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Ultrastable Photonic Microwave Oscillator as Flywheel for Microwave or Optical Atomic Clocks

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One key element of future time scale generation will be the complementary use of mixed ensembles of RF, microwave and optical oscillators [1–3]. This approach calls for the development of oscillators that provide frequency references with high phase coherence [4] and spectral purity [5] for all frequency domains. The optical frequency comb is the instrument capable of facilitating this task [6,7]. In this paper, we present the deployment of a rack-mounted ultrastable photonic microwave system (UMS), which divides the $< 5\times10^{-15}$ (1 s) stability of a 194.4 THz optical reference oscillator down to 10 GHz and 100 MHz, preserving the fractional stability. The system was shipped to and operated at NIST Boulder and INRiM Torino. The first measurement campaign was aimed at reducing the Dick effect noise of a Primary Frequency Standard (PFS), the NIST F-4 Cs fountain clock, using the UMS as the source for the clock-transition oscillator. In the second deployment, an advanced signal characterization took place using the established optical and cryogenic microwave local oscillators (LO) used for the Italian PFS.

At INRiM Torino, we characterized the frequency stability of the system across the optical, the microwave and the RF domains, respectively at 194.4 THz, 10 GHz and 100 MHz. Two auxiliary oscillators, one cryogenic sapphire oscillator (CSO), and one resident photonic microwave generated from a frequency comb locked to an ultrastable cavity with comparable stability (resident comb), were employed to allow absolute stability assessments via cross-variance stability measurements. Both, the UMS and the resident comb, were steered by either the same or two separate HMs.

For the measurement campaign at NIST, the UMS was used as the reference oscillator of the LO synthesis, generating the ~9.2 GHz signal interrogating the clock transition of the cesium fountain PFS. The long-term drift of the UMS cavity was compensated via a frequency lock of the UMS to a commercial cold Rb atomic clock (SpectraDynamics cRb). This compact system (~40 l) provides long-term stability of about $3 \times10^{-13}/\surd$. The UMS drift-correction actuates on the offset between the ORS and one mode of the frequency comb, stabilizing the repetition rate at a target value. The performance of the free-running UMS as LO for the fountain clock and the combined UMS+cRb system was then compared to its performance when driving the LO chain via an OCXO disciplined to a local Hydrogen maser (HM). We will present the system constituents in detail, and the obtained results of the two deployments.

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