19-digits Accurate Optical-to-microwave Phase Coherent Link

Michele Giunta[1,2], Benjamin Rauf[1], Ignacio Baldoni[1], Martin Wolferstetter[1], Wolfgang Hänsel[1], Andreas Fricke[1], Marc Fischer[1], Ronald Holzwarth[1,2]

[1]Menlo Systems GmbH, Bunsenstr. 5, 82152 Planegg, Germany
[2]Max-Planck-Institut fuer Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany
Email: m.giunta@menlosystems.com

In order to take full advantage of the higher stability and accuracy provided by optical frequency standards with respect to their microwave counterparts, it is necessary to divide such optical frequency down to the microwave domain preserving phase coherence[1,2] , fractional stability[3] and accuracy. We have conceived and qualified an ultra-low noise frequency comb system based on a 125 MHz figure-9 fiber laser (1.5 um) in a 15HU transportable rack. The system includes comb branches for synthesizing the required optical frequencies to reference the relevant transitions' cw lasers used in the operation of an Yb lattice clock and to conduct frequency ratio measurements between Yb ion (871 nm), Yb/2 (1156 nm) and Sr (698 nm) lattice clocks. A tailored 10 GHz photonic microwave output provides the phase coherent down-conversion for the Yb optical clock frequency, rendering the clock signal output. The spectral purity transfer in the optical as well as the microwave domain has been assessed. The phase of the optical and microwave output signals, respectively at 1156 nm and 10 GHz, between the device described in this work and a reference comb system were compared on the same phase-frequency counter, while both systems were phase locked to the same ultra-stable cavity-stabilized laser at 1542 nm. In Fig. 1 the phase evolution of both, the optical and microwave comb-comparisons, is shown together with the stability of the individual measurements. For the left hand plot the optical phase was scaled to the microwave frequency. The measurement bandwidth was 0.5 Hz. The residual of the optical to microwave phase difference corresponds to a phase time error (root mean square value) of 1.61 fs. The microwave stability shown yields to a relative accuracy of $0.43 \pm 9.87 \times 10^{-20}$ after 40 hours of measurement time, with the uncertainty taken as MADEV at 40ks.

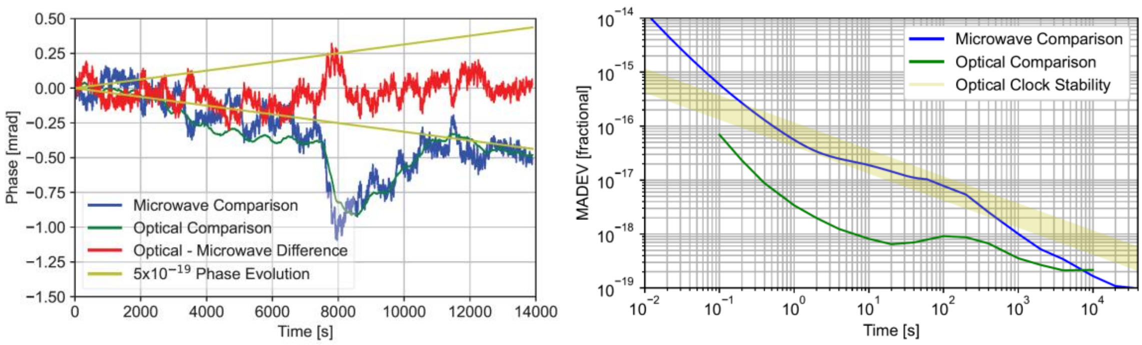

Fig. 1: Left: Phase Evolution of the microwave and optical comparisons and residual between them. The cone of a 5×10^{-19} phase evolution is indicated in yellow. Right: Stability of the microwave and optical comparisons and of the best reported optical clocks.

1. Xie, X. *et al. Nat. Photonics* **11**, 44–47 (2016).
2. Giunta, M. *et al. Opt. Lett.* **45**, 1140 (2020).
3. Nakamura, T. *et al. Science* **368**, 889–892 (2020).