System performance of a slow-light delay line for 10-Gb/s data packets

Yikai Su, Lilin Yi and Weisheng Hu

State Key Lab of Advanced Optical Communication Systems and Networks, Department of Electronic Engineering
Shanghai Jiao Tong University, 800 DongChuan Rd, Shanghai 200240, China, yikaisu@sjtu.edu.cn

Abstract: We perform, to the best of our knowledge, the first system experiment of delaying 10-Gb/s data in an optimized slow-light device based on parametric process. We also study a wideband SBS slow-light device with phase-modulated pump.

OCIS codes: (190.4410) Nonlinear optics, parametric processes; (190.5530) Pulse propagation and solitons

1. Introduction

Slow-light techniques have many potential applications for future optical communication and computing systems, e.g., optical buffering, optical memories, data synchronization, and all-optical signal processing. Recently, slow-lights based on fiber nonlinearities such as stimulated Brillouin scattering (SBS) [1-3], parametric amplification [4], and stimulated Raman scattering (SRS), [5] are attracting much attention because they are compatible with the optic-fiber communication systems. In general slow-light can be achieved with resonant effects that increase the group index in a narrow amplification (or absorption) bandwidth and therefore change the group velocity of optical pulses. In many previous works [1-5], a single pulse was used to measure the time delay, thus the pattern-dependent pulse delay and distortion effects were not investigated. The pattern dependence was studied and the Q value of the signal was evaluated in [6-8]. However, no bit rate error (BER) measurement of the delayed data had been demonstrated prior to the work reported in [9].

In this paper, we review our results on the first system performance of delayed 10-Gb/s return-to-zero (RZ) data packets in the 1550-nm telecommunication window through a fiber optic parametric amplifier (FOPA). We first optimize a FOPA-based delay line through simulations, and then experimentally demonstrate such a delay line. We investigate the pulse distortion and sensitivity penalty due to saturated parametric gain. Our experiment verifies the feasibility of fine-tuning of the time delay for 10-Gb/s packets, and reveals that higher-speed data can be supported by this slow-light delay line.

In addition, we attempt another approach to realizing Gb/s-rate slow-light delay line based on SBS. We propose and demonstrate a pump-phase modulation scheme that broadens the Brillouin gain bandwidth, while the constant envelope of the pump eliminates the need for time synchronization between the signal and the pump, which is required in [7] where the pump is directly modulated by a Gaussian noise source. In our particular demonstration, 1.25-Gb/s PRBS data is delayed by 520 ps. We expect that 10-Gb/s data can be delayed by increasing the phase-modulation rate of the pump if a phase modulator with wider bandwidth were available.

2. Slow light in a parametric amplifier

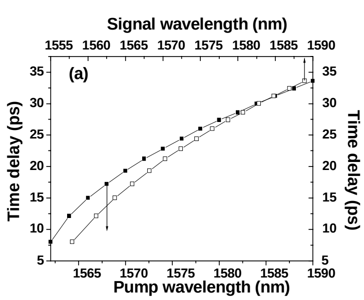

Fig.1 Time delay in FOPA

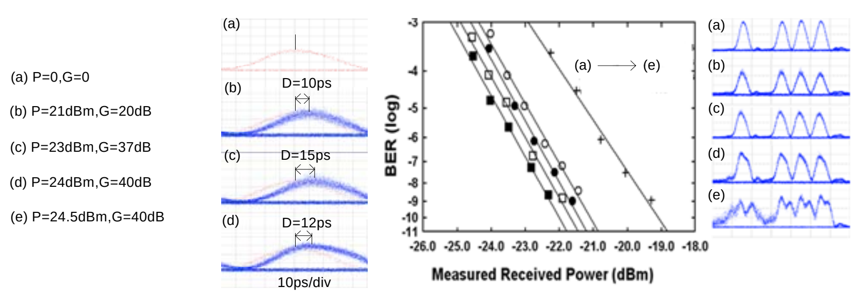

Fig.2 The delay time, BER and waveforms of the signal versus the pump power.

In a fiber-based parametric amplifier, the wavelength separation between the pump wavelength and the zero-dispersion wavelength of the fiber have significant impacts on the signal-gain bandwidth, which changes the time delay. A greater wavelength separation induces a narrower gain bandwidth, which leads to a larger time delay, as shown in Fig. 1. When the pump wavelength is 1590nm, the 3-dB gain bandwidth is ~0.45nm, and the maximal time delay at 1588.9 nm is ~33.6 ps.

The experimental setup can be found in [9]. We investigate the impact of the pump power on the delay time, the BER, and the signal waveforms respectively, as shown in Fig. 2. When the pump power is 21 dBm, corresponding to a 20-dB gain, the delay of the pulse is 10 ps. BER measurement indicates 0.3-dB power penalty in receiver sensitivity, and pulse distortion is not observed. When the pump power is varied to 23 dBm, the corresponding gain increases to 37 dB, the delay becomes 15 ps, and the sensitivity penalty is 0.6 dB. No noticeable distortion of the signal pulses is observed. A 24-dBm pump power results in only 12-ps delay, while the pulses are broadened and distorted because of the parametric gain saturation. If the pump power is further increased, the signal pulses are drastically distorted, and the sensitivity penalty is as high as 3 dB. It is expected that higher speed (e.g.160-Gb/s) data can also be delayed owning to the sufficient gain bandwidth of 1.6 nm. We believe that the ratio of the delay to the pulse width can be increased if system parameters are further optimized.

3. Slow light based on SBS effects

We use phase modulation with PRBS data pattern to broaden the pump spectral width. The Brillouin gain bandwidth is approximately determined by the phase-modulation rate of the pump. In our experiment, we phase-modulate the pump using 2.5-Gb/s 2^{23}-1 PRBS data, which generates ~1.6-GHz Brillouin gain bandwidth as shown in Fig. 3 (a). Because of the constant envelope of the phase-modulated pump, the data signal can be readily amplified and delayed without time synchronization, as required in [7]. In our particular demonstration, 1.25-Gb/s NRZ PRBS data experiences 400-ps delay at a 15-dB signal gain with certain pulse distortions because of the 1.6-GHz Brillouin gain bandwidth, resulting in a distorted eye diagram shown in Fig.3 (b). Fig.3 (c) shows the delay versus the signal gain. At 17-dB signal gain, the delay time is approximately 520 ps, corresponding to a delay-bandwidth-product of 0.7. By increasing the modulation bit rate of the pump and the pump power, wider Brillouin gain bandwidth and larger delay-bandwidth-product can be obtained.

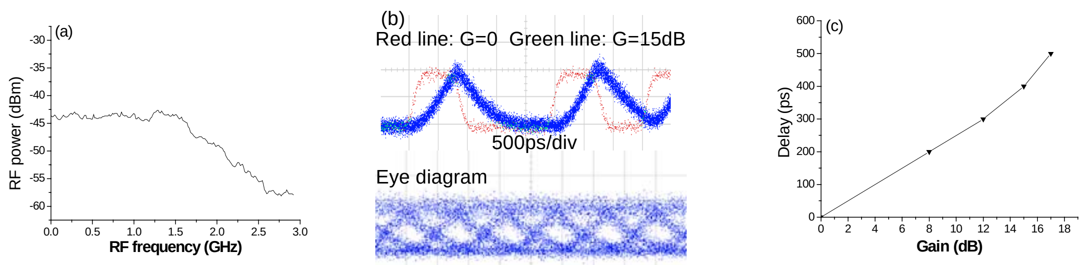

Fig. 3 (a) The baseband response of the Brillouin amplifier with enhanced gain bandwidth. (b) The 1.25Gb/s signal pulse delay and eye diagram at 15-dB signal gain. (c) The 1.25Gb/s signal delay versus the signal gain.

4. Conclusion

We review the system performance of slow lights based on FOPA and broadened SBS methods. The BER measurements of a 10-Gb/s RZ delayed data packet in a FOPA are performed, for the first time to the best of our knowledge. In addition, by phase-modulating a Brillouin pump, a 1.25-Gb/s NRZ PRBS data is delayed by 520 ps without time synchronization between the pump and signal. SBS based slow lights at higher data-rate can also be demonstrated if a wider bandwidth phase modulator were available.

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