High spectral purity phase-locked optoelectronic oscillator

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We present our recent work on an optoelectronic oscillator (OEO) operating at 10 GHz. Using a dual-loop configuration, we optimized fiber length to reach high sidemode suppression ratio both in the phase and amplitude noise spectra, low phase noise at low offset frequencies, while keeping the fiber delay line as short as possible[1]. The combination of 500 m and 650 m of fiber in a compact freestanding coil leads to an overall 130 dBc/Hz sidemode suppression on the spectrum (including the parasitic Rayleigh mitigation modulation, see Fig. 1(a)), and a -90 dBc/Hz phase noise at 100 Hz (see Fig. 1(b)). The spectral purity is, to our knowledge, the best ever reported by far.

We also carefully adjusted the fiber length so that the oscillation frequency matches 10 GHz. This way, the OEO can be phase-locked to a low frequency OCXO with better stability over long time-scales. When the coil is set in a temperature-controlled oven, the OEO frequency relative stability is 10^{-7} over 4 hours of operation. The limitation comes both from the temperature control stability (10 mK) and the temperature sensitivity of the optical and RF components operating in open air.

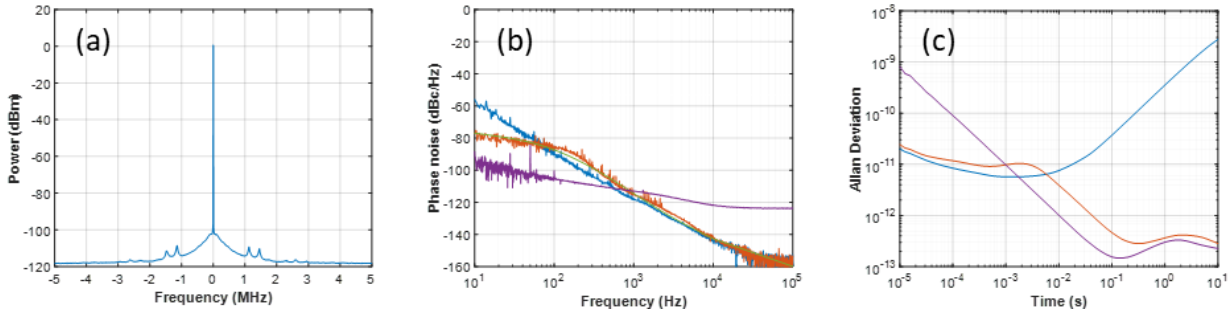

Fig. 1: (a) OEO spectrum at 10 GHz (resolution bandwidth 100 Hz, 100x average). (b) Phase noise and (c) Allan deviation of the OEO with (red) and without (blue) lock on the reference (purple). In (b), the reference is shifted by 40 dB to compare phase noise at 10 GHz, the green line corresponds to simulation.

We then locked the OEO on a 100 MHz reference, using an ADF41513 phase-lock loop (PLL) chip and a phase shifter in the RF path of the OEO. Fig. 1(b) shows the performances of the locked OEO, compared to simulations. We observe a good agreement between experimental measurements and simulations, except from an extra-noise around 200 Hz, and in the 1-10 kHz range. According to the simulations, the main limitation in the 10-100 Hz range is shared between the OEO phase noise and the PLL chip. The phase noise performances are similar to recently published results using an analog PLL based on a double-balanced mixer[2], in which the OEO is locked to a low phase noise synthesizer whose frequency finely tuned so that it matches the OEO frequency. In our case, the OEO is to directly compared to the OCXO with the PLL chip, avoiding complex frequency synthesis. The locked OEO stability is $<4.10^{-13}$ at 1 s, following the reference stability (see Fig. 1(c)). Optimization on the filter should improve the stability in the 1-100 ms timescale.

[1] O. Lelièvre, et al. "A model for designing ultralow noise single-and dual-loop 10-GHz optoelectronic oscillators" J. Lightw. Technol. vol. 35, p. 4366-4374, 2017.

[2] X. Wang, and X.S. Yao. "Phase-Locked Opto-Electronic Oscillator (OEO) of Ultralow Phase Noise With Record-Low Allan Deviation of $3.4.10^{-14}$ at 1 s" IEEE Trans. Microw. Theory Techn. vol. 71, p.5381-5392, 2023.