Numerical Study of 40Gbit/s Optical Soliton Transmission System Using In-Line All-Optically Regenerative Repeater Constructed by Nonlinear Optical Loop Mirror

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Abstract: The performance improvement of 40Gbit/s soliton transmission system employing nonlinear optical loop mirror (NOLM) as all-optical regenerative repeater is investigated. The switching characteristic of NOLM is optimized using our design strategies. By inserting the optical repeater where the eye-penalty of the transmitted signal becomes 1dB, we achieve the improvement of 0.3dB eye-penalty resulting in further 480km transmission distance.

1. Introduction

One promised method to simultaneously overcome both soliton interaction effect [1], and Gordon-Haus effect [2] in optical soliton transmission systems is the use of all-optical regenerative optical repeaters periodically placed on the systems. To this purpose, all-optical repeater constructed by nonlinear optical loop mirror (NOLM) has been proposed and demonstrated its potential [3-6].

In this paper, we propose the basic design strategies for obtaining the switched power and width of signal pulse identical to the input signal pulse as much as possible. Moreover, we report, by computer simulations, the performance improvement of 40Gbit/s non-dispersion-managed soliton transmission system by applying all-optical repeater constructed by NOLM. To our knowledge, our work first practically takes into account the propagation of optical signal and optical control pulses in NOLM. Moreover, we first focus the use of optical repeaters in non-dispersion-managed soliton transmission system.

2. Design for Achieving Optimum Operating Conditions of NOLM

To operate NOLM at optimum condition, we figure out the optimum operating peak power of the control pulse and the optimum operating peak power of the signal pulse by simulating 25ps time-slot single pulse propagation in NOLM. For the fiber of NOLM, highly-nonlinear dispersion-shifted fiber (HNDSF) [7] with nonlinear coefficient as large as $20.4W^{-1}km^{-1}$ is used for the fiber of NOLM, therefore, the length of NOLM can be set as short as 110m. The wavelength of the signal and the control pulses are respectively positioned in anomalous and normal dispersion region, at 400GHz equally shifted from zero-dispersion point to eliminate the group-velocity mismatch (walk-off) of signal and control pulses. The anomalous dispersion is used for inducing soliton compression effect on signal transmission to prevent signal pulse broadening in NOLM.

Figure 1 shows the normalized output signal peak power, defined by the ratio between the output and input signal power, as a function of control pulse peak power. In the calculation, the input power of signal is set constant at 1.2mW. In Fig. 1, two input control pulse powers which give the normalized signal power = 1 are observed. We choose 1.53W as optimum control power by confirming better signal waveform.

Figure 2 shows the normalized output signal pulse width, defined by the ratio between the output and input signal pulse width, as a function of signal pulse peak power. The input signal power has to be finely tuned to induce soliton compression effect in order to prevent signal pulse broadening in NOLM. For the calculation of Fig. 3, the power of control pulse is set at an optimum value 1.53W.

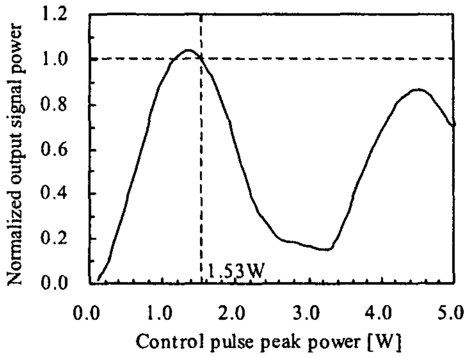

Fig. 1: Normalized output signal power as a function of control pulse peak power.

According to the result shown in Fig. 2, the normalized pulse width larger than 0.8 is obtained for almost all of the range of input signal power. Therefore, we can freely use the input signal power without the necessity of tuning it to an optimum value. This is due to the use of HNDSF with sufficiently short length. However, we cannot achieve normalized pulse width of 1. This is resulted from the dependence of switching window on control pulse peak power. The control pulse will induce π-phase-shift to the signal only at the peak, which can completely transmit out of NOLM, while part of the signal where the clock pulse power is low will be reflected back to the input arm.

Also in Fig. 2, the relation between the normalized output signal peak power and the input signal power is shown. The normalized output signal peak power keeps constant value at 1 for all range of the input signal power.

This confirms that the change in input signal power has no influence to the signal power switching characteristic of NOLM.

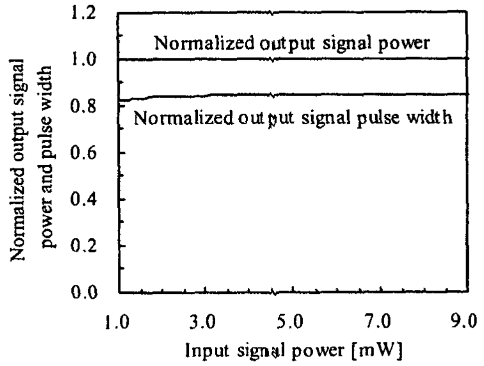

Fig. 2: Normalized output signal power and width as a function of input signal power.

3. Computer Simulations of 40Gbit/s Soliton Transmission

To evaluate the performance of the NOLM-based optical repeater, we perform computer simulations of non-dispersion-managed soliton transmission systems. It should be noted that the dispersion management concept itself can simultaneously reduce the soliton interaction effect and Gordon-Haus effect in soliton transmission [8]. However, in this work, we concentrate to the non-dispersion-managed soliton systems aiming to study the pure performance of the optical repeater.

The input signal is composed of 32bit pseudorandom hyperbolic secant pulse train whose data rate equals to 40Gbit/s. The transmission fiber is dispersion-shifted fiber (DSF) with the loss coefficient of 0.2dB/km, the group velocity dispersion of $0.01\text{ps}^2/\text{km}$, the higher-order group velocity dispersion of $0.2\text{ps}^3/\text{km}$, and the nonlinear coefficient of $2.6\text{W}^{-1}\text{km}^{-1}$. The amplifier spacing of 40km with the optical amplification of 8dB are included in the calculations. The optical amplifier produces ASE noise figure of 5.3dB. The system performance is evaluated in term of eye-penalty of transmitted signal. The maximum transmission distance is determined as the distance where the detected eye-penalty of the signal reaches 1dB.

The optical repeater is inserted into the system at the distance where the eye-penalty becomes 1dB. From Fig. 3, as the width of the signal is almost constant independently on the signal input power, the signal is launched to NOLM without adjusting the power. On the other hand, the power of the control pulse is set at the optimum value (1.53W).

Figure 3 shows the calculated eye-penalty, as a function of transmission distance, of 40Gbit/s soliton transmission systems. Without the optical repeater, the calculated result indicates the maximum transmission distance of only 640km at eye-penalty 1dB. When we insert the NOLM-based optical repeater at 640km, the eye-penalty of the transmitted signal improves approximately 0.3dB. By further transmitting the optical signal, we can achieve longer 480km distance to reach eye-penalty 1dB at 1,120km again. We have tried to install another optical repeater at the distance where the eye-penalty of the regenerated signal becomes 1dB again. However, we can not obtain the improvement of such longer transmission distance. This is because the output signal from NOLM is severely frequency-chirped through XPM effect by the control pulses in NOLM, which consequently results in the loss of soliton property. Also in Fig. 3, the eye-penalty after NOLM once rapidly increases to higher value than 1dB and then reduces to a value below 1dB again at 1,120km. This can be interpreted as the soliton train attempts to recover the chirp induced from control pulse while propagating in fiber.

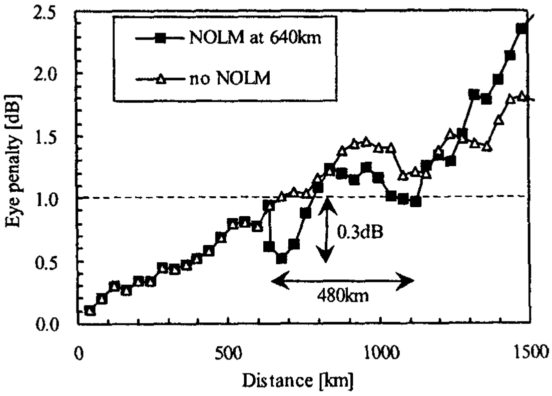

Fig. 3: Calculated eye-penalty as a function of transmission distance of 40Gbit/s soliton transmission system.

4. Conclusions

In this paper, we have reported the performance improvement of 40Gbit/s non-dispersion-management soliton transmission system by employing NOLM-based all-optical repeaters. By using the optimum control pulse power and optimum signal input power in NOLM, an improvement of eye-penalty 0.3dB was achieved and the signal could transmit longer 480km. To further improve the performance of the optical repeater, the serious frequency-chirp induced from the control pulse must be overcome.

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