On-chip signal processing

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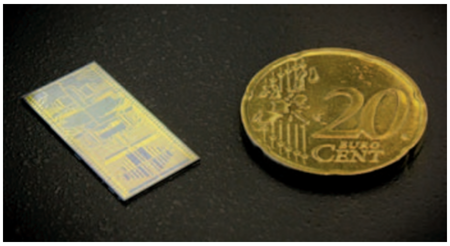

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Reconfigurable optical delay lines (ODLs) and tunable, wideband phase shifters are important for microwave photonic applications such as signal filtering and arbitrary waveform generation. The common limitation of existing approaches is the trade-off between maximum achievable delay, operating frequency and bandwidth. Maurizio Burla and co-workers from The Netherlands have now presented a photonic signal processor that not only offers a wideband and fully tunable ODL, but is also monolithically integrated on a single compact CMOS-compatible chip. The processor consists of a reconfigurable ODL, a separate carrier tuning unit and an optical sideband filter. The optical sideband filter — a Mach–Zehnder interferometer loaded with an optical ring resonator in one of its arms — removes one of the radiofrequency sidebands of a double-sideband intensity-modulated optical carrier. The ODL and separate carrier tuning unit are individually implemented using a pair of cascaded optical ring resonators. Varying the group delay of the signal sideband by tuning the resonance frequencies and the coupling factor of the optical ring resonators in ODL, while also applying a full 0–2π carrier phase shift in separate carrier tuning, allowed the researchers to demonstrate a two-tap microwave photonic filter whose notch position can be shifted by 360° over a bandwidth of 1 GHz. *RW*

Comb-based pulse shaping

IEEE Photon. Tech. Lett. **23,** 1618–1620 (2011)

Microwave photonic filters offer attractive features such as low loss, low sensitivity to electromagnetic interference, and rapid tunability and programmability over large bandwidths. Most of them are based on multiple physical delay lines — a concept that is difficult to scale to large numbers of taps. Recent work has used broadband light sources and a single dispersive element. Because the medium introduces a differential delay between optical frequencies, the multiple optical frequencies function as multiple taps, thus avoiding the use of many physical delay lines. Andrew Weiner and co-workers from the USA now demonstrate a reconfigurable and tunable flat-top microwave photonic filter using an electro-optic frequency comb and a dispersive medium, in which each individual optical frequency component in the comb becomes an independent filter tap. They implemented a flat-top filter by applying positive and negative weights across 32 comb lines, and tuned the filter central frequency by adding a phase ramp to the tap weights. The scheme provides flexible and tunable filter characteristics by programming the amplitude and phase of individual comb lines using an optical line-by-line pulse shaper. The researchers say that increasing the number of comb lines may provide lower pass-band ripple, narrower transition bands and stronger sidelobe suppression. *JB*

Scaling down frequency

J. Lightwave Technol. **29,** 3091–3098 (2011)

Although directly sampling an electric field at optical frequencies is impossible owing to the frequency limitation of electronic sampling devices, indirect sampling can be achieved through heterodyne processes that generate beat notes in the radiofrequency domain. Peter Delfyett and co-workers in the USA have now used frequency combs as local oscillators to downconvert and compress optical signals through multiheterodyne detection, a process by which two combs that share an optical reference are mixed to deduce the effect of a medium on the signal comb. The researchers used a commercially available 250 MHz erbium-doped fibre frequency comb as a local oscillator in three distinct experiments: mixing two mutually incoherent mode-locked laser combs; mixing a mode-locked comb and phase-modulated continuous-wave light; and performing spectral interferometry on downconverted white light. The researchers demonstrated spectral compression by factors of 1,600 for phase-modulated light and 17,000 for mode-locked pulses, during which carrier frequencies were converted from ~200 THz to ~100 MHz. They also showed that interference patterns can be obtained in the microwave regime by summing photocurrents, and that these patterns can be used for high-resolution white-light spectral interferometry. *DP*

Waveform mathematics

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Many tasks in signal processing severely stretch or are beyond the capabilities of electronic circuitry. The ability to perform such signal processing tasks on high-frequency microwave waveforms, therefore, is one of the key attractions of microwave photonic devices. One of the latest devices to demonstrate this ability is a photonic temporal integrator developed by José Azaña and co-workers in Canada. The device uses a superluminescent diode, a semiconductor optical amplifier, an electro-optic modulator and a cascade of fibre interferometers to generate an output signal that is the cumulative temporal integration of an arbitrary input waveform. The microwave signal to be integrated is used as the drive signal for the electro-optic modulator and the output of the calculation is an optical signal that is collected by a photodetector connected to a sampling scope. Tests show that the device can accurately process signals with bandwidths of ~36 GHz over a measurement time window of 4 ns, thus significantly outperforming electronic technologies. Such integrators are required for applications in computing, control and communications networks. *OG*

Ultralow phase noise

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Microwave signals with low phase noise are important for applications such as large-scale high-precision remote synchronization and long-baseline interferometry. It has been shown that an ultralow phase noise of -104 dBc Hz^{-1} at an offset of 1 Hz from a 10 GHz carrier can be generated by a Ti:sapphire-based optical frequency divider (OFD). Achieving this noise level using an erbium-doped fibre-based OFD would allow large-scale pulse distribution at telecommunications wavelengths. Scott Diddams and co-workers in the USA have now presented a scheme that is capable of producing 10 GHz microwave signals with absolute phase noise below -100 dBc Hz^{-1} at an offset of 1 Hz, limited by the optical frequency reference. For frequencies of >10 kHz, the phase noise is shot-noise-limited to -145 dBc Hz^{-1}. The key component of the scheme is a 200 MHz erbium-doped fibre mode-locked laser with a high-speed intracavity electro-optic phase modulator and low intrinsic relative intensity noise. The team achieved a phase noise that is equal to or better than the 10 GHz phase noise from cryogenic microwave oscillators and is more than 40 dB lower than 10 GHz room-temperature oscillators at an offset frequency of 1 Hz. *NH*

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