Delay of RZ PRBS Data Based on Wide-Band SBS by Phase-Modulating the Brillouin Pump

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Abstract *A wide-band SBS slow light method is achieved by phase-modulating the Brillouin pump. A 1-Gb/s RZ PRBS data is delayed by 600ps with certain pulse distortion using such a technique.*

Introduction

The ability to control the speed of light is useful in many applications such as optical memories and buffers for optical communications. Recently, slow light generation based on fibre nonlinearities such as stimulated Brillouin scattering (SBS)[1-4], stimulated Raman scattering [5], and parametric process [6-7] has attracted much attention. Among them, SBS slow light can practically be achieved at any wavelength, but its main restriction is the narrow Brillouin gain bandwidth, which limits the bit rate of the delayed signal. A previously proposed spectrum broadening technique was used to increase the Brillouin bandwidth [2-3]. Direct modulation of the Brillouin pump using a low-speed pseudorandom binary sequence (PRBS) data [2] or a Gaussian noise source [3] has been demonstrated to broaden the pump spectral width. However, as the pump is intensity modulated, the pulse pump would lead to the relaxation oscillation and modulation instability of the signal [8].

In this paper, we broaden the Brillouin gain bandwidth by phase-modulating the Brillouin pump, so that a constant pump power level is maintained, which could avoid the problems in the pulse-pump based techniques, and makes it feasible to amplify and delay high bit rate PRBS or true data. In our demonstration, 1-Gb/s return-to-zero (RZ) PRBS data is delayed by ~600ps, which corresponds to a delay-bandwidth-product of 1.2. By increasing the bit rate of the phase-modulation, higher bit rate signals could be amplified and delayed.

Experiment

Fig.1 depicts the experimental configuration. The output of a laser diode (LD) operating at 1549.69nm is divided into two parts. In the lower path, the light is sent to a phase modulator (PM) driven by a PRBS (2^23-1) data from a pulse pattern generator (PPG). The phase-modulated light is boosted by a high power erbium-doped fibre amplifier (EDFA) and then launched into a 12.5-km single mode fibre (SMF) through an optical circulator (OC) to serve as the wide-band Brillouin pump. The Brillouin frequency shift of the SMF is ~10.96GHz. In the upper path, the light is sent to a Mach-Zehnder modulator (MZM) driven at the Brillouin frequency, resulting in two sidebands. A fibre Bragg grating (FBG) filters the lower sideband and sends the upper sideband into a second MZM. The insets (a), (b) and (c) in Fig. 1 show the optical spectra at the output of the LD, before the FBG, and after the FBG, respectively. The upper sideband of the light is sequentially modulated by two MZMs to generate a RZ PRBS (2^18-1) data, shown as inset (d). The RZ data is then sent into the SMF through an optical isolator to serve as the Brillouin signal. The amplified and delayed signal is exported from the OC and then attenuated by a variable optical attenuator (VOA) before measurement. An optical spectrum analyzer (OSA), an oscilloscope, a photodetecor (PD) and an electrical spectrum analyzer (ESA) are used to measure the optical spectra, the signal waveforms, and the electrical spectra, respectively.

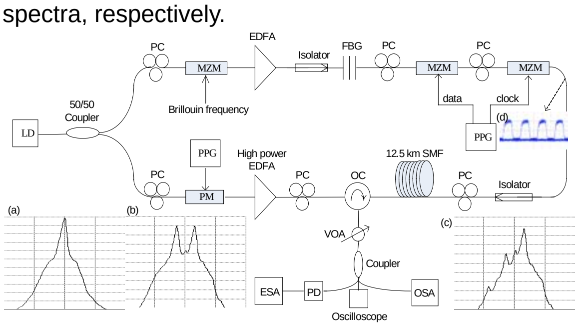

Fig. 1 the experimental setup

Results and Discussion

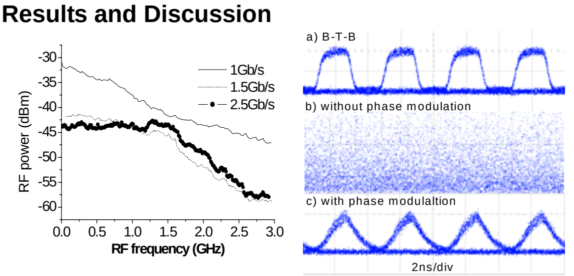

Fig.2 The Brillouin gain bandwidth measurement results (Left). The eye diagrams of a 500-Mb/s RZ signal (Right).

The Brillouin gain bandwidth is the convolution of the

Brillouin pump spectral width and the intrinsic Brillouin bandwidth [2], so it could be increased by broadening the Brillouin pump spectrum. Phase-modulating the Brillouin pump using a PRBS data can broaden the pump spectrum, whose spectral width is determined by the bit rate of the modulation signal. The left part of Fig.2 shows the baseband response of the Brillouin amplifier to the pump-modulation signals at different bit rates. At 2.5 Gb/s, the 3-dB bandwidth of the Brillouin gain is about 1.6 GHz. The Brillouin gain bandwidth can be further increased by increasing the bit rate of phase-modulation. Limited by the bandwidth of the phase modulator used in this experiment, here we show phase modulation of the pump up to 2.5 Gb/s. In the following, the modulation signal of the pump is fixed at 2.5Gb/s. The Brillouin gain bandwidth broadening by phase modulation is demonstrated in Fig.2, where (a) is the back-to-back eye diagram of a 500-Mb/s RZ signal with a PRBS length of 2^18-1. Without phase modulation, the signal is totally distorted due to the narrow bandwidth of Brillouin gain, as shown in (b). When the pump is phase modulated, the signal is amplified and delayed with some degree of distortion, as shown in (c).

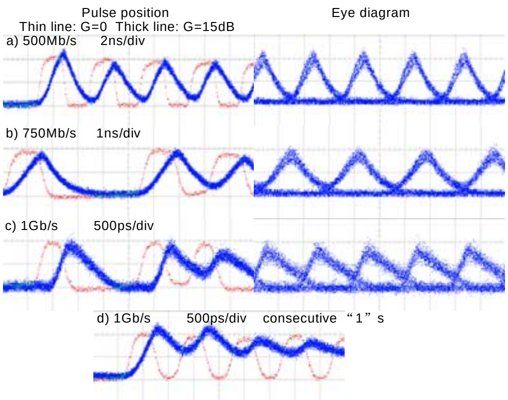

Fig. 3 The signal pulse waveforms and the eye diagrams at different bit rates: a) 500Mb/s, b) 750Mb/s, c) 1Gb/s, d) 1Gb/s with consecutive "1"s.

In Fig.3, we show the signal pulse waveforms (left) and the eye diagrams (right) at 500Mb/s, 750Mb/s, and 1Gb/s, respectively. At 500-Mb/s, the pulses experience ~300ps delay for 20-dBm pump power, corresponding to 15-dB gain, and a clear eye diagram is obtained. Note that we define the temporal centre of gravity of the amplified pulse as the pulse position considering the pulse distortion [4]. With increasing signal bit rate, the delay-bandwidth-product improves. The 1-Gb/s signal is delayed by about one bit for 15-dB gain. However, due to the 1.6-GHz Brillouin gain bandwidth, the delayed signal experiences large distortion. The consecutive "1" pulses experience severe distortion as the broadened pulses overlap with each other, as shown in Fig. 3(d). Detuning the Brillouin gain peak from the signal carrier can reduce the pattern dependence effects [9].

The delay time variation with the signal gain at the signal bit rate of 500Mb/s, 750Mb/s, and 1Gb/s is shown in Fig.4, respectively. All the delay times are measured for a single "1" pulse. Increasing the signal bit rate will enhance the delay-bandwidth-product. For 18-dB gain, the delay time of the 1-Gb/s signal is about 600ps, which corresponds to a delay-bandwidth-product of 1.2. Enhancing the pump power can enlarge the delay-bandwidth-product, however, the narrower Brillouin gain bandwidth will further distort the signal pulses. By simultaneously increasing the bit rate of the phase-modulation and the pump power, the delay of higher bit rate signals and larger delay-bandwidth-product can be achieved.

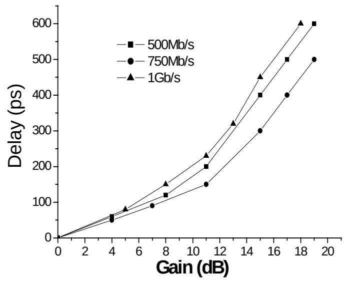

Fig. 4 The delay time versus the signal gain at different signal bit rates.

Conclusions

We have broadened the Brillouin gain bandwidth by phase-modulating the Brillouin pump. In such a wide-band SBS slow light method, true data could be delayed owing to the constant power of the pump. In our demonstration, 1Gb/s RZ PRBS data is delayed by ~600ps by phase-modulating the pump at 2.5Gb/s.

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References

1. K. Y. Song et al, Opt. Express 13(2005), 82
2. M. G. Herraez et al, Opt. Express 14(2006), 1395
3. Z.M. Zhu et al, OFC 2006, PDP1
4. C. Jauregui et al, OFC 2006, PDP2
5. J. E. Sharping et al, Opt. Express 12(2005), 6092
6. D. Dahan et al, Opt. Express 13(2005), 6234
7. L.L. Yi et al, OFC 2006 OFH3
8. G. P. Agrawal, Nonlinear Fiber Optics, Third Edition (Academic Press, 2002) Chap. 9
9. L. Zhang et al, OFC 2006 OFP7.