Demonstration of a photonic analog-to-digital converter scalable to 40 GS/s with 8-bit resolution

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Abstract: An initial system demonstration is shown for a CMOS-compatible optically-sampled analog-to-digital converter with potential to achieve 40 GS/s with 8-10 effective number of bits (ENOB). Using commercial components, 7.6 ENOB has been achieved.

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For high-sampling-rate analog-to-digital converters (ADC), the maximum resolution achievable—the effective number of bits (ENOB)—is limited by the aperture jitter during the sampling period [1]. As an example, to achieve 40 GS/s from an analog signal with 15 GHz bandwidth with eight ENOB requires an aperture jitter <30 fs. This is only possible to generate with expensive, custom rf oscillators. An alternative approach is to exploit the extremely low timing jitter available from a modelocked laser via optical sampling [2]. Numerous approaches to optically-sampled ADCs have been proposed and demonstrated, including phase-encoded sampling [3-4], time stretching [5-6], and MSM switching [7]. Each method requires channelizing the high-rate optical samples to a lower rate that can be quantized, and the resolution of the system requires that each channel be carefully controlled with extreme precision. We have proposed an optically-sampled ADC where most of the device functions, including the optical modulator, filter bank, and photodetectors—GigaHertz Optical Sampling Technology (GHOST)—are integrated on a CMOS chip using devices developed as part of a library of Electronic Photonic Integrated Circuit (EPIC) devices, as described elsewhere [8]. The two major challenges to such an approach are to demonstrate the CMOS-compatible performance of each device, and secondly, to demonstrate the viability of the optically-sampled ADC architecture. In this work we demonstrate the system performance of the optically-sampled ADC using commercial components, shown schematically in Figure 1. Transform-limited optical pulses are generated off-chip at 2 GHz (derived from a 10 GHz erbium fiber laser and downconverted to 2 GHz using a high-extinction-ratio electro-optic modulator) and temporally broadened to ~500 ps after propagation through a dispersive fiber. The chirped pulses are then sent to an electro-optic modulator biased at quadrature where the test signal to be sampled is applied to the RF terminal electrodes. The exiting optical waveform leaving the modulator is amplitude modulated by the test signal and split into two complimentary outputs. The optical waveform from each modulator output is demultiplexed by a 1xN wavelength-division-multiplexed (WDM) filters (200 GHz spacing, <2.5 dB insertion loss/channel, >40 dB extinction) to separate out sections of the spectrum. Because the pulses are chirped, each of the N spectral outputs is a sample from a different part of the waveform. To reach 40 GS/s, one would need 20 x 2 (doubled for the complimentary modulator output) quantizers, since each wavelength channel is sampling one temporal portion of the test signal at 2 GS/s. For this experiment, four (two separate wavelength channels) and the complimentary outputs out of the total 40 output channels were detected and amplified (MITEQ SCRM-100M6G, Analog Devices ADL5541) to the full-scale voltage of the quantizer (a four-channel LeCroy SDA 6020 oscilloscope). No interleaving of the four output channels was performed.

Figure 2, top panel, shows the frequency response of one of the digitized quantizer channels for the case where a two-tone test signal of 811 MHz and 813 MHz is applied to the modulator RF electrodes. Each of the four channels was calibrated to map the quantizer output to the amplitude of the test signal before the data was collected. The modulator drive voltage was V/V_π ~ 0.12, the single-channel excess optical insertion loss measured from the input to the modulator to the photodetector was ~5.5 dB, and the

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optical power illuminating each photodetector was ~200 μW. 5 MSamples of data was collected for a pair of complimentary channels and analyzed offline with a computer. The single-channel spur-free dynamic range was less than 24 dB. By time-alignment of a pair of complimentary, differential outputs of the quantizer [3], the dynamic range was extended to over 47.3 dB as shown in Fig 2, bottom panel, thus resulting in ~7.6 ENOB. At present, we believe that the resolution is limited by the ~1 ps timing jitter of the modelocked laser which is currently being upgraded to achieve <20 fs jitter [9]. In future work, we intend to demonstrate a CMOS chip with an integrated modulator [10], filter bank, and photodetectors [11].

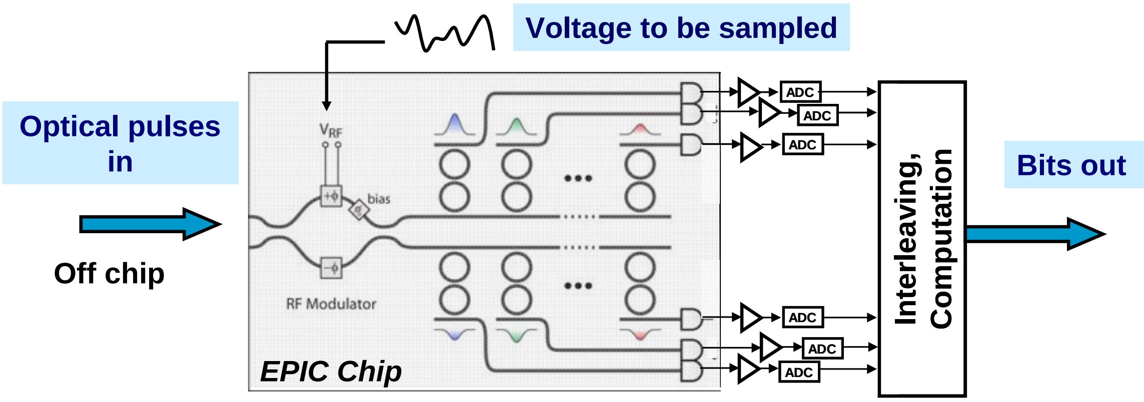

Figure 1. System layout for the optically sampled analog-to-digital converter. The grey-box elements show the devices that will be integrated onto a monolithic CMOS EPIC chip. For this demonstration the functionality of the chip is implemented by a discrete optical modulator and WDM filters. The ADC used here is a four-channel LeCroy digitizing oscilloscope with >8 ENOB, 6 GHz analog bandwidth.

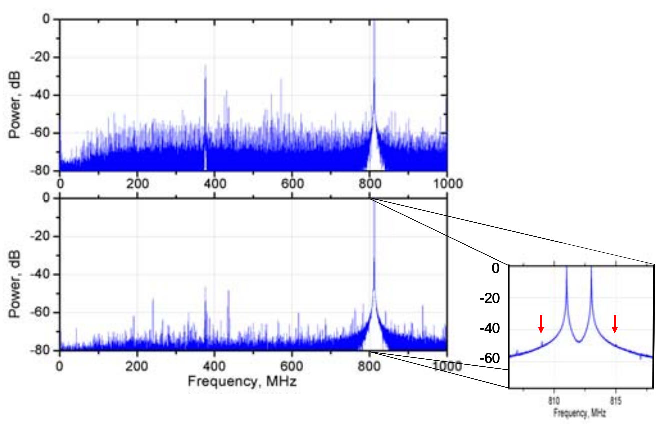

Figure 2. Signal spectrum from the optically-sampled ADC system in response to two tones at 811 and 813 MHz. The top panel shows the output from one of the quantizer outputs. The bottom panel shows the differential output of a pair of complimentary quantizer outputs. The inset shows the 47.3 dB suppression of the third-order intermodulation distortion products.

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