Accurate Bootstrapping of an Optical Frequency Comb to a 1542 nm reference

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***Summary*—The referencing of an optical clock transported outside the laboratory is a requirement to ensure the accuracy of the measurements. Here we present preliminary results on the generation of a RF signal accurate down the 10^{-14} level by frequency division of a 1542 nm reference disseminated by a compensated fiber link network.**

Keywords— optical fiber links; transportable clock; remote clock comparison; optical frequency comb

I. Introduction

With an uncertainty at the 18 significant digits level or better, optical clocks have now the capacity to contribute to the field of Earth Sciences. Their sensitivity to the local gravitational potential allows a direct measurement of geopotential differences with a resolution equivalent to 1 cm in altitude, thus offering an alternative to traditional leveling techniques. Several projects of transportable optical clocks have started in the world, and a few of them have already led to visible landmarks in the field of chronometric geodesy [1-3].

A project of transportable ytterbium lattice clock started in 2021 at SYRTE, Observatoire de Paris, with the objective of connecting it to the REFIMEVE+ fiber link disseminating a 1542 nm ultrastable carrier throughout France [4]. Connecting the clock to one of the ~60 outputs of the network will allow all-optical, very low noise, remote comparisons to the ~12 operational stationary European optical clocks.

Nevertheless, one of the issues to address is the referencing of the clock once it is in the field. Here we discuss the capacity of a transportable Optical Frequency Comb (OFC) to be bootstrapped to the 1542 nm carrier [5] to generate locally a RF reference necessary to the clock operation.

II. Methods/Results

Once the clock is in the field, an optical frequency comb is necessary to measure the frequency ratio between the clock transition (e.g. 578 nm for ytterbium) and the optical signal provided by the network (1542 nm). Additionally, an accurate RF signal is necessary to reference multiple onboard instruments, notably frequency counters, frequency shifters and synthesizers. To this end, several methods have been experimented so far: onboard Rb clock [2], RF transferred by modulation through the fiber link [1], or GPS receivers [6].

In this paper, we propose to derive a local RF reference directly by frequency division of the 1542 nm signal disseminated by the REFIMEVE+ network itself. The source of this signal is located at SYRTE and is locked to the reference H-maser with a time constant of a few 100 s, which ensures its accuracy is 1×10^{-14} or better. This level is guaranteed over the entire network since offsets introduced along the propagation are accurate well below the Hz level.

We present preliminary results on the bootstrapping of an Er fiber-based OFC to the 1542 nm signal, by phase locking a tooth of the comb to an harmonics of the repetition rate. We discuss the possibility of tuning the tooth number and an initial offset imprinted by an electro-optic modulator in order to generate an accurate 250 MHz, and subsequently derive the necessary signals at 10 MHz and 1 GHz to operate the instruments attached to the clock. The results include the comparison to the SYRTE ultrastable microwave reference based on a cryogenic sapphire oscillator to characterize the performance of the system.

III. Conclusions

In this paper, we present a combination of two techniques, the all-optical bootstrapping of an OFC and the exploitation of an accurate 1542 nm reference, in order to generate locally an accurate RF signal, even in an environment away from a metrology laboratory. We successfully demonstrated that the RF signal reproduces the accuracy of the reference maser, based at SYRTE, better than 5×10^{-16} (limited by the statistical resolution of the measurement), and that the stability of the optical to microwave conversion is 5×10^{-16} (resp. sub 10^{-17}) at 1 s (resp. 10^4 s). The frequency measurement of optical beatnotes with counters referenced to this local RF signal was found to be in agreement with counters referenced to the SYRTE maser at a level better than 10^{-20} of the optical frequencies.

This development is under study in the context of the development of a transportable optical lattice clock, and in the perspective of the generation of low noise microwave by frequency division with an OFC to probe Cs and Rb atoms in the SYRTE fountains [7].

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