Ultra-low Phase Noise Microwave Generated with Photonics

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A record-low phase noise floor for photonics-generated microwaves obtained from commercial PIN InGaAs photodiodes has been achieved. At a carrier frequency of 9.6 GHz, the microwaves were generated using optical frequency combs based on diode-pumped solid-state lasers emitting at telecom wavelength and referenced to a cavity-stabilized continuous-wave laser. Using a novel fibered polarization-maintaining pulse interleaver, a single-oscillator phase-noise floor of -171 dBc/Hz has been measured.

The generation of microwave signals with very low phase-noise and frequencies typically in the range of 10 GHz is essential in applications such as telecommunications, radar technologies, synchronization of scientific facilities, and time and frequency metrology. In recent years, photonics-based approaches have opened new routes towards the generation of ultra-low phase-noise microwave signals, in particular the approach described here, based on the use of optical frequency combs (OFC) [1]. Compared to other types of microwave sources, this method, illustrated in Figure 1, results in the lowest close-to-carrier phase noise and short term instability that can be achieved today, while reaching very low far-from-carrier noise floors.

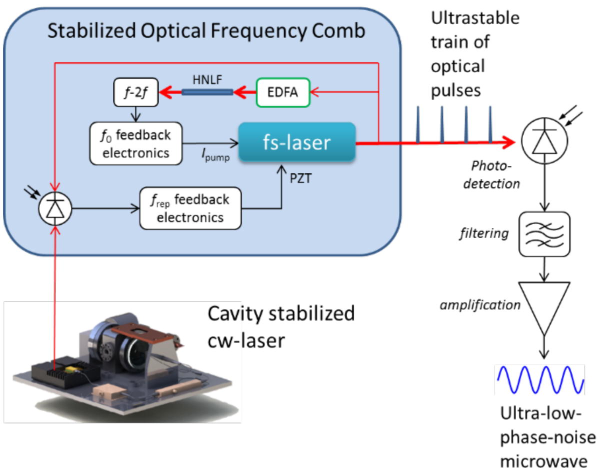

Figure 1: System diagram for photonics-based source of ultra-low phase-noise microwaves.

At the origin of the stability of this oscillator there is an optical frequency reference consisting in a continuous wave (cw) laser, stabilized on a high-finesse cavity. At CSEM, this type of optical frequency references have demonstrated Hz-level stability at 1s time-scale, corresponding to a fractional frequency stability in the order of 10^{-15}. To put it in perspective, this corresponds to the ratio of 1 s to 30 million years.

Using this type of laser as frequency reference it is possible to stabilize the whole spectrum of an optical frequency comb (OFC) by means of several feedback mechanisms. The OFC in our case consisted in a passively mode-locked diode-pumped solid state laser, emitting femtosecond pulses at 1550-1560 optical wavelength (eye-safe, telecom band). When the spectrum of the OFC is stabilized, the train of femtosecond optical pulses emitted by the laser exhibits ultra-low timing jitter, corresponding to the same relative stability of the cw frequency reference. The pulses can then be detected with a photodiode to produce a periodic electronic signal with ultralow-phase noise. Unfortunately, the pulse repetition rate of a femtosecond oscillator is typically in the range of tens of MHz to 1 GHz. In order to generate a signal with 10 GHz carrier frequency, a high harmonic of the electronic signal can be selected by filtering; but in general, due to the small amplitude of high harmonics, the quantum shot-noise effect will severely limit the relative phase noise floor of such microwave. To circumvent this problem, the pulse repetition rate of the laser can be multiplied by splitting, delaying and recombining the optical pulses in a pulse interleaver scheme [2] as shown in Figure 2.

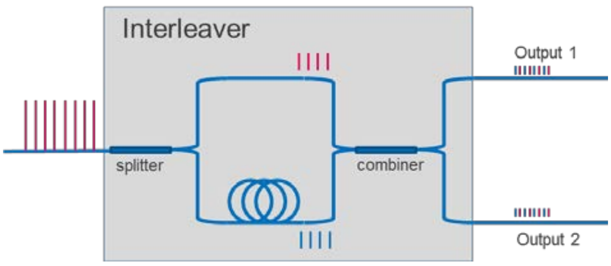

Figure 2: 1-stage optical pulse interleaver scheme resulting in duplication of pulse repetition rate.

A novel design of fiber pulse interleaver conceived and fabricated at CSEM allowed selectively enhancing the 9.6 GHz harmonic of the photo-detected signal from an original optical pulse train of 100 MHz rate. The protocol for fiber interleaver fabrication developed at CSEM, allows control of the inter-pulse delay to a precision of 1 ps, and permits recovering the whole input optical power at a single output channel, with only minor losses at the interface between the 6 implemented stages. This strategy, combined with the high performance of in-house developed control electronics for laser stabilization enabled the generation of ultra-low phase noise microwaves, demonstrating the lowest noise floor far-from-the-carrier obtained so far with commercial PIN InGaAs photodiodes, at a level of -171 dBc/Hz for a single oscillator [3].

[1] A. Bartels, S. A. Diddams, C. W. Oates, G. Wilpers, J. C. Bergquist, W. H. Oskay, L. Hollberg, "Femtosecond-laser-based synthesis of ultrastable microwave signals from optical frequency references," Opt. Lett. 30(6), 667–669 (2005).

[2] A. Haboucha, W. Zhang, T. Li, M. Lours, A. N. Luiten, Y. Le Coq, G. Santarelli, "Optical-fibre pulse rate multiplier for ultralow phase-noise signal generation," Opt. Lett. 36(18), 3654–3656 (2011).

[3] E. Portuondo-Campa, G. Buchs, S. Kundermann, L. Balet, S. Lecomte, "Ultra-low phase-noise microwave generation using a diode-pumped solid-state laser based frequency comb and a polarization-maintaining pulse interleaver", Opt. Expr. 23(25), 32441-32451 (2015).