Real-time photonic analog-digital converter based on discrete wavelength-time mapping

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Abstract—A real-time two-channel photonic analog-digital converter operating at >2 GSPS has been constructed and demonstrated for the first time, to our knowledge. The architecture is based on the time-interleaving of discrete, spectrally-distinct optical pulses.

I. INTRODUCTION

The advancement of analog-digital conversion toward high-resolution digitization in the microwave frequency regime promises to impact many commercial and military systems including radar, electronic warfare, communications, and test and measurement instrumentation. The progress of electronic analog-digital technology toward multi-gigasample rates has been slow and accompanied by high power dissipation and limited effective resolution [1]. Current digital receivers require multiple stages of mixing and filtering to downconvert microwave signals to frequencies within the bandwidth of electronic analog-digital converters (ADCs). This leads to increased size, weight, and power requirements for receive modules and results in limitations on the instantaneous bandwidth and dynamic range.

An attractive alternative is a photonic digital receiver. Photonics offers many advantages including broadband sampling [2], highly-stable, low-noise optical clocks [3][4], nearly lossless fiber remoting, and the potential for highly parallel operation. In this paper, we present a real-time parallel photonic analog-digital converter architecture based on discrete time domain to wavelength domain mapping. The architecture utilizes commercially available technology. Preliminary digitization results and system analysis are presented.

II. SYSTEM DESCRIPTION

The two channel parallel ADC architecture with a photonic sampler based on the time interleaving of spectrally distinct pulses [5][6] is shown in Figure 1. A harmonically mode-locked fiber laser [4] externally driven by a low noise synthesizer (Hewlett-Packard 8662A) produces transform limited 2-ps pulses (sech² shape) at a repetition rate of 1.2 GHz with 2 mW average power. The pulse train is amplified with an erbium-doped fiber amplifier (EDFA) to ~15 mW and directed to 1 km of dispersion decreasing fiber (DDF) resulting in supercontinuum generation [7] with a 10 dB width of ~60 nm in a 250 fs duration pulse. Figure 2(a) shows the output spectrum of the DDF. The spectrally broad pulses are sliced by a wavelength division multiplexer (WDM) into 8 discrete wavelength channels separated by 3 nm each with a 3dB width of 1 nm. Two of these channels are used in the current experiments. Connected to each channel is a fiber stretcher (FS), variable in-line optical attenuator (AT), fiber delay line (DL) and Faraday mirror (FM). Dispersion shifted fiber is used to
reduce the pulse broadening and relative dispersion between the channels. The Faraday mirror provides polarization compensation for the non-polarization maintaining components of each channel system as well as a second pass through the WDM to multiplex the two channels to the same fiber. The length of the channels' propagation loop is chosen to discretely fill the interpulse period of the original pulse train. The fiber stretcher provides temporal fine-tuning with a total tuning range of ~200 ps and temporal resolution of 0.5 ps. The variable attenuators allow for compensation of the input pulse spectrum, providing equal optical power in each channel. A polarization maintaining EDFA amplifies the two-wavelength pulse train. Figure 2(b) shows the pulse train spectrum after amplification by the EDFA. A LiNbO₃ Mach-Zehnder modulator amplitude modulates the pulse train with the signal to be digitized. The modulated time- and wavelength-interleaved pulse train signal is demultiplexed by a second WDM for the parallel digitization of the two channels. The pulse train for each channel was directed to a 1.5 GHz photodetector. The resultant sinusoidal signal representing the channel pulse train was amplified by a low noise rf amplifier and directed to a high speed real-time digitizing oscilloscope employing a single 8-bit 4 GSPS electronic ADC for each channel.

are uncertainty in the sampling time of the input signal and uncertainty in the sampled amplitude. The effect of timing error on the ADC system resolution can be estimated by considering the worst case of digitizing a sinusoidal signal at the zero crossing with a frequency equal to the system bandwidth limit. The maximum effective number of bits can be shown to be

\[ N_e = \log_2 \left( \frac{f_b}{2 \tau} \right) \]

where \( \tau \) is the timing error. The effect of uncertainty in the sampled amplitude can be estimated from the expression

\[ N_a = \log_2 \left( \frac{A}{\delta A} \right) \]

where \( A \) is the full-scale signal amplitude and \( \delta A \) is the amplitude error.

III. SYSTEM ANALYSIS

Two major limiting factors in the performance of an analog-digital converter
In our system, the amplitude noise and timing jitter of the laser are expected to be important in the ultimate resolution of the system. We have measured the amplitude noise and timing jitter of the laser used in the above-described ADC system. The timing jitter of a clock is typically calculated from absolute phase noise measurements [4] measured with respect to a reference source with lower noise. The single sideband phase noise of our laser is shown in Figure 3. The timing jitter for the laser source, calculated from the phase noise data, over a frequency range of 100 Hz to 1 MHz (equivalent measurement time of ~1.5 msec) is 95 fs for a 1 GHz repetition rate. For the 2.4 GSPS ADC of this paper, this would correspond to a maximum resolution at the Nyquist frequency of 11.5 bits. The pulse amplitude to rms amplitude noise ratio was measured using a low barrier Schottky diode and DC blocking filter as an amplitude modulation detector over the same measurement time to be 32 dB corresponding to 10.6 bits.

IV. CONCLUSIONS

A real-time two-channel photonic analog-digital converter based on wavelength-time mapping has been constructed. The noise characteristics of the optical clock used in the system have been characterized and are expected to limit the current system to a maximum resolution of 10.6 bits at the system Nyquist frequency of 1.2 GHz. Real-time digitization of sinusoidal signals has been performed with a resolution currently...
limited by the electronic ADC used at the current signal level.

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V. REFERENCES


