Optik 124 (2013) 2593–2596

Contents lists available at SciVerse ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Performance optimization of RZ-DQPSK modulation scheme for dispersion compensated optical link

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ARTICLE INFO

Article history:
Received 16 March 2012
Accepted 23 July 2012

Keywords:
RZ-DQPSK
SSMF
ASE
TW-RS
LEAF

ABSTRACT

This paper presents a simulative analysis for performance optimization of RZ-DQPSK modulation scheme for dispersion compensated Amplified Spontaneous Emission (ASE)-noise-limited optical link at 10 Gbps. The link performance analysis has been carried out for different duty cycles of RZ-DQPSK to achieve an optimized performance of the system at 80% duty cycle. The analysis has also been extended to three different types of commonly used optical fiber: SSMF, TW-RS and LEAF to report the similar qualitative behavior for the optimized duty cycle of the modulation scheme considered. The investigation reported in the paper helps in selecting the type of the fiber and best suitable duty cycle for long distance communication.

1. Introduction

To meet the ever-increasing demand of high capacity optical systems for data transmission at 40 Gbps and beyond with acceptable signal quality tremendous research is being carried out to explore new multiplexing, modulation and optical signal processing techniques [1]. Obviously, as the transmission data rate increases beyond 10 Gbps, the channel dispersion becomes the limiting factor for the successful transmission for a given length of the fiber [2]. Other impairments such as polarization mode dispersion (PMD), self phase modulation (SPM) also become significant at higher data rate transmission [3,4]. Thus to get the optimized performance at higher data rate we need to go for alternative schemes such as dispersion management or different modulation techniques to enhance the spectral efficiency of the system [5,6]. A strong bit pattern dependency in optical transmission links employing multilevel modulation techniques viz. optical differential quadrature phase shift keying (DQPSK) offers various advantages like high spectral efficiency, improved chromatic dispersion (CD) and PMD tolerance and resilience to fiber nonlinearity and thus, is a promising modulation format for high speed data transmission [7,8]. DQPSK is a true multi-level modulation format which allows a transmission of information at four different levels of phase $\{0, +\pi/2, -\pi/2, \pi\}$ of optical signal [9,10]. To investigate the system performance for long-haul communication we have done the analysis with 3 different fiber types such as standard single mode fiber (SSMF), true wave-reduced slope fiber (TW-RS) and the large effective area fiber (LEAF).

The present paper has been organized as follows: Section 2 begins with the description of DQPSK modulation format. Our simulation setup is described in Section 3. Section 4 reports the results and Section 5 concludes the findings.

2. DQPSK modulation format

Duobinary and QPSK are the modulations schemes widely used in optical communication to offer significant bandwidth efficiency. The theoretical bandwidth required to transmit a signal at a rate of R symbols/s with no Inter Symbol Interference (ISI) is $R/2$ Hz [11]. With Duobinary modulation, finite amount of ISI is introduced which is unraveled later, however, it can only transmit 1 bit per symbol and thus, the symbol rate is equals to the bit rate. The QPSK modulation is more bandwidth efficient scheme as it can transmit 2 bits per symbol; therefore the symbol rate is half of the bit rate [12,13]. Thus the effect of dispersion is comparatively low in case of QPSK Modulation. The main problem with the QPSK modulation is its higher OSNR requirement and the complexity of the system [14,15].

DQPSK is the promising alternative as it transmits each differential of phase coded in a group of two bits called symbols such as (11), (10), (00), (01). Hence, the symbol rate is half the bit rate and thus the theoretical bandwidth requirement is ¼ of the bit rate with somewhat reduced complexity of the system [15]. The signal intensity coded in DQPSK remains constant in time, except on the level of transitions from one phase to another where reductions in

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http://dx.doi.org/10.1016/j.ijleo.2012.07.027

Table 1
Physical parameters of the fibers used for the analysis.

Fiber type	Fiber Attn. α_0 (dB/km)	D (ps/nm/km) Ref. λ @1550 nm	Disp. slope S (ps/nm^2/km) Ref. λ @1550 nm	Nonlinear refractive index $n \times 10^{-20}$ m^2/W	Effective core area A (μm^2)	Length for single span (km)
SSMF	0.22	17	0.016	3	80	25
DCF_{SSMF}	0.55	−80	−0.076	2.5	20	5.3125
TW-RS	0.2	4.5	0.045	2.5	55	25
$DCF_{TW\text{-}RS}$	0.55	−80	−0.8	2.5	20	1.40625
LEAF	0.2	4	0.1	2.5	72	25
DCF_{LEAF}	0.55	−80	−2	2.5	20	1.25

the intensity are observed in certain transmission assemblies. Both NRZ and RZ line-coding can be possible with DQPSK modulation but the RZ coding is slightly more complex as compared to NRZ one and at the same time RZ-DQPSK modulated signal is less susceptible to PMD and nonlinear effects [16].

3. Simulation setup

Fig. 1 shows the simulation setup for 10 Gbps RZ-DQPSK modulated optical signal transmission in ASE-noise-limited optical channel. OptSim^{TM} platform [17] has been used to simulate the system in this paper.

Simulation setup remains same throughout the analysis process except we have used different fiber types and the details of which are given in Table 1.

DQPSK pre-coder encodes the data signals from PRBS sources (P) and (Q) so that the signal at the receiver should match the transmitted one. RZ driver 1 and 2 convert the input logical data signal into electrical signal and these electrical signals pass through LPF(P) and LPF(Q) with centre frequency of 15 GHz (in each LPF) for further transmission. DQPSK modulator modulates these electrical data signals with the optical continuous wave signal provided by the optical laser source having output power of −10 dBm, linewidth of 10 MHz and centre frequency of 194 THz and thereafter transmits the RZ-DQPSK modulated optical signal through the optical fiber loop. Optical fiber loop consist of an Erbium-Doped Fiber Amplifier (EDFA), Single Mode fiber (SMF) followed by Dispersion Compensation Fiber (DCF). EDFA have the maximum gain of 35 dB with the ASE noise of 4.5 dB. Thus, we can say that the ASE noise is the most dominating factor in the degradation of our system performance. BER estimator is used to measure the performance of the simulated system. We have used semi-analytic BER evaluation method to estimate system performance in terms of BER. Then BER-equivalent Q factor has been used to perform qualitative analysis which is calculated from the BER measurement via the relationship

$$Q(\text{dB}) = 20\log\left(\sqrt{2}\,erfc^{-1}(2\,\text{BER})\right)$$

We start our analysis considering a single span of each type of SMF fiber followed by a single segment of respective DCF (specifications as given in Table 1) to determine the optimum duty cycle of the input RZ-DQPSK signal. The simulation results are shown in Figs. 2–4. After the optimized duty cycle has been found for each fiber type, we have used the similar simulation model for the comparison of RZ-DQPSK performance in longer spans of fiber links. This extended analysis helps us to evaluate RZ-DQPSK performance in long-haul communication in optical links made up of different fiber type. Finally we have analyzed the system with optimum duty cycle and fixed value of OSNR (20 dB) for different fiber types considering 10–100 identical spans and the result of this analysis has been reported in Fig. 5.

4. Results and discussion

Fig. 2 shows the performance of the RZ-DQPSK system with the SSMF type single mode fiber followed by DCF_{SSMF} when operated at different duty cycles for varying OSNR. From these plots we can observe that the performance of the system for the 40% duty cycle is unacceptable even up to OSNR value as high as 25 dB. However, the

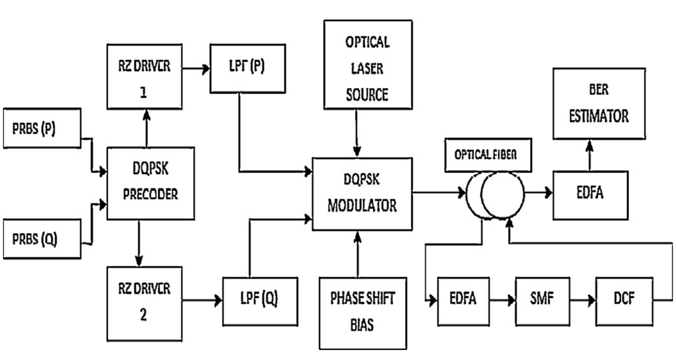

Fig. 1. Simulation setup for RZ-DQPSK modulation transmission.

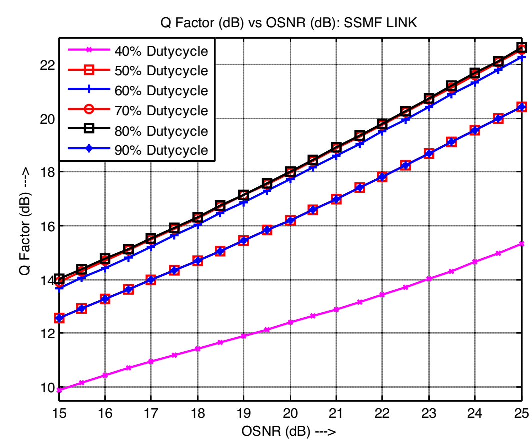

Fig. 2. SSMF type single mode fiber followed by DCF_{SSMF} for different duty cycles.

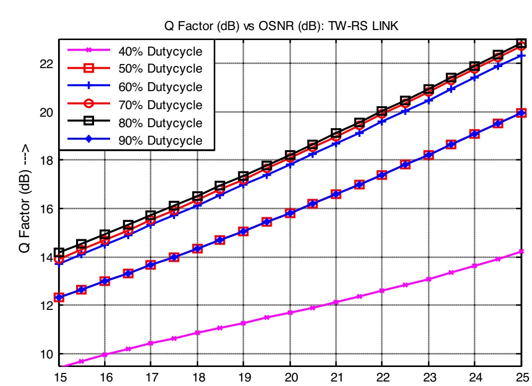

Fig. 3. TW-RS type single mode fiber followed by $DCF_{TW\text{-}RS}$ for different duty cycles.

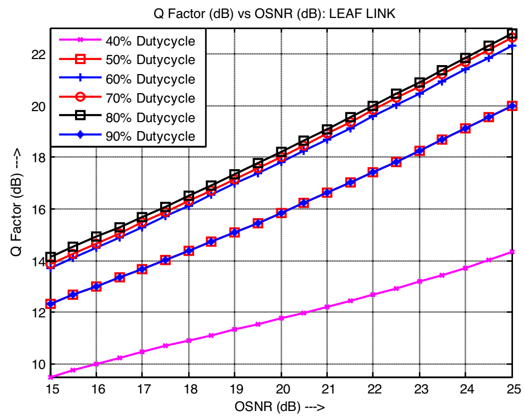

Fig. 4. LEAF type single mode fiber followed by DCF_{LEAF} for different duty cycles.

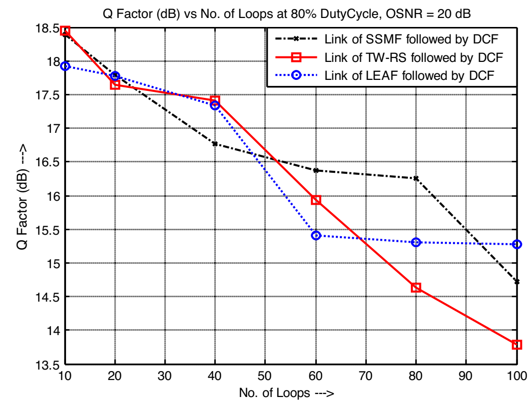

Fig. 6. Performance of the system for three different fibers with optimum duty cycle for different fiber spans.

performance of the system at 50% duty cycle improves and becomes acceptable beyond 20 dB OSNR providing BER equivalent Q-factor greater than 16 dB to provide equivalent BER as low as 10^{-9}. It is also noted from the graphs that the system starts performing even better for lower OSNR values for duty cycles of 70% and 80%. It is inferred that the performance peaks for 80% duty cycle and deteriorates as the duty cycle is increased to 90%.

Figs. 3 and 4 show the performance corresponding to TW-RS and LEAF types of fibers respectively. It is observed that these performances also follow the similar pattern with different duty cycles as in the case of SSMF fiber. Here, we observe that the performance for both TW-RS and LEAF types of fibers optimize at duty cycle of 80% as was seen in the case of SSMF.

From the simulation results obtained so far, it can be easily interpreted that all different fibers offer their best performance when RZ-DQPSK pulse is having 80% duty cycle in an ASE-noise-limited system.

The reason why 80% duty cycle RZ-DQPSK provides the best performance can be analyzed having a close look at the optical power spectrum. In Figs. 2–4 it can be easily observed that 40% duty cycle pulse performs the worst. RZ-DQPSK pulses with 50% and 60% duty cycle follow each other very closely when compared in terms of Q-factor variation with OSNR. Hence, we focused on duty cycle of 70%, 80% and 90% and compared their spectrum. As shown in Fig. 5 70% duty cycle pulse has the widest main lobe where as 80% and 90% pulses have very identical and close lying main lobes. The only differentiating factor between 80% and 90% pulse thus becomes the spectral distribution of side lobes. It can be seen with a closer look into the spectrums that 90% pulse has higher side lobes, i.e. more power in side lobes as compared to 80% pulse. Therefore, because of its spectral distribution 80% duty cycle RZ-DQPSK outperforms all other possible pulses having higher or lower duty cycle.

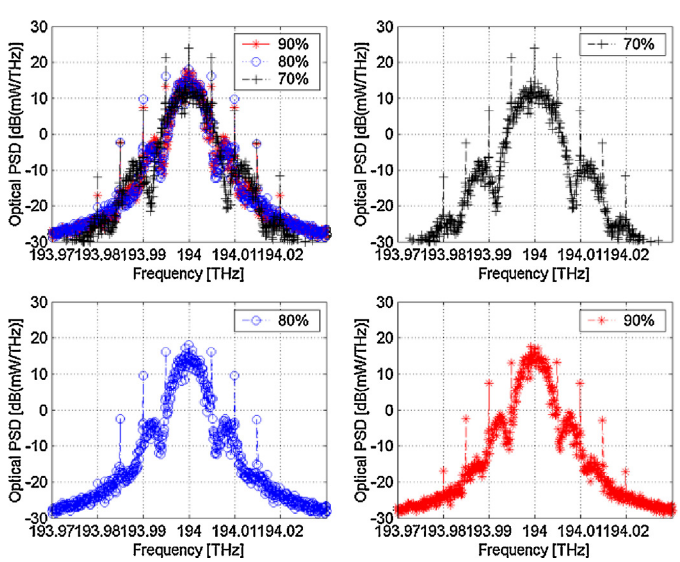

Fig. 5. Comparison of spectrum of RZ-DQPSK signals having 70%, 80% and 90% duty cycle.

Degradation due to Group Velocity Dispersion (GVD) is avoided by deploying appropriate DCFs in fiber links. Signal launch power has been kept low enough so that SPM induced nonlinearities cannot affect the system performance. Thus, 80% duty cycle RZ-DQPSK modulation scheme provides optimum performance when the system performance is mostly limited by ASE noise.

Scope still remains open in finding out which type of fiber assembly one should prefer when designing a long distance communication link for transmitting RZ-DQPSK modulated signals with 80% duty cycle.

Fig. 6 shows the performance of the system for long distance optical channels made of fiber spans. System performance has been compared for three different cases where the links are made of each type of SMF and DCF listed in Table 1. From this analysis it can be observed that the performance of the system with SSMF type of fiber outperforms the TW-RS and LEAF types of fibers as number of spans increases proving that SSMF should be the fiber of choice to design RZ-DQPSK long distance communication links.

5. Conclusion

This paper investigates the optimum duty cycle for RZ-DQPSK modulation technique for a 10 Gbps optical link and reports that 80% duty cycle is optimum for RZ-DQPSK in dispersion compensated optical link under the limitations imposed mostly by ASE noise. In the present work, three different types of single mode fibers have been compared for the performance analysis. It can be concluded from the findings that the system performance with link designed using SSMF is superior as compared to those made of TW-RS and LEAF type of fibers. Thus, the paper concludes that SSMF type fiber with 80% duty cycle of pulse in RZ-DQPSK modulation scheme is recommended for 10 Gbps long distance optical communication system.

Acknowledgement

Authors are thankful to the Director, B.I.T.S Pilani for extending the facility in the optical communication lab to implement the concept.

References

[1] M.E. Mohamed, EL-Halawany, Efficient Raman amplifiers within propagation and multiplexing techniques for high capacity and ultra long haul transmission systems, Int. J. Comput. Sci. Telecommun. 2 (2011) 16–23.
[2] G.P. Agrawal, Nonlinear Fiber Optics, Academic, New York, 2001.
[3] G.P. Agrawal, Fiber-Optic Communication Systems, Wiley, New York, 2002.
[4] B. Mukherjee, WDM optical communication networks: progress and challenges, IEEE J. Select. Areas Commun. 18 (2000) 1810–1824.
[5] P.J. Winzer, G. Raybon, H. Song, A. Adamiecki, S. Corteselli, A.H. Gnauck, D.A. Fishman, C.R. Doerr, S. Chandrasekhar, L.L. Buhl, T.J. Xia, G. Wellbrock, W. Lee, B. Basch, T. Kawanishi, K. Higuma, Y. Painchaud, 100-Gb/s DQPSK transmission: from laboratory experiments to field trials, IEEE J. Lightwave Technol. 26 (2008) 3388–3402.
[6] P.J. Winzer, -J.R. Essiambre, Advanced optical modulation formats, Proc. IEEE 94 (2006) 952–985.
[7] W.S. Vincent, L. Chan Katherine, Modiano Hall Eytan, A. Kristin Rauschenbach, Architectures and technologies for high-speed optical data networks, J. Lightwave Technol. 16 (1998) 2146–2168.
[8] S.E. Susskind, de A. Souza, 40 Gb/s RZ DQPSK transmission with SPM and ASE suppression by dispersion management, in: Proc. SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC), 2009, pp. 106–109.
[9] S. Ghoniemy, K.F. George, L. MacEachern, Performance evaluation and enhancements of 42.7 Gb/s DWDM transmission system using different modulation formats, in: Ninth Annual Communication Networks and Services Research Conference (CNSR), 2011, pp. 189–219.
[10] P.J. Winzer, R.J. Essiambre, Advanced optical modulation formats, Proc. IEEE 94 (2006) 952–985.
[11] V. Bobrovs, G. Ivanovs, Comparison of different modulation formats and their compatibility with WDM transmission system, Latvian J. Phys. Tech. Sci. 45 (2008) 3–16.
[12] T. Ono, Y. Yano, K. Fukuchi, T. Ito, H. Yamazaki, M. Yamaguchi, K. Emura, Characteristics of optical duobinary signals in terabit/s capacity, high-spectral efficiency WDM systems, J. Lightwave Technol. 16 (1998) 788–797.
[13] K. Yonenaga, S. Kuwano, Dispersion-tolerant optical transmission system using duobinary transmitter and binary receiver, J. Lightwave Technol. 15 (1997) 1530–1537.
[14] I. Lyubomirsky, C.-C. Chien, Optical duobinary spectral efficiency versus transmission performance: is there a tradeoff? in: Proc. Quantum Electronics and Laser Science Conference (QELS), 3, 2005, pp. 1774–1776.
[15] H. Badaoui, Y. Frignac, P. Ramantanis, B. Eddine Benkelfat, M. Feham, Numerical analysis of the DQPSK modulation formats implementation with 40 Gbits/s Int. J. Comput. Sci. Issues 7 (2010) 30–36.
[16] L.N. Binh, Optical Fiber Communication Systems: Overview of Modelling Techniques for Optical Transmission Systems, CRC Press, 2010.
[17] OptSim Application Notes and Examples, Rsoft Design Group, Inc.