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EXPERIMENTAL EVALUATION OF GORDON-HAUS TIMING JITTER OF DISPERSION MANAGED SOLITONS

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Abstract: We performed a transmission experiment of dispersion managed solitons in a sliding frequency recirculating loop to estimate timing jitter of transmitted solitons. The estimated jitter was minimized when average group velocity dispersion of transmission fiber was zero.

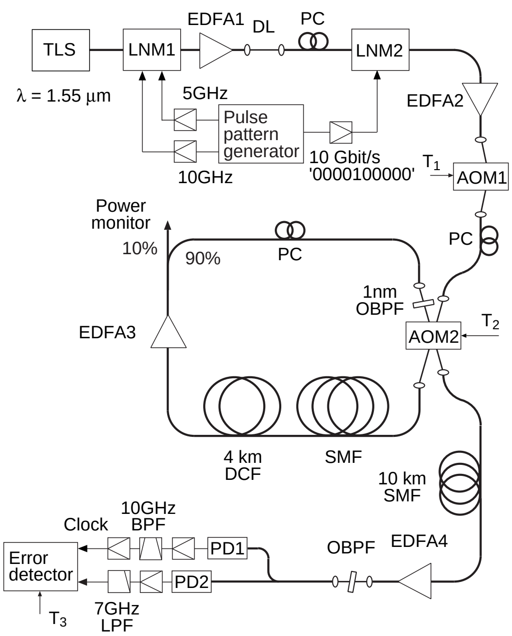
Introduction

Dispersion managed soliton (DM soliton)/1-3/, which is a quasi-steady state nonlinear optical pulse propagating in a fiber with large group velocity dispersion (GVD) variation, has the advantage of high peak power/3/ and wide dynamic range in peak power to form solitons/4/ over standard soliton in uniform GVD. Due to the property of the power enhancement, the Gordon-Haus timing jitter of transmitted DM solitons becomes smaller than that of standard solitons/5/. It is known that DM solitons propagate in a fiber with the average GVD of slightly negative region/6/. So far, theoretical investigations of the timing jitter have been carried out in optical communication systems/7,8/ and a passively mode-locked stretched pulse fiber laser/9/. These results indicate that the jitter is minimized when average GVD of transmission fiber becomes close to zero. In this paper, we perform DM soliton transmission experiment in order to show the relationship between the timing jitter of transmitted solitons and average GVD of the transmission fiber. Sliding frequency soliton control/10,11/ is used for suppressing ASE noise accumulation which affects the accuracy of jitter estimation.

Experiment

Figure 1 shows the experimental setup. A tunable laser source (TLS) and an optical pulse shaper/12/ using a $LiNbO_3$ modulator (LNM1) generate 10-GHz, 33 ps chirped optical pulses of 1.55 μm. In order to reduce the nonlinear interaction between adjacent pulses, the optical pulses were encoded by a 10-Gbit/s 0000100000 pattern by a $LiNbO_3$ intensity modulator (LNM2). The recirculating loop was constructed by a standard single mode fiber (SMF) and a 4-km dispersion compensating fiber (DCF). The DCF, whose group delay dispersion was –340 ps/nm, was designed for compensating the accumulate GVD of 20 km SMF at 1.55 μm. The average GVD of the recirculating loop D_{ave} was changed by inserting a piece of SMF or by slightly changing the operating wavelength. An acousto-optic modulator (AOM2) and an optical band pass filter (OBPF) with the 3-dB bandwidth of 1 nm were inserted in the loop as the frequency shifter and the guiding filter to perform sliding frequency soliton control. Thus, ASE accumulation in the loop was suppressed during recirculating transmission. The transmitted DM solitons, which include frequency chirping, were switched by the AOM2, chirp compensated by 10 km SMF, and fed into fast photo diodes followed by an error detector to measure bit error rate (BER).

Figure 1: Setup for timing jitter measurement of dispersion managed solitons.



TLS : tunable laser source, LNM : $LiNbO_3$ intensity modulator, DL : adjustable delay line, AOM : acousto-optic modulator, OBPF : optical bandpass filter, T_1...T_3 : timing control signals

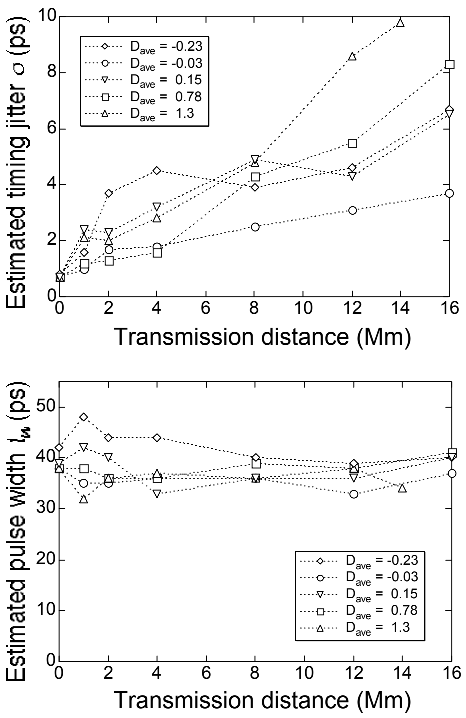
The timing jitter was estimated by measuring the BER versus deviation of decision time t_d [ps] of the error detector/13/. In this paper, we assume that (1) the waveform of transmitted DM soliton is constant, (2) no noise and no amplitude fluctuation are included in the DM soliton, and (3) the timing jitter obeys a Gaussian distribution with the standard deviation of σ [ps]. Under these assumptions, the BER of 10-Gbit/s 0000100000 data can be obtained by the following equation

$$\mathrm{BER} = \frac{1}{10}\left[\frac{1}{2}\mathrm{erfc}\left(\frac{t_w - t_d}{\sqrt{2}\sigma}\right) + \frac{1}{2}\mathrm{erfc}\left(\frac{t_w + t_d}{\sqrt{2}\sigma}\right)\right] + \frac{1}{10}\sum_{\substack{i=0 \\ i\neq 4}}^{9}\left[\frac{1}{2}\mathrm{erfc}\left(\frac{-t_w + t_d + 100i - 400}{\sqrt{2}\sigma}\right) - \frac{1}{2}\mathrm{erfc}\left(\frac{t_w + t_d + 100i - 400}{\sqrt{2}\sigma}\right)\right], \quad (1)$$

where $2t_w$ [ps] is the pulse width at decision level of the error detector.

The experiment was made by using 20 km SMF + 4 km DCF (D_{ave} = -0.03 ps/nm/km), 21 km SMF + 4 km DCF (D_{ave} = 0.78 ps/nm/km) and 22 km SMF + 4 km DCF (D_{ave} = 1.3 ps/nm/km) as a transmission fiber. Moreover, we changed the operating wavelength at 1547.8 nm (D_{ave} = -0.23 ps/nm/km) and 1556.5 nm (D_{ave} = 0.15 ps/nm/km) when transmission fiber was 20 km SMF + 4 km DCF. The average power of transmitting pulses was adjusted to minimize BER for each fiber. We obtained σ and t_w by fitting the theoretical value obtained by equation (1) to the experimental data. Figure 2 (a) and (b) show the obtained σ and t_w versus transmission distance, respectively.

Figure 2: Estimated (a) timing jitter σ and (b) pulse width t_w of DM solitons versus transmission distance.



The estimated timing jitter obtained when D_{ave} = - 0.23 ps/nm/km before 4 Mm was larger than those obtained in other D_{ave}'s at the same transmission distance. In the case where the pulses include noise or amplitude fluctuation, the estimated σ may be described as follows

$$\sigma = \sqrt{{\sigma_T}^2 + {\sigma_A}^2 + {\sigma_{Init}}^2}, \quad (2)$$

where σ_T, σ_A and σ_{Init} are the standard deviation of timing jitter of the pulses, jitter comes from amplitude jitter or noise in the pulses, and timing jitter included in equipment. σ_A should depend on the pulse width and shape even though the noise level is constant. As a matter of fact, figure 2 (b) shows that the estimated t_w's at this range are larger than the others. Consequently, the transmission distance of 4 Mm may not be enough to reach steady state condition at this D_{ave}. However, we expect that the pulses propagate in a steady state over 8 Mm, although the position of the guiding filter may affect the stability of DM solitons.

Figure 3: Estimated timing jitter σ versus average group velocity dispersion of the transmission fiber D_{ave}.

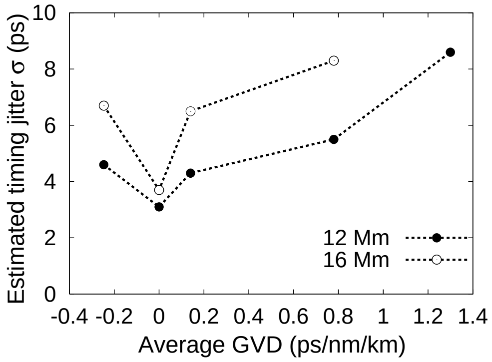


Figure 3 shows the estimated timing jitter versus D_{ave} of the transmission fiber at 12 Mm and 16 Mm. The figure clearly shows that the jitter is minimized when D_{ave} is zero.

Conclusion

We have performed a DM soliton transmission experiment in a sliding frequency recirculating loop. In the absence of the nonlinear interaction between adjacent pulses, we confirmed that the estimated timing jitter of transmitted DM solitons was minimized when average group velocity dispersion of transmission fiber was zero.

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