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Resolution improvement of all-optical ADC using SPM-induced spectral compression

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Abstract

Resolution improvement of our proposed all-optical analog-to-digital conversion using self-phase modulation induced spectral compression is described. From numerical simulation results, the spectral compression ratio 2 to 1, or 3 dB resolution improvement was obtained.

1 Introduction

Analog-to-digital conversion (ADC) has been investigated as a key interface technology to convert an analog signal into a digital one which is manageable for electrical digital signal processing, transmission, storage and so on. Recent tremendous growths of high-speed digital signal processing and optical communication systems have encouraged the demand for a high-speed and high-resolution ADC. Although a 24 Gsps 3 bit electrical ADC has been proposed [1], it would be difficult to realize high-speed and high-resolution electrical ADC over a few tens Gsps due to RC delay bottleneck, the amplitude and timing jitters of electrical sampling pulse and so on. To overcome these electrical limitations, optical ADC has attracted much attention recently [2]. In general, ADC consists of three procedures; sampling, quantization and coding. The optical sampling technique has been proposed and applied to quality evaluation of high-bit rate optical data signals over 500 Gb/s [3]. On the other hand, optical quantization and optical coding have been investigated for various high-speed and high-resolution applications [4]-[6]. Previously, we have proposed the all-optical ADC composed of optical quantization using soliton self-frequency shift (SSFS) in a fiber [4] and optical coding using optical interconnection based on a binary conversion table, and demonstrated its operation with 3 bit resolution [7]. The proposed system realizes the high-speed operation without speed limitation of electrical signal processing. Meanwhile, the resolution of the proposed all-optical ADC depends on the spectral width of the wavelength-shifted signal after SSFS [4]. To improve the resolution of the all-optical ADC, spectral compression of the wavelength-shifted signal is one promising approach. In this paper, we describe the numerical study of self-phase modulation (SPM) induced spectral compression after SSFS for the resolution improvement of the proposed all-optical ADC.

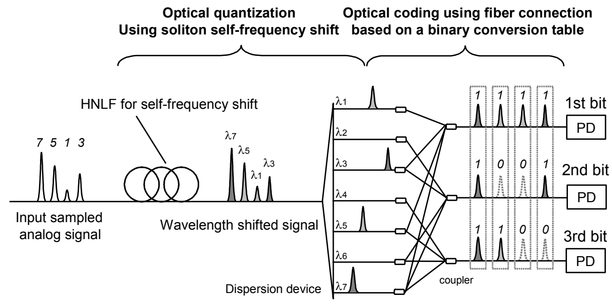

Fig.1. Schematic diagram of the proposed ADC.

2 Resolution improvement of the proposed all-optical ADC

The schematic diagram of the proposed all-optical ADC is shown in Fig. 1. It realizes optical quantization and optical coding after an optical sampling process. In optical quantization, we use SSFS in a fiber and a dispersion device. Since the amount of the center wavelength shift increases with increasing the peak power of an input pulse, power levels of an input analog signal converts into the amount of the center wavelength shift. After SSFS, each wavelength-shifted signal is promptly output to each different port of a dispersion device. In optical coding, we use the optical interconnection based on a binary conversion table. It allows us to broadcast the output signal after optical quantization to eigen output port corresponding to each bit in a multiple-bit binary number. Consequently, each bit in a multiple-bit binary number corresponding to the power levels of an input analog signal can be detected by each binary photo detector.

In general, the resolution of ADC is described by the achievable quantization level M. In the proposed all-optical ADC, the achievable quantization level M is described by eq. (1) [4].

$$M=\frac{\lambda_s+\Delta\lambda_{FWHM}}{\Delta\lambda_{FWHM}} \qquad (1)$$

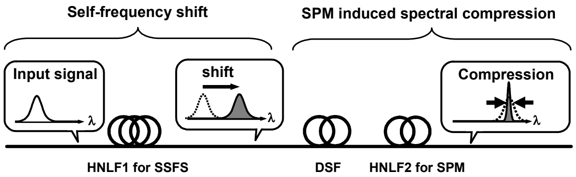

Fig. 2. Schematic diagram of the SPM-induced spectral compression after SSFS.

where λ_s and $\Delta\lambda_{FWHM}$ are the amount of center wavelength shift and the spectral width of wavelength-shifted signal after SSFS, respectively. From eq. (1), the compression of the spectral width $\Delta\lambda_{FWHM}$ enables the improvement of the achievable quantization level M according to the spectral compression ratio. Previously, spectral compression due to the negatively chirped pulse SPM in a fiber has been proposed [8]. To apply this technique to the resolution improvement of the all-optical ADC, we should choose appropriate fiber combination to generate negatively chirped pulse SPM for wavelength shifted signal. To confirm the spectral compression of the wavelength shifted signal, we numerically study the SPM-induced spectral compression of wavelength shifted signal by propagating dispersion shifted fiber (DSF) and high-nonlinear fiber (HNLF).

3. Numerical simulation of SPM-induced spectral compression for wavelength shifted signal

To verify the SPM-induced spectral compression of wavelength shifted signal, we executed the numerical simulation of pulse propagation in fibers using a split step Fourier method. The schematic diagram is shown in Fig. 2. In the simulation, we used three fibers; HNLF1 for SSFS, DSF for generation of a negative dispersed pulse and HNLF2 for SPM. We used a transform limited sech^2 pulse as an input sampled analog signal. The center wavelength and the pulse width were 1558 nm and 0.53 ps, respectively. For the generation of SSFS, the input pulse was propagated in a 1 km HNLF1 (dispersion: D=+7.2 ps/nm/km, nonlinearity: γ=16 /W/km) As a result, the center wavelength of the input pulse was shifted to longer wavelength side depending on the peak power of an input pulse. The SSFS signal was propagated in a 50 m DSF (D=+2.0 ps/nm/km) for generation of a negative dispersed pulse and 100 m HNLF2 (D=+0.28 ps/nm/km, γ = 9.0 /W/km) for SPM. Figure 3 shows the simulation results of the spectral evolution of an input pulse propagating in fibers in the case of the peak power of an input pulse was 21 W. From these results, we can confirm the SPM-induced spectral compression of the wavelength shifted signal. Figure 4 shows the simulation results of the relationship between the center wavelength after SSFS

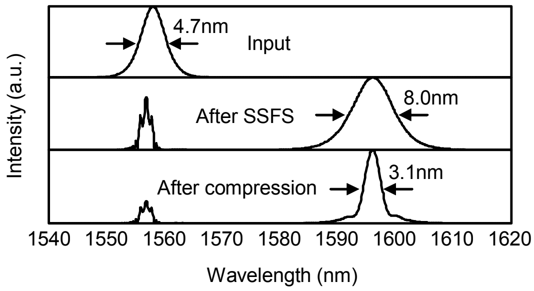

Fig. 3. Simulation results of the spectral evolution of an input pulse propagating fibers. The peak power of an input pulse was 21 W.

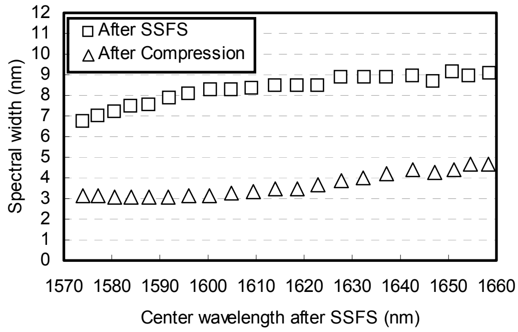

Fig. 4. Simulation results of the relationship between the center wavelength after SSFS and the spectral width before and after spectral compression.

and the spectral width before and after the spectral compression. From Fig. 4, we can confirm that the spectral compression ratio of 2 to 1 was obtained without wavelength dependence. That means 3 dB resolution improvement of the proposed all-optical ADC.

4. Conclusion

We have described the resolution improvement of the proposed all-optical ADC using SPM-induced spectral compression. From numerical simulation results, we can confirm that the spectral compression ratio 2 to 1, or 3 dB resolution improvement was obtained. There is the promise of all-optical ADC with greater M=32 (5 bits) resolution.

References

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