Available online at www.sciencedirect.com
ScienceDirect
Optik 120 (2009) 614–618
Optik Optics
www.elsevier.de/ijleo

Robustness of NRZ, RZ, CSRZ and CRZ modulation on fiber nonlinearities and amplifier noise at 40 Gbps for (OC-786) long haul link

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Received 5 August 2007; received in revised form 20 January 2008; accepted 2 February 2008

Abstract

In this paper, the robustness of NRZ, RZ, carrier-suppressed RZ (CSRZ) and chirped RZ (CRZ) modulation formats at 40 Gbps for (OC-786) long haul link on the amplifier noise figure and fiber nonlinearities has been investigated. The investigations reveals that highest Q^2(dB) of the order of [20, 25]; [19, 20]; [18, 19] and [16, 18] has been obtained in case of RZ, CSRZ, CRZ and NRZ modulation formats, respectively, in the presence of fiber nonlinearities and with and without amplifier noise figure of 6 dB. It has been observed that Q^2(dB) in case of CRZ fluctuate between 18 and 14 at power variation of −10 to 4 dBm and NF of 6 dB, while it is between 19–9, 20–0 and 16–0 in case of CSRZ, RZ and NRZ. It has been identified that CRZ and CSRZ have shown the robustness on fiber nonlinearity and noise at 40 Gbps up to the transmission distance of 450 km. The wide eye opening in case of CRZ modulation also proved the robustness on fiber nonlinearity and noise.

Keywords: Noise figure; Modulation formats; Long-haul link; Fiber nonlinearities

1. Introduction

The need of increased capacity transmission systems has motivated the interest on new modulation formats with high spectral efficiency and robustness. As a result, intensive research activities have been done to witness the robustness of several novel modulation formats on the performance of optical transmission links. Carrier-suppressed RZ (CSRZ) modulation is one of the recently proposed modulation formats for high bit rate transmission systems, which has been intensively investigated in numerical and experimental works [1–4]. The main target of this modulation format is a reduction of the nonlinear impacts in a transmission line and an improvement of the spectral efficiency in high bit rate optical transmission links. Additionally, it can be expected that the dispersion tolerance of the transmission can be improved as well by CSRZ modulation, due to its reduced spectral width compared to conventional RZ modulation. Similarly, chirped RZ (CRZ) modulation is a special case of RZ modulation realized by the implementation of the pre-chirp on the conventional RZ pulses at the transmitter side. To date, CRZ modulation is basically used in long-haul under-sea transmission systems at channel data rates up to 40 Gb/s [5].

In this paper, the tolerance of modulation formats like NRZ, RZ, CRZ and CSRZ at 40 Gbps on the

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0030-4026/$ - see front matter
doi:10.1016/j.ijleo.2008.02.015

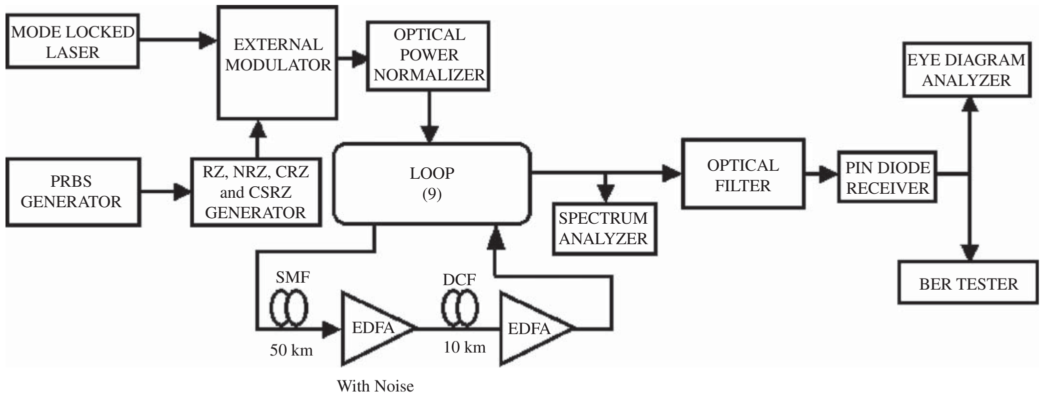

Fig. 1. System configuration.

amplifier noise figure and higher-order dispersion has been investigated. Performance metrics like Q-factor and eye diagram have been indicated. The system configuration and its description is mentioned in Section 2 after giving a brief introduction in Section 1. Results are discussed in Section 3 and concluding remarks are reported in Section 4.

2. System configuration and its description

The system configuration/topology shown in Fig. 1 simulates a noiseless and noisy link by using RZ, NRZ, CRZ and CSRZ modulation formats. Here, the transmission link of each span comprises of SMF (distance: 50 km, dispersion: +20 ps/nm km, dispersion slope: $S_o = +0.085$ ps/nm km^2, $\beta_2 = -25.44$ ps^2/km and $\beta_3 = +0.179$ ps^3/km, loss: 0.2 dB/km and nonlinear coefficient γ: 1.31 W^{-1}/km), dispersion compensating fiber (DCF) (distance: 10 km, dispersion: −80 ps/nm km, dispersion slope: +0.08 ps/nm km^2, loss: 0.5 dB/km and nonlinear coefficient γ: 5.24 W^{-1}/km) and amplifiers (noise figure: 6 dB).

The settings in the amplifier model allow inclusion or exclusion of noise. The nonlinear coefficient γ can be controlled in OptSim™ via the parameter "$n2$" (nonlinear refractive index of the fiber $n^{(2)}$) according to the relationship: $\gamma = 2\pi f n^{(2)}/cA_{\text{eff}}$, where the dimensionless parameter "a_{Eff}" of *OptSim*™ is related to Aeff as $A_{\text{eff}} = a_{\text{Eff}}\pi(d/2)^2$, where d is the diameter of the fiber core. Here, the Raman effects are disabled for the sake of simplicity. The simulation has been carried out at the dispersion properties of nonlinear dispersive SMF and DCF including second- and third-order dispersion parameters as depicted in Fig. 2.

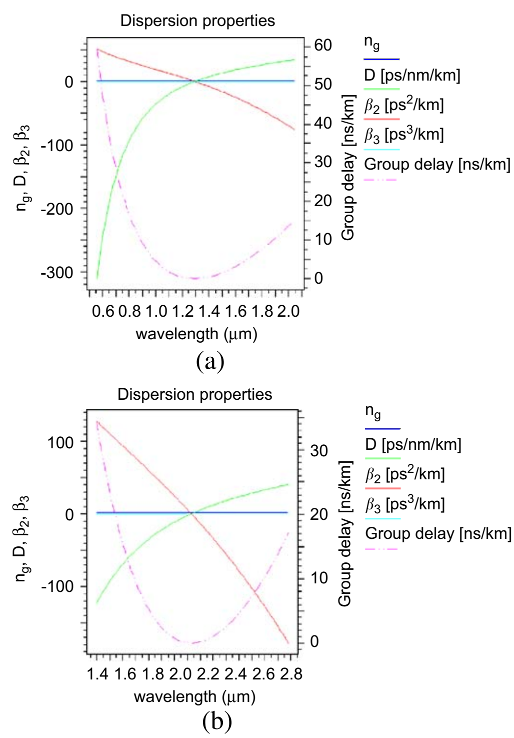

Fig. 2. Dispersion properties of (a) SMF (b) DCF.

3. Results and discussion

In this paper, the robustness of NRZ, CRZ, CSRZ and RZ modulation formats at 40 Gbps for (OC-786) long haul link on the amplifier noise figure and fiber nonlinearities has been investigated. The investigations reveal that the highest Q^2(dB) of the order of 25, 20, 18 and 16 is achievable in case of RZ, CSRZ, NRZ and CRZ modulation formats, respectively, in the presence of fiber nonlinearities and without amplifier noise figure of 6 dB. The value of Q-factor reduces to 20, 19, 18 and 16 in case of RZ, CSRZ, CRZ and NRZ, respectively, with a noise figure of 6 dB

Fig. 4 shows Q-factor vs. average fiber input power plots at 450-km transmission for this topology with linear ($\gamma = 0$) and nonlinear DCF, with and without amplifier noise. As the launched power increases, the performance keeps on improving until the launched power becomes high enough to cause nonlinearities adversely dominate the overall link performance.

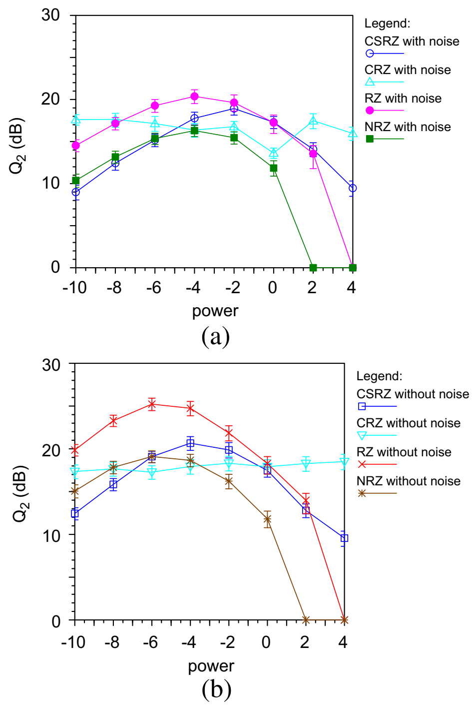

Fig. 3. Q^2(dB) for NRZ, RZ, CRZ and CSRZ modulation at 40 Gbps for (OC-786) long haul link with nonlinear effects and chromatic and fiber attenuation fully compensated for each span in case of (a) with noise NF = 6 dB (b) without noise.

For our topology, if we examine the curves corresponding to the cases with and without amplifier noise, we see that until the launched power is low enough, the link noise plays a dominant role. However, at higher launched powers, the nonlinearities dominate the performance impairments as compared to the influence of link noise. Because of the smaller core diameter of the DCF, optical intensities are enhanced, thereby resulting in higher nonlinear effects in the DCF section. The nonlinearities in the DCF, as seen in Fig. 3, can deteriorate the Q-factor by 20–0; 16–0; 19–9 and 18–14 dB depending upon the launched power (−10 to 4 dBm) in case of RZ, NRZ, CSRZ and CRZ, respectively, at NF = 6 dB. Here, the curves reveal that the CSRZ and CRZ are robust to noise and fiber nonlinearities even at higher launched power of 4 dBm, and the Q-factor is of the order of 9 and 12, respectively.

Further, the robustness of CRZ and CSRZ on noise and higher-order nonlinear effects has been warranted by indicating the curves of Q^2(dB) versus fiber input power in Fig. 4 at noise figure of 3 and 6 dB up to the transmission distance of 450 km. Here, the plots indicate that CRZ is robust among the rest of the data modulation formats because the Q-factor lies within the limit of 16–17.7 and 16.4–18.2 at noise figure of 6 and 3 dB, respectively, and with the presence of higher-order nonlinear effects of the DCF and SMF fiber.

Fig. 5 indicates the comparison of eye opening for NRZ, RZ, CSRZ and CRZ. Here (see Fig. 5), the wider eye opening in case of CRZ in comparison of NRZ, RZ

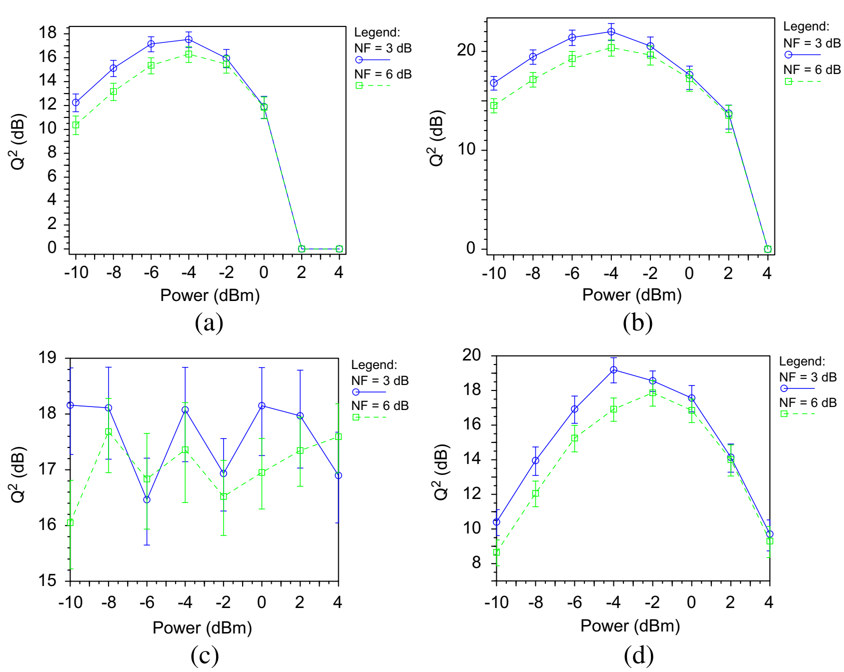

Fig. 4. Q^2(dB) for NRZ, RZ, CRZ and CSRZ modulation at 40 Gbps for (OC-786) long haul link with nonlinear effects and chromatic and fiber attenuation fully compensated for each span in case of (a) NRZ, (b) RZ, (c) CRZ and (d) CSRZ.

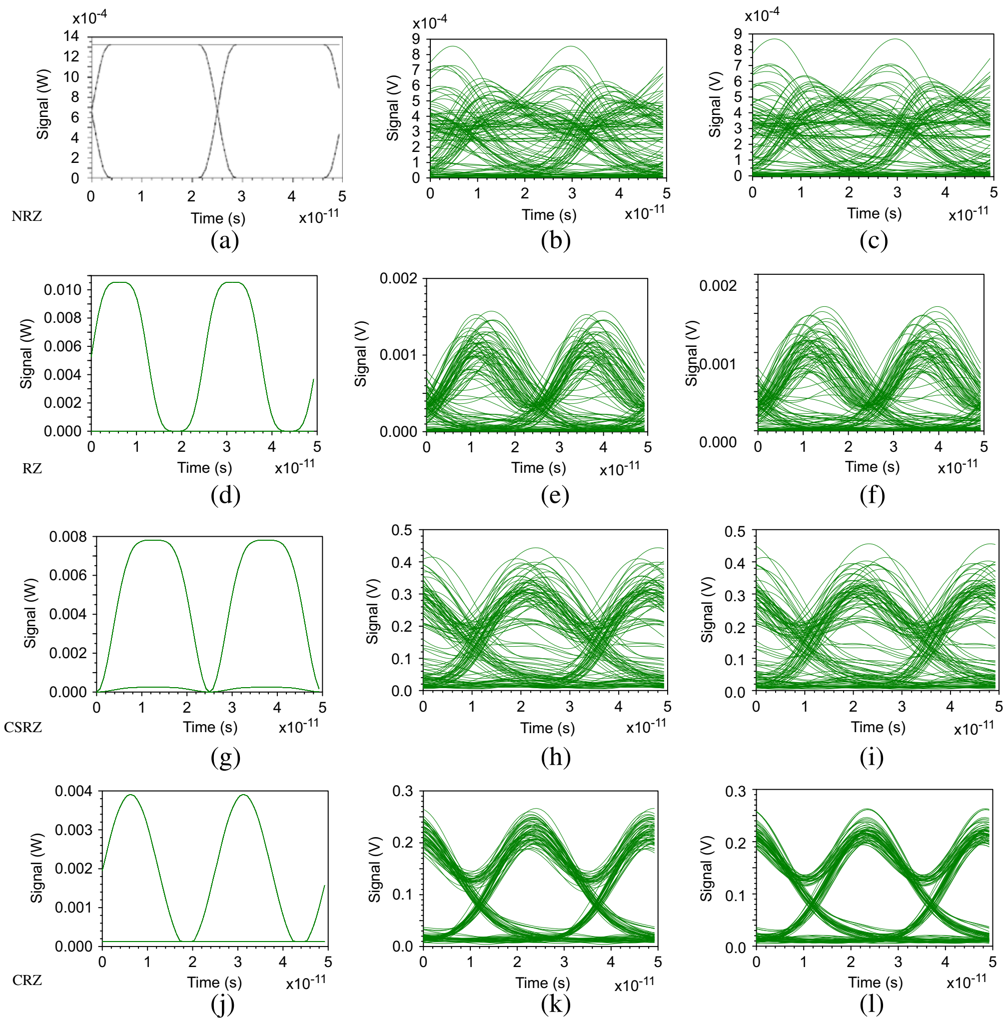

Fig. 5. Eye diagram for NRZ, RZ, CRZ and CSRZ modulation at 40 Gbps for (OC-786) long haul link with nonlinear effects and chromatic and fiber attenuation fully compensated for each span in case of NRZ (a) input, (b) NRZ with noise NF = 6 dB, (c) NRZ without noise, RZ, (d) input RZ, (e) RZ with noise, (f) RZ without noise, CSRZ, (g) input CSRZ, (h) CSRZ with noise, (i) CSRZ without noise and CRZ, (j) input CRZ, (k) CRZ with noise and (l) CRZ without noise.

and CSRZ demonstrates its robustness on noise and higher-order nonlinear effects.

4. Conclusions

In this paper, the robustness of NRZ, RZ, CSRZ and CRZ modulation formats at 40 Gbps for (OC-786) long haul link on the amplifier noise figure and fiber nonlinearities has been investigated. It has been noticed that as the launched power increases, the performance keeps on improving until the launched power becomes high enough to cause nonlinearities adversely dominate the overall link performance. But CRZ and CSRZ modulations are robust and indicate the better link performance. Further, the robustness of CRZ on noise and higher-order nonlinear effects has been warranted by indicating that the value of Q^2(dB) lies within the limit of 16–17.7 and 16.4–18.2 at noise figure of 6 and 3 dB, respectively, and with the presence of higher-order nonlinear effects of the DCF and SMF fiber up to the transmission distance of 450 km. The investigations reveal that CRZ is best suited for noisy and dispersive optical links. Moreover, the robustness on dispersive noisy link for CRZ modulation has been justified by wide eye opening in comparison with RZ, NRZ and CSRZ.

References

[1] D. Breuer, K. Petermann, Comparison of NRZ- and RZ-modulation format for 40-Gb/s TDM standard-fiber systems, IEEE Photon. Technol. Lett. 9 (3) (1997) 398–400.
[2] M.I. Hayee, A.E. Willner, NRZ versus RZ in 10–40Gb/s dispersion-managed WDM transmission systems, IEEE Photon. Technol. Lett. 11 (8) (1999) 991–993.

[3] T. Matsuda, A. Naka, S. Saito, Comparison between NRZ and RZ signal formats for in-line amplifier transmission in the zero-dispersion regime, J. Lightwave Technol. 16 (3) (1998) 340–348.
[4] C. Casper, et al., RZ versus NRZ modulation format for dispersion compensated SMF-based 10 Gb/s transmission with more than 100 km amplifier spacing, IEEE Photon. Technol. Lett. 11 (4) (1999) 481–483.
[5] Anes Hodzic, Investigations of high bit rate optical transmission systems employing a channel data rate of 40 Gb/s, Ph.D. Thesis, Tag der wissenschaftlichen Aussprache, Berlin, 2004.