Paper

Improvement of amplitude and phase margins in optical RZ receiver using nonlinearity in normal dispersion fiber: effect on the Gordon-Haus timing jitter

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We propose a new technique to reduce the influence of timing jitter without increasing the intersymbol interference by utilizing Kerr nonlinearity in normal dispersion fiber. We carried out numerical simulations of 10 Gb/s soliton transmission and confirmed that the proposed method is more effective than the conventional RZ receiver with a Bessel-Thompson filter in reducing the influence of Gordon-Haus timing jitter. We also employed this technique to the 10 Gb/s optical soliton pulses transmitted at 16,000km in a sliding frequency recirculating loop. The phase and amplitude margins obtained with the proposed method were 18 % and 67 % wider than that with the lowpass filter with 7.5 GHz bandwidth.

Keywords: optical communication systems, optical RZ receiver, amplitude margin, phase margin, optical nonlinearity, Gordon-Haus jitter

1. Introduction

In optical fiber communication systems, an electrical Bessel-Thompson lowpass filter is normally employed after direct detection at the receiver. The filter limits the receiver bandwidth in order to reduce the noise power due to the accumulated amplified spontaneous emission (ASE) noise generated by EDFA repeaters. When return-to-zero (RZ) pulse format is used, the detected voltage of each RZ pulse at a certain detection time changes if detection time differs from the pulse peak. Thus, the displacement of pulse position at receiver caused by timing jitter causes the bit error. The Bessel-Thompson filter also broadens the pulse width and therefore reduces the influence of the timing jitter of received pulses(1). This technique is widely used in RZ optical communication experiment and seems suitable, however there exists a trade-off in the cut-off frequency of the filter between intersymbol interference, signal amplitude and signal-to-noise ratio. For example, when the cut-off frequency is too low, the intersymbol interference increases and the pulse amplitude decreases. To solve this problem, we propose a new technique to reduce the influence of timing jitter without increasing the intersymbol interference by utilizing Kerr nonlinearity in normal dispersion fiber. This technique enables us to improve amplitude and phase margins. In this paper, we employ the proposed method to 10 Gb/s soliton transmission and present the effectiveness on the Gordon-Haus timing jitter of transmitted solitons (2), which is caused by ASE noise of EDFA repeaters. In Section 2, we show the principle of the proposed method. In Section 3, we present the results of numerical simulations of the proposed RZ receiver. In Section 4, we employ the proposed method to 10 Gb/s sliding frequency soliton transmission experiment. In the experiment, we verify the effectiveness on the Gordon-Haus timing jitter.

2. Principle of the proposed optical RZ receiver

It is well known that when an optical pulse propagates along normal dispersion fiber with Kerr effect, its temporal waveform changes to a rectangular-like profile with steep leading and trailing edges as shown in Figure 1(3), (4). This figure shows the evolution of hyperbolic secant pulse with the peak power 25 times larger than the fundamental soliton. The time, the distance and the power are normalized by the pulse width, the soliton peak power and the dispersion length, respectively. By utilizing this property, the phase margin at the optical RZ receiver can be improved.

Figure 2 shows the schematic diagram of the setup. The system is

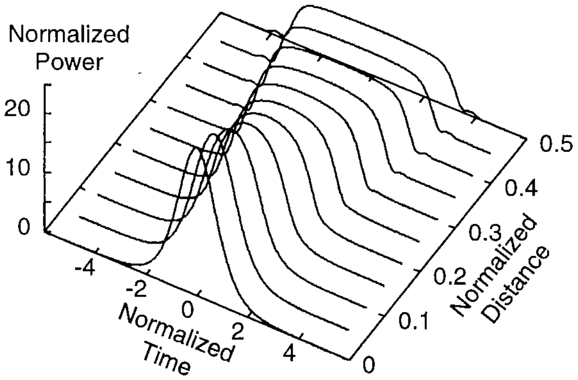


Figure 1. Pulse shape propagating along normal dispersion fiber with Kerr nonlinearity.

constructed by an erbium-doped fiber amplifier (EDFA), an optical bandpass filter (OBPF) which removes the ASE noise, and normal dispersion fiber (NDF). If the system utilizes optical soliton, the normal dispersion of the NDF may be effective in reducing the Gordon-Haus timing jitter accumulated in the transmission fiber of anomalous dispersion⁽⁵⁾. In the proposed method, the optical RZ pulses are amplified by the EDFA in order to utilize not only dispersion but also nonlinearity in normal dispersion fiber. Therefore, the influence of the timing jitter can be more effectively reduced.

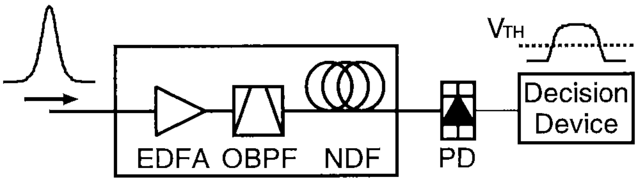


Figure 2. Schematic diagram of the proposed optical RZ receiver.

Table 1. Parameters used in numerical simulation

Wavelength	1.55 μm
Bit rate	10 Gb/s
Word length	64
FWHM pulsewidth	20 ps
Transmission fiber	
Dispersion	0.88 ps/nm/km
Loss	0.2 dB/km
Nonlinear coefficient	2.6×10^{-20} m^2/W
Effective area	55.4 μm^2
EDFA repeater	
Spacing	20 km
Noise figure	4.4 dB
Guiding filter bandwidth	0.5 nm
Sliding rate	110 MHz/20 km
Noise figure of EDFA before NDF	5.5 dB
Filter bandwidth before NDF	0.5 nm
NDF	
Dispersion	- 3 ps/nm/km
Loss	0.2 dB/km
Nonlinear coefficient	2.6×10^{-20} m^2/W
Effective area	87.9 μm^2
Electrical bandwidth of optical receiver	15 GHz

3. Reduction of the influence of timing jitter caused by the Gordon-Haus effect

We carried out numerical simulations of soliton transmission by solving the nonlinear Schrödinger equation using split-step Fourier method, in order to estimate the effectiveness of the proposed method on the Gordon-Haus timing jitter. The parameters used in the simulation are summarized in Table 1. In the simulation, we transmit 10 Gb/s optical soliton pulses of pseudorandom bit sequences (PRBS) along the constant anomalous dispersion fiber. In the transmission line, sliding frequency control technique⁽⁶⁾⁻⁽⁹⁾ is used. Therefore, the ASE accumulation during the transmission is effectively suppressed and the transmission distance is mainly limited by the timing jitter of the received optical pulses. The transmission distance is set to be 20,000 km.

Figure 3 (a) and (b) are the eye diagrams of the received pulses without and with the proposed scheme. As shown in Figure 3 (a), the eye opening became significantly narrower. In Figure 3 (b), the peak power of pulses

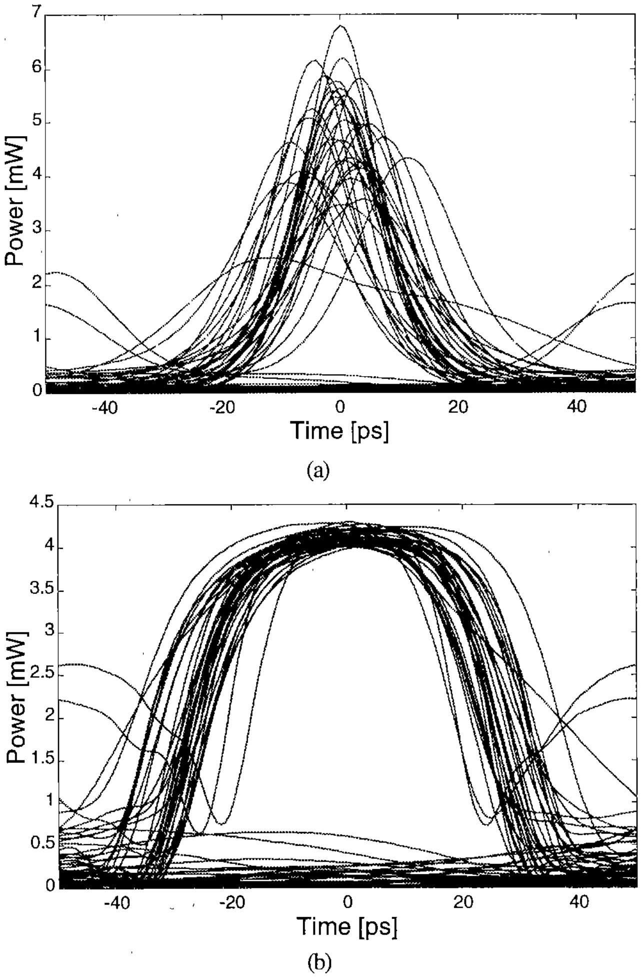
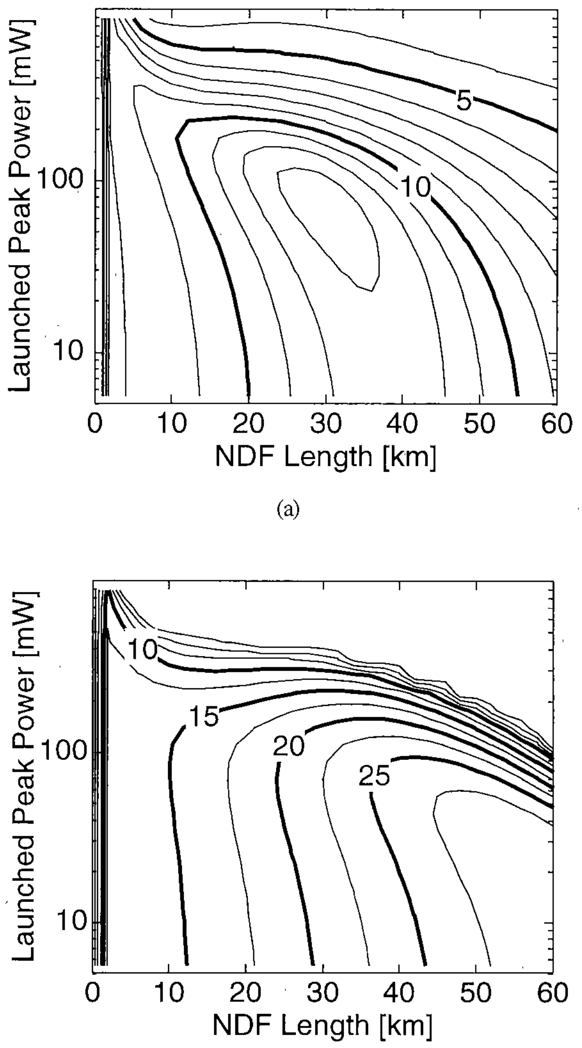


Figure 3. Eye diagrams of the received pulses (a) without and (b) with the proposed scheme. Transmission distance is 20,000 km.



(a)

(b)

Figure 4. Contour plots of (a) Q factor and (b) phase margin (ps) at 20,000km.

launched to 20 km long NDF is 280 mW. We can see that the pulse shapes changed to rectangular-like. The eye opening became much wider than the case of Figure 3 (a). Figure 4 shows the contour plots of Q factor and phase margin versus the NDF length and the peak power of the pulses launched into NDF. The peak power indicates the averaged peak power of pulses after OBPF in the proposed scheme. In this case, the electrical bandwidth of the BER detection was 15 GHz. We defined the phase margin as the range of detection time where the Q factor is more than 6.0, which corresponds to the bit error rate (BER) of 10^{-9}. It can be seen in Figure 4 (a) that there exists an optimized condition in NDF length and launched peak power for maximizing the Q factor. When the launched power is 70.4 mW and the NDF length is 30 km, the phase margin of 22.6 ps is obtained with the maximized Q of 13.6. In contrast, when the same signals are detected with the conventional RZ receiver using a 5th order Bessel-Thomson lowpass filter with 7.5 GHz bandwidth, the phase margin of only 15.7 ps is obtained with the Q factor of 7.2. The maximum Q factor of 11.8 is obtained when 11.5 GHz filter is used. However, the phase margin is still only 19.6 ps.

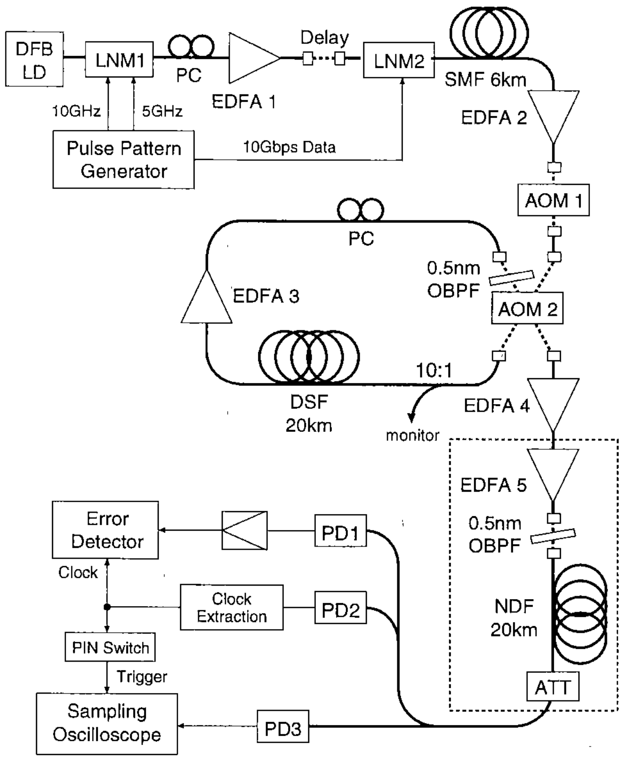
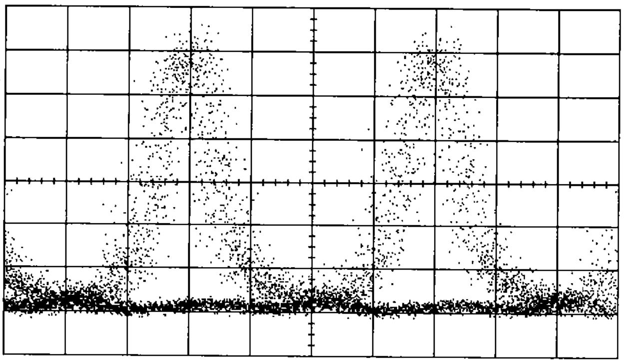


Figure 5. Experimental setup for 10 Gb/s soliton transmission in a sliding frequency recirculating loop.

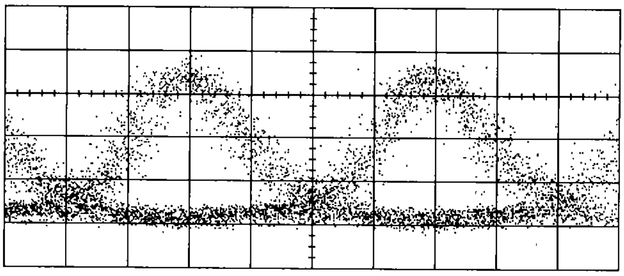
4. Experiment

We carried out 10 Gb/s soliton transmission experiment in a sliding frequency recirculating loop in order to compare the receiver characteristics of the proposed method and the conventional RZ receiver. Figure 5 shows the experimental setup. A DFB laser diode operating at 1.553 μm was used as a signal light source. 10 Gb/s RZ optical pulses were generated with two $LiNbO_3$ modulators LNM1 and LNM2(10),(11). The SMF placed after the LNM2 was used for chirp compensation of the pulses. The full-width at half-maximum after the chirp compensation was 23.5 ps. The recirculating loop consisted of 20km DSF. In the recirculating loop, the sliding frequency control was carried out by the acoustic optical modulator AOM2 and the 0.5-nm bandwidth optical bandpass filter (12). After transmission, the pulses were detected with the proposed method or the conventional scheme. The electrical bandwidth of the BER detection was 15 GHz. When the pulses were detected with the proposed method, the launched average power to the NDF was set to be 19 dBm. The length and the group velocity dispersion of the NDF was 20 km and- 3 ps/nm/km. When the pulses were detected with the conventional scheme, the EDFA and NDF were removed and the electrical lowpass filter was inserted after the photodiode. We used Picosecond Pulse Labs 5915 Z-matched lowpass, which has the attenuation and the group delay frequency responses that are similar to a Bessel-Thompson lowpass filter.

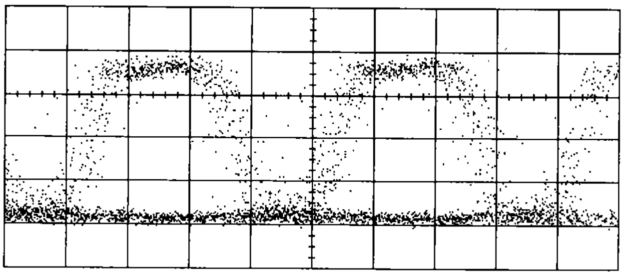
Figure 6 shows the eye diagrams of the transmitted pulses at 16,000 km detected (a) without lowpass filter, (b) with lowpass filter with 7.5 GHz



(a) Without lowpass filter



(b) With 7.5GHz lowpass filter



(c) With the proposed method

Figure 6. Eye diagrams of the transmitted 10 Gb/s soliton pulses in a sliding frequency recirculating loop at 16,000 km (25 ps/div).

bandwidth, and (c) with the proposed method, respectively. The electrical bandwidth of the photo diode PD3 and the sampling oscilloscope were 32 and 50 GHz, respectively. We kept the average optical power to the photodiode equal for all measurement. We can see in Figure 6 (b) that the pulse is broadened by the lowpass filter as in the normal optical RZ receivers. However, the amplitude jitter on "0" signals was increased even through the bandwidth is limited as compared with the case of Figure 6 (a). This may be due to intersymbol interference. On the other hand, when the pulses were detected with the proposed method, the waveform of the pulses is changed to rectangular-like by utilizing dispersion and nonlinearity in the NDF. The eye opening is wider than that detected with the lowpass filter. In addition, the amplitude jitter on "1" and "0" signals at the center portion of pulses is remarkably small. Next, we measured the threshold voltage and detection time of the BER detector where BER equals 10^{-7}. Figure 7 shows the result. The improvement of the phase margin was about 18 %. In addition, the amplitude margin obtained with the proposed method was 100 mV, which was 1.7 times larger than that with the conventional method.

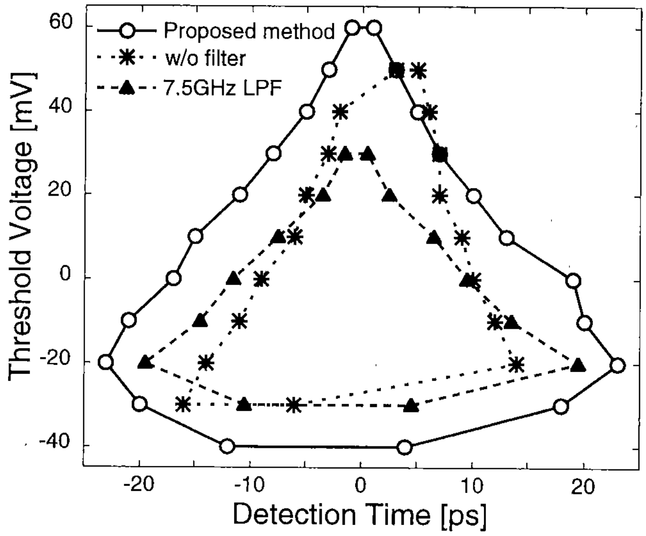


Figure 7. Measured threshold and detection time of the BER detector where BER equals 10^{-7}.

5. Conclusion

We proposed a new technique to improve the amplitude and phase margins in an optical RZ receiver using Kerr nonlinearity in normal dispersion fiber. By numerical simulation, we confirmed that the proposed method is effective to reduce the influence of Gordon-Haus timing jitter. In 10 Gb/s sliding frequency soliton transmission experiment, we observed that the waveform of the transmitted soliton pulses at 16,000 km changed to rectangular-like profile. Both amplitude and phase margins were improved without intersymbol interference. The improvement of the phase margin was about 18 %. The amplitude margin obtained with the proposed method was 1.7 times larger than that with the conventional method. In the proposed scheme, the required bandwidth is wider than that of the conventional optical RZ receivers because the spectrum of the pulses is also broadened. This leads to the decreasing of signal to noise ratio in the detected electrical signals. Therefore, the proposed method is effective in a jitter-limited transmission system. However, if the transmitted optical pulse width is narrow, the detected signal amplitude with the conventional receivers are decreased due to the bandwidth limitation. In such a case, the proposed scheme may be effective even in a noise-limited system.

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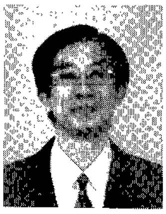

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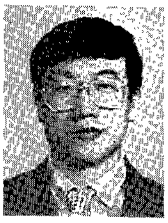

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