THE INTEGRATION OF THE ALL-OPTICAL ANALOG-TO-DIGITAL CONVERTER BY USE OF SELF-FREQUENCY SHIFTING IN FIBER AND A PULSE-SHAPING TECHNIQUE

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Abstract: Integration of the all-optical analog-to-digital (A/D) converter using self-frequency shifting in fiber and a pulse-shaping technique is described. Optical A/D conversion has attracted much attention, in order to realize high-speed and high-throughput system for photonic networks. A/D conversion generally consists of sampling, quantization and coding. Whereas various optical sampling techniques have been proposed, there are few investigations of the optical quantization and optical coding. Previously, we have proposed an all-optical A/D converter. In this paper, we aim at the integration of the proposed all-optical A/D converter using high nonlinear fiber, arrayed waveguide grating, and variable optical attenuator, and demonstrate its operation.

1. INTRODUCTION

Analog-to-digital (A/D) converters have been widely investigated as connecting continuous analog signals in nature to discrete digital signals for signal processing and transmission. Because of the difficulty in achieving high-speed A/D converter by use of current electronic technology, the A/D converter has been and continues to be a bottleneck of the realization of high-speed, high-throughput system. Recent advance in communication markets has renewed interest in pursuit of high-speed A/D converters. For realization of high speed A/D converter, optical approach has attracted much attention recently [1].

A/D conversion consists of three operation parts: sampling, quantization, and coding. In the most of previously proposed optical A/D conversion system, quantization and coding are realized by electrical processing technique after the optical sampling process [2–4]. Because of the difficulty in realizing optical multilevel thresholding, which is essential to optical quantization, there are few investigations of the optical quantization and optical coding technique [5–7]. Nevertheless, all optical A/D conversion, which consists of optical sampling, optical quantization and optical coding, is indispensable for high speed A/D converter.

Previously, we have proposed the all-optical A/D converter for realization of optical quantization and optical coding by use of self-frequency shifting in a fiber and a pulse-shaping technique [8]. The proposed system is composed of dispersion shifted fiber (DSF) and a bulk system including gratings and lenses. To make it more stable one which can be used in the actual field, it would be one promising approach to integrate a whole of system by use of planar lightwave circuit technique. Besides, we have to make fiber much shorter for generating self-frequency shift. Because of the low nonlinearity of DSF, we need to propagate the ultra-short pulse in a long DSF for generating self-frequency shift.

In this paper, we aim at the integration of the proposed all-optical A/D converter by examining the above-mentioned points. We consider the use of high nonlinear fiber (HNLF), arrayed waveguide grating (AWG) and variable optical attenuator (VOA) for the system integration. And we demonstrate the integrated all-optical A/D conversion.

2. PRINCIPLE OF ALL OPTICAL A/D CONVERTER

2.1 Theoretical Background

The proposed A/D converter is composed of two parts: optical quantization and optical coding. In optical quantization the center wavelength of an output signal is shifted as a function of the power of an analog input signal. By using the difference of the center wavelength, we can achieve optical quantization of an input signal. In optical coding an output signal after optical quantization is shaped to an arbitrary digitized signal by use of the pulse-shaping technique.

In optical quantization, we use self-frequency shifting in a fiber [9, 10] and AWG. The Raman self-frequency shift in a fiber, given by

$$\frac{d\kappa}{dZ} = \frac{8}{15}\sigma_R \eta^4 \tag{1}$$

where κ is the center frequency of a soliton pulse, Z is the propagation distance in a fiber, σ_R is a coefficient of the self-induced Raman effect, and η is the amplitude of an input pump pulse [11]. Equation (1) suggests that the amount of frequency shift increases in proportion to the fourth of the amplitude of an input pulse. On the other hand, some experimental results show that the wavelength shift of a dispersed pulse increases in proportion to the twice of the amplitude of an input pulse [11, 12]. Although the mechanism of wavelength shift of a dispersed pulse is still under investigation, this power-proportional feature is suitable for quantization processes.

In optical coding, we use the pulse-shaping technique [13]. The pulse-shaping technique enables to generate high bit rate digitized signals by modulating a seed ultrashort pulse in frequency domain.

The pulse-shaping operation can be derived and described by

$$e_{out}(t) = \int E_i(\omega)H(\omega)exp(-i\omega t)d\omega \quad (2)$$

where $e_{out}(t)$, $E_i(\omega)$, and $H(\omega)$ are the modulated temporal signal, the complex spectral amplitude of the original ultrashort pulse, and the Fourier transform function of the frequency-filter function. If we use an adequate frequency filter $H(\omega)$ in a pulse-shaping system and modulate the spectra of the original ultrashort pulse, we can synthesize an arbitrary-shaped pulse from a cross correlation between the original seed ultrashort pulse and the frequency filter function.

To provide a digitized signal corresponding to each power of an analog input signal, we use this pulse-shaping technique. Since the center wavelength of an ultrashort pulse is changed after self-frequency shifting, we can obtain an arbitrary digitized signal by preparing a different frequency filter for each center wavelength.

2.2 Integrated System Configuration

Figure 1 shows the schematic diagram of the integrated all-optical A/D converter by using a fiber and PLC devices.

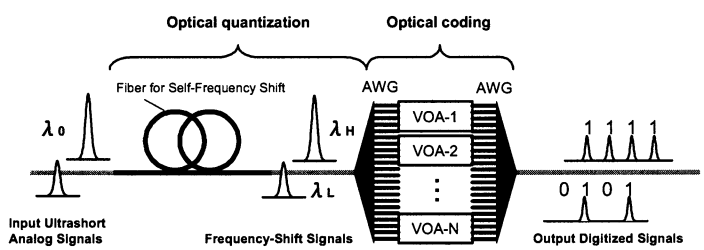

Figure 1. Schematic diagram of the integrated all-optical A/D converter

We compose the all-optical A/D converter by use of HNLF, AWG and VOA for integration of the system. The self-frequency shifted signals by use of short HNLF are generated more effectively and lower noise than by use of long DSF, and enable the integration of the system. The pulse-shaping technique by use of AWG and VOA enable to compose the compact system and achieve the high stability. On the other hand, a fiber for generating self-frequency shift is still long to integrate a whole of system.

If we can make it much shorter, we can integrate the system further. To do so, we need to optimize various parameters of fiber.

2.3 Simulation of self-frequency shift for integration of A/D converter

For the integration of the all-optical A/D converter, we have to make a fiber much shorter for generating the self-frequency shift. Because a high nonlinear fiber can be generated the low noise frequency shifted signal by propagating in a short fiber, we try to use a HNLF. To verify the characteristic of the shift of the center wavelength, we have a simulation of the pulse propagation in 5-m HNLF.

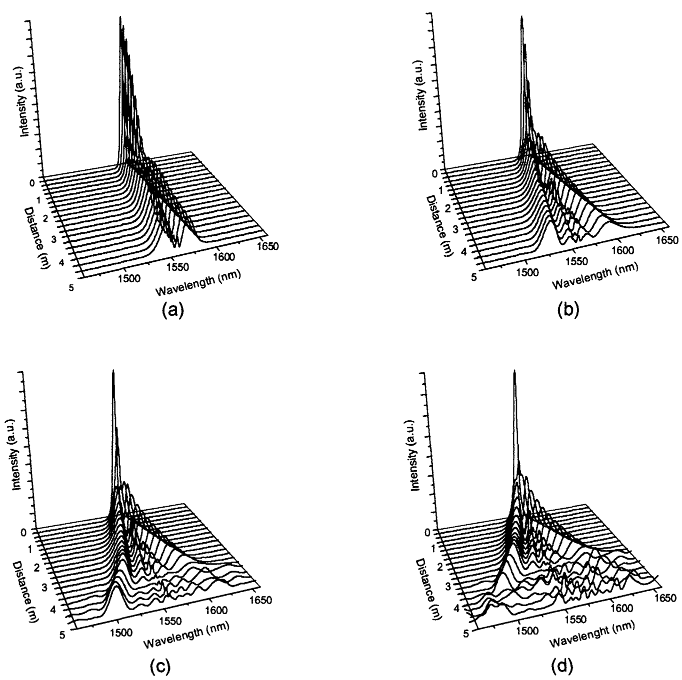

Figure 2. Simulation result of ultra short pulse propagation in 5m-HNLF: Peak power of input pulses (a) 100W (b) 200W (c) 300W (d) 400W

Figure.2 shows the simulation result of pulse propagation in 5-m HNLF by Split Step Fourier method [14]. The pulse width and the center wavelength of an input Fourier transform-limited pulse were 300fs and 1560nm, respectively.

From Fig.2 we can obtain the self-frequency shifted signal respected to the input pulse power by propagating in a short fiber. However, as the power of an input signal is higher, the noise of the self-frequency shifted signal is increased. It is necessary to achieve the low noise self-frequency shifted signal at wide range of the input power for the improvement of the quantization bit rate.

Figure.3 shows the simulation result of variation of the shift of the center wavelength in 2-m, 5-m, and 10-m HNLF

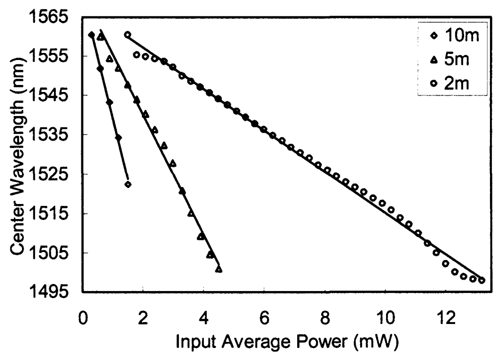

Figure 3. Simulation result of the shift of the center wavelength of an output signal form a HNLF by varying of the power of the input signal.

From Fig.3 we can see that the low noise self-frequency shifted signal at wide range of the input power is obtained by using shorter length fiber. From these results, we suggest that the use of a 2-m HNLF is ideal for integration of the system.

3. EXPERIMENTAL SETUP AND RESULT

To verify the operation of the integrated all-optical A/D converter, we executed preliminary experiments. Figure 5 shows the experimental setup of the proposed all-optical A/D converter.

We used an ultra-short pulse from a femtosecond fiber laser as a light source. The pulse width and the center wavelength were 300fs and 1560nm. As input analog signals, we prepare three average power for the input pulses of 9.8mW, 10.1mW and 10.3mW adjusting the power of the input pulse by using a variable attenuator. To generate the self-frequency shift, signals propagated in a 2-m HNLF. Figure 4 shows the experimental result of variation of the shift of the center wavelength in a 2-m HNLF. From Fig.4 we verify the shift of the center wavelength in proportion to the power of input pulse.

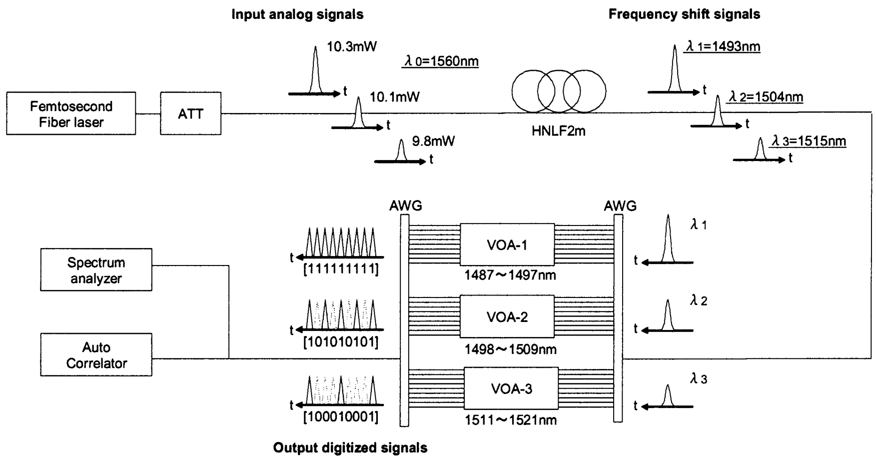

Figure 4. Experimental setup of the composed all-optical A/D converter

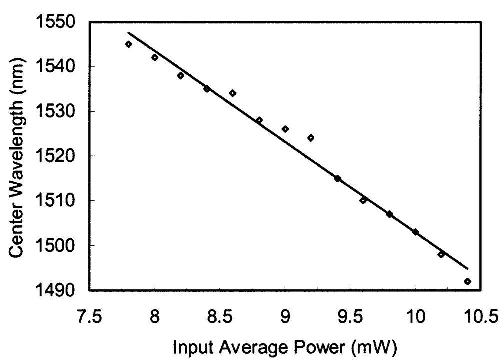

Figure 5. Experimental result of the shift of the center wavelength of an output signal from a 2m-HNLF by varying of the power of the input signal.

From this result, the center wavelengths of each analog signal changed to 1515nm, 1504nm and 1493nm, respectively. The wavelength shifted signals input to a pulse-shaping system composed of two AWGs and three VOAs. Each signal inputs to VOA-1, VOA-2, VOA-3 after by branching by AWG, and then is filtered in the frequency domain, as a result output three different digitized signals in the time domain. To measure the temporal profile of a generated signal, we used an interferometric autocorrelator.

Figure 6(a), 6(b), and 6(c) show spectral profiles measured with a spectrum analyzer at input powers of 9.8mW,10.1mW and 10.3mW after filtering by VOAs. Figure 7(a), 7(b), and 7(c) show the result of the output signal wave-form measured by the autocorrelator at input powers of 9.8mW,10.1mW and 10.3mW, respectively.

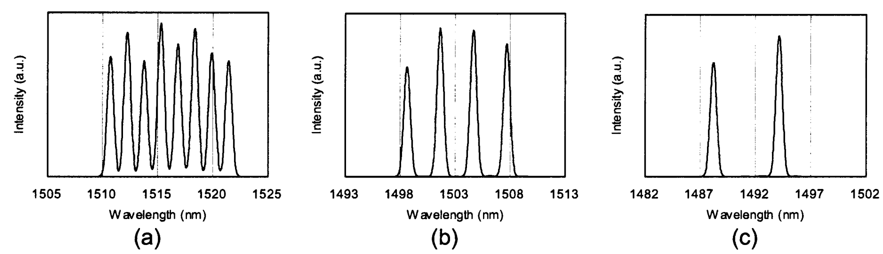

Figure 6. Experimental result of the output spectrum after filtering by VOA: Input average power (a) 9.8mW (b) 10.1mW (c) 10.3mW

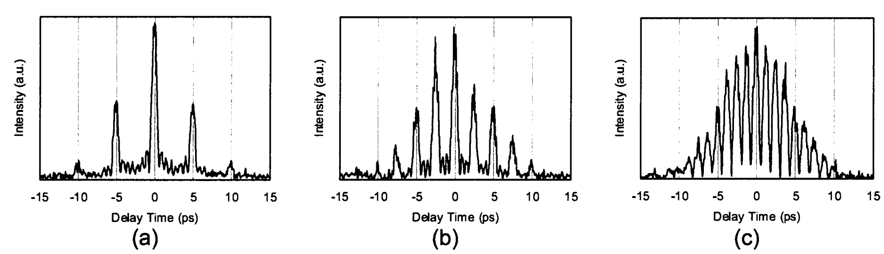

Figure 7. Experimental result of autocorrelation of output signal: Input average power (a) 9.8mW (b) 10.1mW (c) 10.3mW

From Figs 6 and 7, we can confirm that the integrated all-optical A/D converter successfully operates and output three different digitized signals, [100010001], [101010101] and [111111111] at three input power 9.8mW, 10.3mW and 10.5mW, respectively.

4. CONCLUSION

We integrate the proposed all-optical A/D converter by using HNLF, AWG and VOA. For integration of a fiber used, we simulate the pulse propagation in a HNLF. From simulation result we verify using HNLF is very effective for the integration of the system.

Preliminary experimental results show that 3-level different digitized signals from three average power of an ultrashort analog input pulse can be generated and the operation of the integrated system can be verified.

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