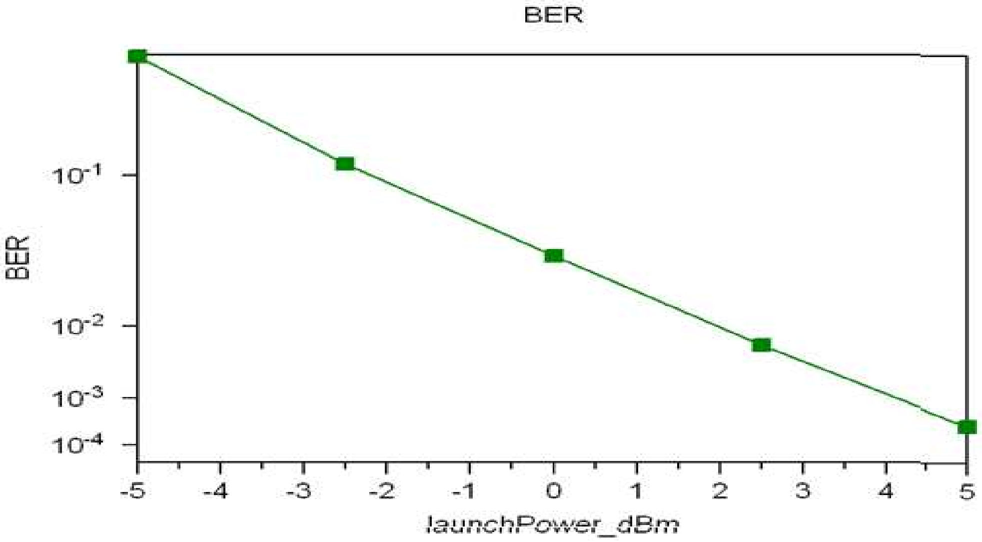

Figure15.MC DPSK BER versus launch power for 20Gbps.

5. Conclusion

Here, performance study for 10Gbps and 20Gb/s systems having optimum post-dispersion compensation using in-line DCF have been carried out for maximum transmission distance of over four thousands of kilometers with ASE noise. The impact of RZ-DPSK data format on the transmission with the variation input powers has been shown. It is also concluded that on the increase of transmission distance and bit rate Q-value decreases.

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Authors

D.K.Tripathi received his B.Sc (Physics) from A.U, B.Tech (electronics and telecommunication) and M.Tech (electronics engineering) from J.K.I.T university of Allahabad (India). Presently he is pursuing P.hd under the guidance of Dr.H.K.Dixit in university of Allahabad (India). His area of interest includes communication technology and fiber optics communication. He is a Life member of ISTE.

Prof. (Dr.) H.K. Dixit is Head of Department of J.K. Institute of Applied Physics and Technology, University of Allahabad (India). He started teaching in the department as lecturer in March 1975 and teaching experience of more than 32 Years. His main research area is fiber optics communication and Holography. He has supervised a number of PhD candidates. He has published a lot of papers in National, International journals and in National and International conferences. He is a member of a number of RDC, and academic bodies of other University and Institution, and life member and fellow in organizations like ISTE, IETE etc

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