tensity level required for the operation of existing commercial liquid crystal spatial light modulators (SLMs).[5]

One advantage of dye doped nematic liquid crystals over SLMs[5] is the resolution capability. As demonstrated in the study of diffraction efficiency dependence on grating spacing,[3] the resolution can be over 200 lp/mm, compared to commercial SLMs typical resolution capability of at most 40 lp/mm.

Acknowledgments

This work is supported by the Army Research Office and the Air Force Research Laboratory.

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OPTICAL ENGINEERING

Photonic Time-stretch Offers Solution to Ultrafast Analog-to-digital Conversion

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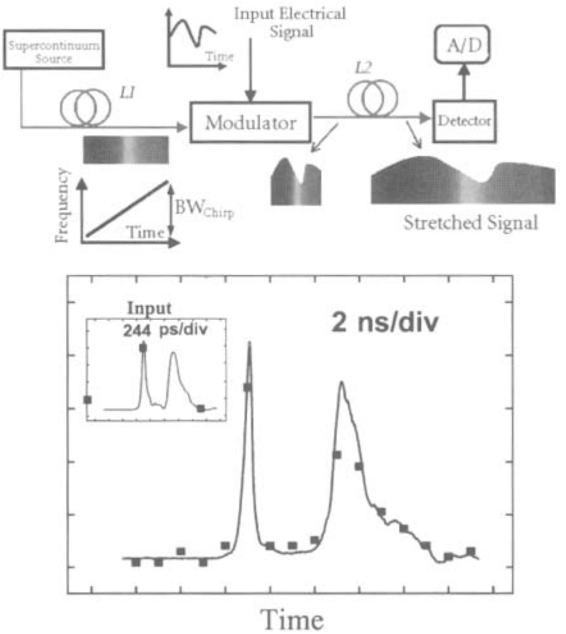
Analog-to-digital (A/D) conversion represents the key bottleneck in high performance radar and communication systems. The current trend in electronic receivers is to perform the conversion at microwave frequencies. In the so-called "digital receiver," the A/D conversion is performed at microwave (carrier) frequencies, thus placing stringent requirements on the sampling frequency and input bandwidth of the A/D. It is widely recognized that new concepts leading to major advances in A/D technology are a priority.

Recently, a new optically-assisted A/D concept was proposed and demonstrated.[1] The electrical signal is time-stretched in the optical domain, prior to sampling and quantization. By reducing the signal bandwidth, the new concept offers revolutionary enhancements in input bandwidth and sampling rate of A/D converters. Further, the noise due to sampling jitter is reduced. Performing the time-stretch in the optical domain is critical as it ensures that both the microwave carrier and its modulation are slowed down.[2] This scheme can be applied to both finite-time as well as continuous-time waveforms. In the latter case, the signal is first segmented and interleaved into m channels and each segment is stretched by a factor m.[1]

While the basic concept of time-stretching has been known for nearly 30 years,[3, 4] its practical implementation has not been successful due to the difficulty of obtaining high chirp rates or highly dispersive elements. In the demonstration of the time-stretch analog-to-digital converter (TS-ADC) shown in Figure 1, pulses from a modelocked erbium-doped fiber ring laser are compressed in a nonlinear fiber to obtain a 7.5-THz supercontinuum, which is subsequently chirped in a single-mode fiber of length L_1. The intensity of this chirped pulse is modulated with the input electrical signal, hence mapping time into optical wavelength. The intensity-modulated chirped pulse is then dispersed in a fiber of length L_2, stretching the modulation envelope. Since the bandwidth of the optical pulse (1–20 THz) is much larger than the electrical bandwidth (< 100 GHz), dispersion-induced signal distortion is negligible.[2] The entire function is implemented with optical fibers and guided wave devices resulting in a compact and rugged system. The stretch factor is approximately given by $M \sim (L_1 + L_2)/L_1 = 8$.[2] The stretched envelope is detected and digitized with an electronic A/D converter with a sample rate of 1 Gs/s and input bandwidth of 500 MHz.

The solid line in Figure 1b shows the waveform captured by the sampling oscilloscope. The data points, spaced 1 ns apart, represent digitized output of the ADC. The inset shows the waveform prior to time stretching. Clearly, the electronic ADC with 1 ns sample interval is unable to capture the waveform. However, after time-stretching, bandwidth of the analog waveform is reduced by the stretched factor, $M = 8$, allowing it to be captured



Jalali Figure 1. Simple time-stretch system (top) and preliminary demonstration of time-stretch A/D conversion (bottom). Data points are the digitized samples and the solid line is the analog waveform. The inset shows the output without time-stretch.

by the ADC. The effective sampling rate of the 1 Gs/s electronic ADC is increased to 8 Gs/s and its input bandwidth is increased to 4 GHz. The optoelectronic TS-ADC is presently the most promising technique for A/D conversions of ultrafast electrical signals.

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Board-level Polymer Optical Clock Delivery Circuit

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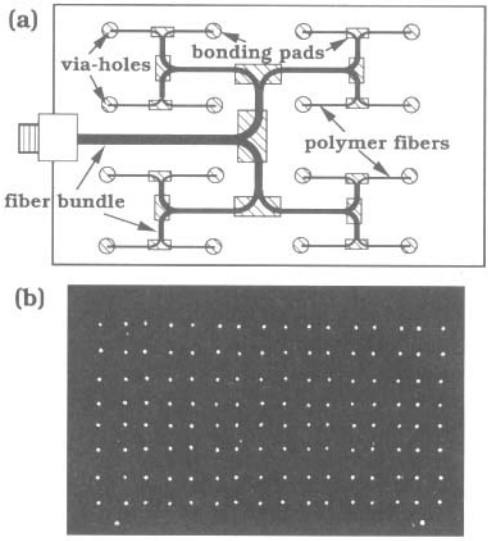
Large-bandwidth optical clock signal delivery has been an active research area since the introduction of the concept 15 years ago.[1] Proposals ranging from using free-space holographic Dammann grating to optical waveguides have been widely studied. To date, it is still a challenging task to have a solution that is packaging-sensible, compact in geometry, and low-loss/high uniformity.

Recently, practical adoption of polymer fibers for various information optics applications has prompted researchers to investigate a polymer fiber embedding method for the board-level optical clock distribution. Polymer fibers offer various advantages against other approaches because they are low loss in the distances the application demands. They are also flexible, able to tolerate small bends, and, most of all, robust against breakage.

Experiments have shown that similar to electronic chip bonding, thin-cladding polymer fibers can be wire-bonded on a conventional G-10 multilayer printed circuit board (PCB).[2, 3] The output ends of these fibers are guided through via-holes to the opposite side of the PCB where O-E detector chips are mounted. These identical length fibers are laminated on the PCB and their input ends fused and tapered together before termination using a standard fiber connector mounted on an edge of the PCB (see Fig. 1a). The connector is designed with a spacer that allows a free-space gap from an input fiber that carries the large-bandwidth optical clock signal. Such a gap is necessary to guarantee that the clock signal power is evenly broadcast to all receptive fibers. Finally, a protective polymer cover is used to seal the fiber side of the PCB.

Such a fiber-embedded optical circuit board has been tested. It shows a fan-out capability up to 128 nodes (see Fig. 1b), an average excess power loss of 5 dB where the loss due to a small bent (R < 1 mm) is less than 0.2 dB. Uniformity among all receiving nodes can be controlled to within 3 dB. A board with 30-cm lengths of individual fiber paths has an optical clock skew around 25 ps. The dispersion/skew-dominated bandwidth of the circuit is 10 Gb/s. The research results demonstrate that optical clock-distributions in computers may not be just a dream.



LI Figure 1. (a) Bonding and termination of polymer fibers on PCB. (b) Photo of light distribution to 128 nodes on a 13 × 19 cm^2 PCB.

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Microresonators for Integrated Optical Devices

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Resonators have frequency selective properties that make them particularly suitable for optical signal processing. By cascading coupled resonators in different configurations, it is possible to synthesize a wide variety of desirable optical filter characteristics.[1, 2] Significantly, resonators behave as lumped elements, tuning as a unit. This is to be contrasted with many interferometric devices in which the details of the device shape are critical to the performance, *e.g.*, in apodized evanescently coupled waveguide filters. Other novel resonator applications for integrated optics, not achievable with conventional devices, include absorption controlled WDM signal routing.[3]

The challenge for integrated optics is fabricating devices small enough so that the free spectral range (FSR) is larger than the optical communications bandwidth (about 30–50 nm centered at 1.55 μm). Depending on the material composition, this FSR is achieved in devices with dimensions less than 10 μm. Light confined to these