Front. Optoelectron. China 2008, 1(3–4): 219–222
DOI 10.1007/s12200-008-0003-7

RESEARCH ARTICLE

2500 km-10 Gbps RZ transmission system based on dispersion compensation CFBGs without electric regenerator

Jihong CAO (✉)[1,2], Yong CHEN[1,2], Ting CHEN[1,2], Shuisheng JIAN[1,2]

1 Key Lab of All Optical Network and Advanced Telecommunication Network of EMC, Beijing Jiaotong University, Beijing 100044, China
2 Institute of Lightwave Technology, Beijing Jiaotong University, Beijing 100044, China

Abstract The characteristics of chirped fiber Bragg gratings (CFBGs) are optimized so that the ripple coefficient of the power reflectivity spectrum and group time delay are less than 1 dB and $|\pm 15|$ ps, group delay is about 2600 ps/nm, polarization module dispersion is very small, PMD <2 ps, -3 dB bandwidth is about 0.35 nm, and insertion loss is about 4–5 dBm. Using dispersion compensation CFBG, a 2500 km-10 Gbps RZ optical signal transmission system on G.652 fiber was successfully demonstrated without an electric regenerator by optimizing dispersion management and loss management. The RZ optical signal was generated through a two-stage modulation method. At 2081 km, the power penalty of transmission is about 3 dB (conditions: RZ signal, $\mathrm{BER}=10^{-12}$, $\mathrm{PRBS}=10^{23}-1$); At 2560 km, the power penalty is about 5 dB. It is superior to the system using NRZ under the same conditions.

Keywords return to zero (RZ) signal, chirped fiber Bragg grating (CFBG), dispersion compensation, power penalty

1 Introduction

To reduce the influence of noise, nonlinearity, dispersion, and other factors in a high-speed ultra-long haul (ULH) optical fiber communication system, as well as enhance the optical signal quality, many technologies have been adopted. For example, replacing erbium-doped fiber amplifier (EDFA) with Raman amplifier, optimizing system management of dispersion and power, setting an adjustable dispersion compensator at the end of the link, compensating the polarization mode dispersion (PMD) and high-order dispersion, paving a special fiber (such as LEAF, DSF), introducing forward error correction (FEC) and the modulation format (RZ, CSRZ, DPSK, etc.) technologies and so on [1–6]. The performance that profits from various modulation formats is particularly prominent in a ULH system [7–15]. It had been validated again in a multi-channel transmission platform of 10 Gbps RZ and NRZ in this paper. The platform is based on dispersion compensation chirped fiber Bragg gratings (CFBGs) that compensate over 2500 km-G.652 fiber.

2 RZ signal

If the duty cycle of RZ is 0.5 (half of NRZ), by Fourier transform relations, the corresponding width of the spectrum will have been doubled, as shown in Fig. 1 [16]. In the figure, for the unipolar code, if the bit rate of the single channel is B, the required bandwidth of NRZ is not less than 2B (2B is the smallest transmission bandwidth required by Nyquist principles when the filter roll-off coefficient is 1 [17]); and that of RZ is not less than 4B. Namely, for 10 Gbps systems, at least 0.32 nm (in C-band) channel bandwidth is required. The widening of the spectrum of RZ increases the group dispersion and decreases the spectral efficiency of the system. However, the dispersion tolerance of a 10 Gbps system is great, and the dispersion compensation is not practically difficult. The smallest channel spacing is 0.4 nm (50 GHz) as recommended in the ITU-T, and 10 Gbps RZ does not reduce spectral efficiency in practice. On the other hand, RZ has better nonlinearity tolerance and clock extraction condition, and the power control and clock synchronization are easier. Thus, it can be expected that transmission performance of 10 Gbps RZ would be better in ULH than in NRZ.

RZ code can be generated through code converters (for example, SHF1551 RZ converter) or two-stage modulation method. The latter was adopted in this paper. The two stage modulation methods are classed as the half

---

Translated from *Optical Technique*, 2006, 32(5): 643–645 [译自: 光学技术]

E-mail: cjhjohn@tom.com

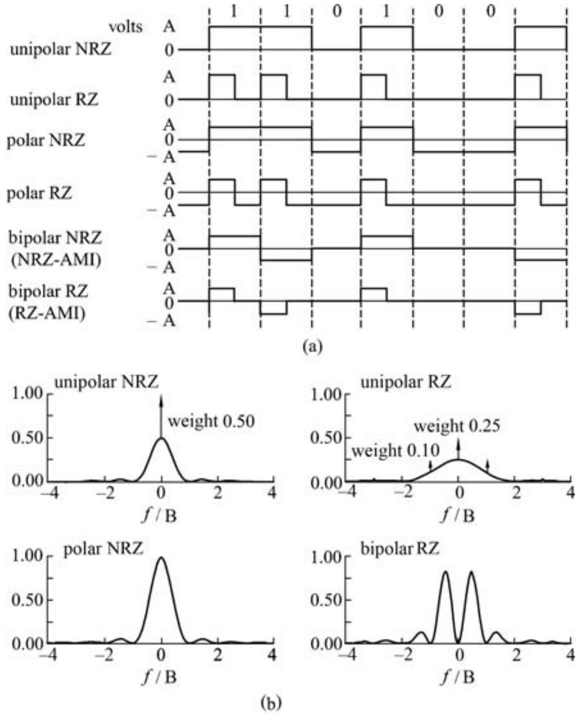

Fig. 1 NRZ and RZ signal. (a) Pulses; (b) spectrums

clock method and the full clock method. In the latter, the pulse modulator is driven by a full clock, in which the modulator work is at the same state as the data modulator (modulation equipment as Fig. 2(a)); In the former, the pulse modulator is driven by a half clock, in which the DC bias of the modulator is at the highest point of the transmission curve, drive voltage is $2V_\pi$ (Fig. 2(b)). The latter one was chosen in the paper.

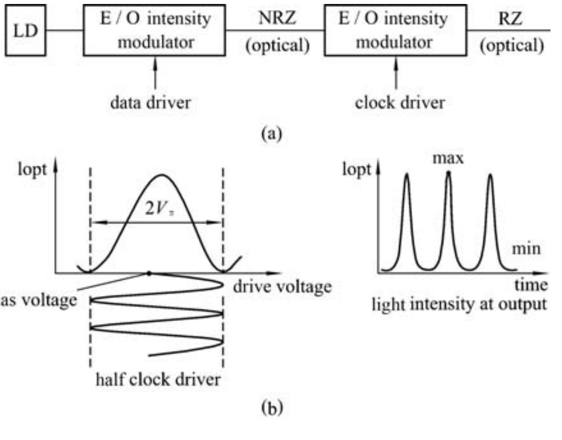

Fig. 2 RZ transmitter and principle. (a) RZ transmitter; (b) principle

3 Dispersion compensation module-linear CFBG

The grating mentioned in this paper is a linear chirped fiber-optic Bragg grating that was researched and manufactured by the Institute of Lightwave Technology of Beijing Jiaotong University [18]. Lots of advanced techniques were adopted such as hydrogen carrier, the apodizer and the packaging technique. As a result, the grating has perfect performance: the temperature coefficient is between 0.2 and 0.5 pm/°C; the polarization module dispersion is very small, $\mathrm{PMD} < 2$ ps; the reflectivity spectrum is flat, the power spectrum ripple is less than 1 dB (Fig. 3); the -3 dB bandwidth is about 0.35 nm, enough for the transmission of the 10 Gbps system (including RZ code and CSRZ code); the group delay ripple is not larger than $|\pm 15|$ ps; the group delay is large, about 2600 ps/nm (the G.652 optical fiber length that can be compensated by CFBG is about 160 km); the insertion loss is low, about 4–5 dBm (the loss is equal to that of 7–8 km DCF, and the DCF of this length can compensate only about 50 km G.652 optical fiber).

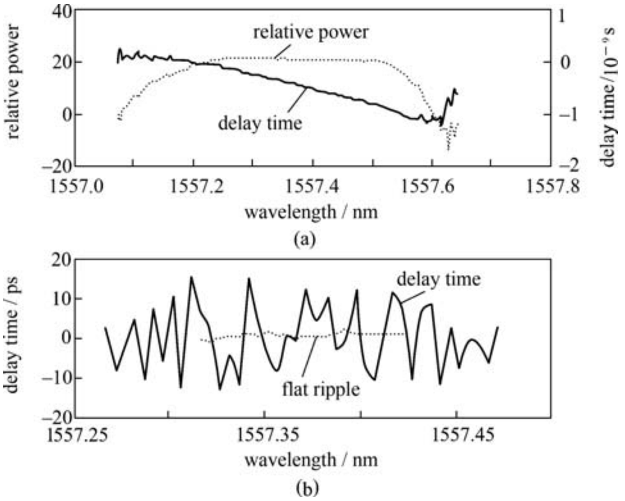

Fig. 3 Reflectance spectrum, delay and delay ripple of CFBG

4 Experiment system

The structure of the system is shown in Fig. 4. This 10 Gbps platform already had been set up, which is about 2500 km in length, and has 16 wavelength channels. The channel space is 0.8 nm (100 GHz), according to the wavelength standard (in C band) of the ITU-T suggestion. The total 2560 km G.652 optical fiber has 27 segments, 22 segments of 100 km, another 5

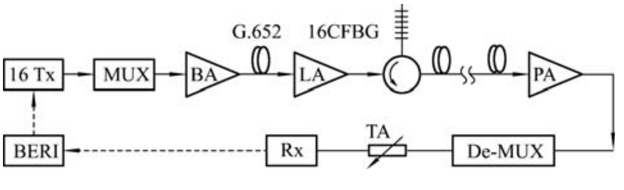

Fig. 4 10 Gbps experimental setup based on CFBG

segments from 60 km to 90 km. This setting is for easier dispersion management.

The structure of the transmitter includes the tunable laser and two $LiNbO_3$-MZ modulators, transmitting 9.953 Gbps pseudo-random bit frame ($PRBS = 10^{23} - 1$). The signal-to-noise ratio (SNR) of the RZ is 30.5. The output eye and spectrum (Note: for ease of comparison, two actual results measured of the spectrum were put in the same picture box) of the transmitter are shown in Fig. 5.

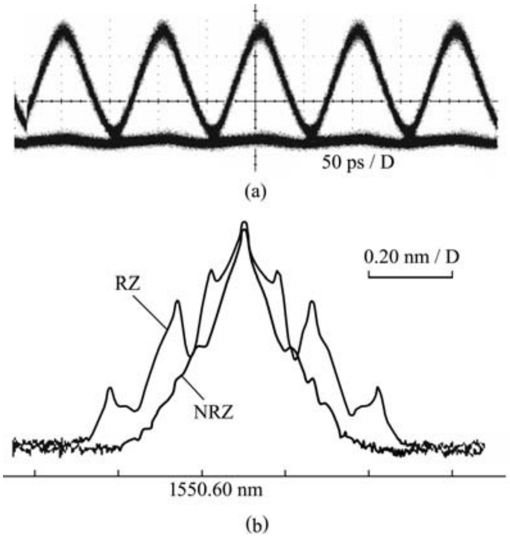

Fig. 5 RZ's eye-pattern & RZ and NRZ's spectrum. (a) RZ's eye-pattern; (b) RZ and NRZ's spectrum

In dispersion management, the dispersion of each channel is compensated by 16 CFBGs. Because the group delay of the CFBG (about 160 km G.652 optical fiber, as shown above) is more than 100 km (the amplification spacing), while less than 200 km (2 times amplification spacing), some segments of 60–90 km was needed fiber to adjust the remains of the total dispersion, making the largest absolute value of the remainder of the total dispersion as small as possible (in this paper it is less than 120 km) at any EDFA. At the same dispersion compensation location, the gratings (16 roots) are connected together in series.

In loss management, the input power of the fiber is 5 dBm. At each segment end, the power can be reboosted to 5 dBm through a light amplifier (EDFA). According to the above, not all segments are connected to the grating. As a result, the loss of each segment is different; the loss of some segments without CFBG is about 21 dBm, and the loss of some segments with CFBG is about 26 dBm. Therefore, the gain of different EDFAs is also different, but all the input power of every segment is certain (5 dBm). The EDFA is the product of our institute [19], the largest gain in small signal is about 30 dB, the maximum output power is 15 dBm, the noise figure is 4–5 dB, and the gain is flat between 1540 nm and 1560 nm. The EDFA location is adjusted with the noise figure, and the small noise figure is set in front.

The receiver is the APD detector. When various biases are placed in the best state, the back to back sensitivity is −20 dBm.

5 Test results and analysis

The eye patterns and bit-error rate (BER) curves of NRZ and RZ had been tested at 2000 km and 2500 km of the transmission system (Figs. 6 and 7, taking CH9 for example, the center wavelength is 1557.365 nm, and channel bandwidth is 0.28 nm at 3000 km, slightly narrow to RZ. Other channels are similar to the following results). As shown in the eye patterns (Fig. 6), the two signals have similar shape at 2000 km. The power penalty can also prove this: NRZ's power penalty is about 2 dB and RZ's is about 3 dB (as Fig. 7, bit-rate is 9.953 Gbps, $PRBS = 10^{23} - 1$). At 2500 km, RZ's eye patterns do not seem to have changed (Fig. 6(b)), while that of the NRZ's have obvious deterioration (Fig. 6(d)). At the same time, the NRZ's power penalty is already very large, and the RZ's power penalty is about 5 dB. The RZ's transmission result is much better than NRZ.

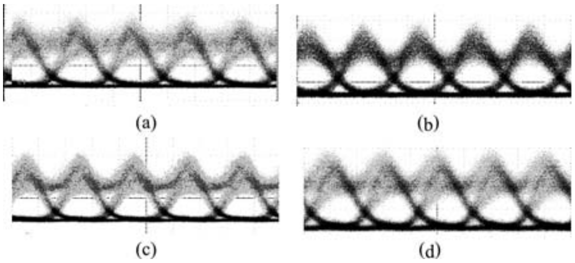

Fig. 6 Eye-patterns at different transmission distance. (a) 2081 km-RZ; (b) 2560 km-RZ; (c) 2081 km-NRZ; (d) 2560 km-NRZ

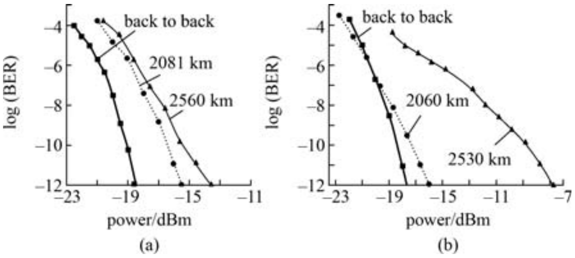

Fig. 7 Bit-error ratio curves. (a) RZ; (b) NRZ

In the 10 Gbps system, there are two factors influencing the optical pulse transmission performance: chrom-dispersion and nonlinearity. Two modulation format pulses have the same input power to fiber, and the RZ's transmission performance is better, so it is indicated that RZ's nonlinearity tolerance is bigger than NRZ. Based on the dispersion tolerance, the RZ should have poor performance. However, the opposite result shows that the RZ's nonlinearity tolerance plays a more important role.

Acknowledgements The work was jointly supported by the National 863 Plan Project (No. 2001AA122012) and the National Natural Science Foundation of China (Grant No. 60337010).

References

1. Rasmussen C, Fjelde T, Bennike J, et al. DWDM 40G transmission over trans-Pacific distance (10,000 km) using CSRZ-DPSK, enahnced FEC and all-Raman amplified 100 km UltraWave^{TM} fiber spans. In: Proceedings of Optical Fiber Communications Conference (OFC2003), 2003, PD18–1-3
2. Yang Zhu, Zeng Hui, Zhang Qiang, et al. 10 Gbit/s CSRZ 3040 km optical transmission experiment without electronic regeneration. Study on Optical Communications, 2004, (1): 1–4 (in Chinese)
3. Zheng Yuan, Zhang Xiaoguang, Chen Lin, et al. Analysis of degree of polarization ellipsoid as feedback signal for polarization mode dispersion compensation in NRZ, RZ and CS-RZ systems. Optics Communications, 2004, 234(1-6): 107–117
4. Yan Juanjuan, Chen Minghua, Xie Shizhong, et al. Performance comparison of standard FEC in 40 Gbit/s optical transmission systems with NRZ, RZ and CS-RZ modulation formats. Optics Communications, 2004, 231(1-6): 175–180
5. Yang Ming, Zhang Lu, Liu Hongjie. Performance analysis of NRZ and CSRZ formats in 40 Gbit/s single channel transmission systems. Study on Optical Communications, 2004, (1): 5–8 (in Chinese)
6. Li Zhihong, Dong Yi, Lu Chao, et al. Novel CS-RZ signal format with tunable pulse width and better tolerance to nonlinear degradation. In: Proceedings of the 16th Annual Meeting of the IEEE Lasers and Electro-Optics Society, 2003, 2: 763–764
7. Tsuritani T, Agata A, Morita I, et al. Ultra-long-haul 40-Gbit/s-based DWDM transmission using optically prefiltered CS-RZ signals. IEEE Journal of Selected Topics in Quantum Electronics, 2004, 10(2): 403–411
8. Appathurai S, Mikhailov V, Killey R I, et al. Nonlinearity and in-line residual dispersion tolerance of π-AP-RZ and CS-RZ modulation formats in 40-Gb/s transmission over standard single-mode fiber. IEEE Photonics Technology Letters, 2005, 17(11): 2457–2459
9. Zhang, Q, Maloney J, Menyuk C, et al. Performance comparison of dispersion managed 40 Gbps transmission: CSRZ vs. RZ. In: Proceedings of CLEO'02, Lasers and Electro-Optics, 2002, 1: 530
10. Cai J X, Nissov M, Li H, et al. Experimental comparison of 40 Gb/s RZ-, CSRZ-, and NRZ-DPSK modulation formats over non slope-matched fibers. In: Proceedings of 31st European Conference on Optical Communication, 2005, 4: 779–780
11. Hirano A, Miyamoto Y, Kuwahara S. Performances of CSRZ-DPSK and RZ-DPSK in 43-Gbit/s/ch DWDM G.652 single-mode-fiber transmission. In: Proceedings of Optical Fiber Communications Conference (OFC2003), 2003, 2: 454–456
12. Takano K, Murakami T, Nakagawa K. Mitigation of SPM effect by using Manchester code on optical BPSK-SSB transmission. In: Proceedings of Optical Fiber Communication Conference, 2006 and the 2006 National Fiber Optic Engineers Conference (OFC/NFOEC2006), 2006, 442–453
13. Charlet G, Klekamp A. Optimum modulation format for high density and/or ultra long haul transmission at 40 Gbit/s. In: Proceedings of Optical Fiber Communication Conference, 2006 and the 2006 National Fiber Optic Engineers Conference (OFC/NFOEC2006), OTh13, 2006, 325–335
14. Anderson W T, Liu L, Cai Y, et al. Modeling 40 Gb/s CSRZ-DPSK and RZ-DPSK trans-Atlantic transmission with dispersion slope compensation. In: Proceedings of Optical Fiber Communication Conference, 2006 and the 2006 National Fiber Optic Engineers Conference (OFC/NFOEC2006), 2006, 301–324
15. van den Borne D, Jansen S L, Khoe G D, et al. Line optimization in long-haul transmission systems with 42.8-Gbit/s RZ-DQPSK modulation. In: Proceedings of Optical Fiber Communication Conference, 2006 and the 2006 National Fiber Optic Engineers Conference (OFC/NFOEC2006), 2006, 336–348
16. Kaminow I P, Li T. Optical Fiber Telecommunications IV-B: Systems and Impairments. California: Academic Press, 2002, 874
17. Proakis J G. Digital Communications. 4th ed. (in Chinese, trans. Zhang Lijun). Beijing: Publishing House of Electronics Industry, 2003, 402–404
18. Pei Li, Jian Shuisheng, Xie Zenghua, et al. Dispersion compensation optical fiber grating with low ripple coefficient. Acta Optica Sinica, 2002, 22(3): 336–339 (in Chinese)
19. Tong Zhi, Wei Huai, Li Tangjun, et al. Study on optimization of high quality EDFAs. Journal of Optoelectronics·Laser, 2001, 12(9): 879–882 (in Chinese)