IT-Yb1 Optical Lattice Clock: Absolute Frequency Measurement at the Cs Fountain Uncertainty Level

IT-Yb1 optical lattice clock: absolute frequency measurement at the Cs fountain uncertainty level

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***Summary* — We report the result of the new absolute frequency measurement of ^{171}Yb performed at INRIM. The frequency of our optical lattice clock IT-Yb1 is measured against the local cryogenic Cs fountain IT-CsF2 during a campaign that lasted 14 months. The frequency measurements were performed with two different techniques, i.e. using a hydrogen maser as a transfer oscillator or by synthesizing a low-noise microwave for the Cs interrogation from the Yb ultrastable laser with an optical frequency comb. The frequency of the Yb unperturbed clock transition $^1S_0 \rightarrow {}^3P_0$ is 518 295 836 590 863.44(14) Hz, with a total fractional uncertainty of 2.7×10^{-16}, limited by the uncertainty of IT-CsF2. This is the absolute frequency measurement of a Yb clock against a Cs fountain with the lowest uncertainty. The result agrees with the Yb frequency value recommended by the Consultative Committee for Time and Frequency (CCTF). Moreover, the Yb data acquired during this campaign have been submitted to the Bureau of Weights and Measures (BIPM) to contribute to the calibration of the International Atomic Time (TAI). This work confirms the reliability of Yb as a secondary representation of the second.**

Keywords—optical lattice clock; frequency metrology; redefinition of the second.

I. INTRODUCTION

Multiple and independent optical frequency measurements against ^{133}Cs primary clocks are crucial for a possible redefinition of the SI second based on an optical standard. In this context, the optical transition $^1S_0 \rightarrow {}^3P_0$ of ^{171}Yb is one of the secondary representations of the second recommended by the CCTF.
IT-Yb1 is the optical lattice clock based on Yb atoms developed at INRiM. In the last years, the absolute frequency of IT-Yb1 has been measured against the local cryogenic Cs fountain IT-CsF2 [1] and via International Atomic Time [2]. Furthermore, the frequency ratio between our ^{171}Yb clock and different ^{87}Sr clocks has been measured. This optical comparison has been performed both with the transportable optical Sr clock developed at PTB [3] and via VLBI (Very Long Baseline Interferometry) against the NICT Sr clock [4]. In 2022 we measured the frequency of Yb against the French Cs-Rb fountain via the new optical link between INRiM and SYRTE [5].
Here we report the improvement of IT-Yb1 in terms of accuracy budget and the measurement of the Yb clock frequency against IT-CsF2 [6] obtained from a new campaign that lasted 14 months [7]. The result of this measurement has an instability limited by the systematic uncertainty of IT-CsF2. Additionally, we submitted the Yb frequency data of this campaign to BIPM for the steering of TAI.

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II. RESULTS

In our experiment, Yb atoms are cooled and trapped into a two-stage Magneto Optical Trap (MOT), exploiting the $^1S_0 \rightarrow {}^1P_1$ and the $^1S_0 \rightarrow {}^3P_1$ transitions at 399 nm and 556 nm, respectively. Then, the atomic cloud remains trapped in an optical lattice that operates at the magic wavelength (759 nm). Lastly, the clock transition is interrogated with a 578 nm laser stabilized on an ultrastable cavity. The typical instability of IT-Yb1 is $2 \times 10^{-15} /\sqrt{\tau/s}$.
Compared to previous measurement campaigns [1,2], our Yb clock setup has been improved for accuracy and robustness: Table 1 shows the evaluation of the updated uncertainty budget.

Effect	Rel Uncert. $\times 10^{-17}$
Density shift	0.2
Lattice shift	1.2
Zeeman shift	0.02
Blackbody radiation	1.3
Static Stark shift	0.2
Probe light shift	0.03
Background gas shift	0.2
Servo error	0.3
Other shifts	0.1
Grav. redshift	0.3
Total	1.9

Table 1: Uncertainty budget of IT-Yb1.

During this measurement campaign, the uncertainty budget of IT-CsF2 presents a total fractional uncertainty of 2.3×10^{-16}. Within this period, the typical instability of IT-

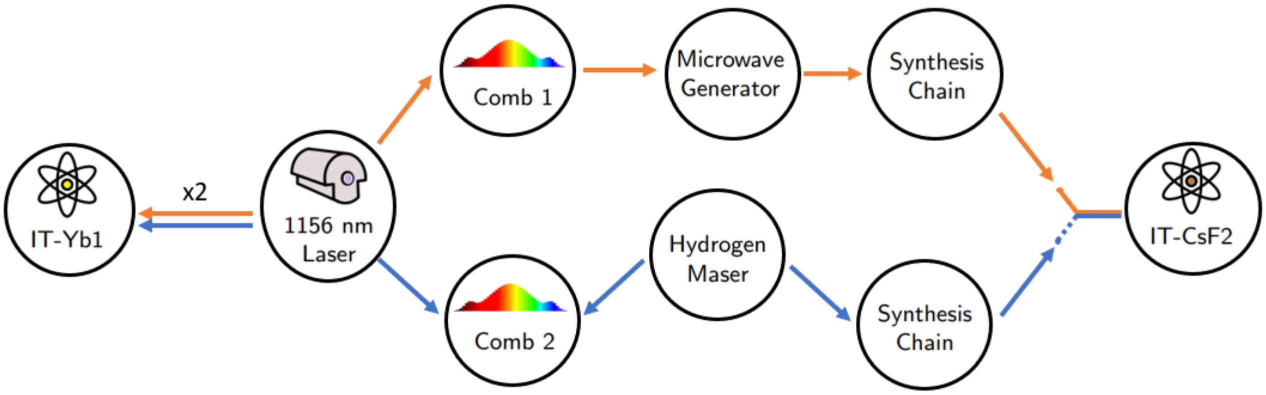

Fig. 1: Setup scheme of the IT-Yb1 absolute frequency measurement against IT-CsF2

CsF2 is about $2.5 \times 10^{-13}/\sqrt{\tau/s}$, dominated by the Dick effect and the background gas fluorescence detection noise.

In this campaign, we used two independent combs to measure the frequency ratio between IT-Yb1 and IT-CsF2. The two techniques are sketched in Figure 1. In a subset of measurements, we used the scheme shown by the orange arrows in Figure 1: the local oscillator for the IT-CsF2 is the Yb clock laser, and the microwave for the Cs interrogation is synthesized starting from Comb1 [7,8]. Otherwise, if we use Comb2 (blue arrows in Figure 1), a hydrogen maser is used as a transfer oscillator between the Cs fountain and the Yb optical clock.

For this measurement, we collected data from June 2021 to September 2022. Within this period, the common uptime between IT-Yb1 and IT-CsF2 is 32 days with Comb2 and 6.9 days with Comb1. The instability of the frequency comparison over the entire campaign is $2.7 \times 10^{-13}/\sqrt{\tau/s}$. We note that the instability is lower if we use the technique involving Comb1 since it suppresses the instability introduced by the Dick effect.

The weighted average of the Yb frequency measurements performed with the two methods is f(IT-Yb1) = 518 295 836 590 863.44(14) Hz. The total fractional uncertainty is 2.7×10^{-16}, limited by the systematic uncertainty of IT-CsF2.

III. Conclusions

We performed a new measurement of the absolute frequency of ^{171}Yb against a primary Cs fountain using two different measurement techniques. With its fractional uncertainty of 2.7×10^{-16}, this is the absolute frequency measurement of a Yb clock against a Cs fountain characterized by the lowest uncertainty found in the literature. Our result agrees with the Yb frequency value recommended by CCTF.

Moreover, the data acquired during this campaign have been submitted to the BIPM for the calibration of the International Atomic Time.

These results are a strong demonstration of the improvements achieved in the field of optical clocks and pave the way towards a new definition of the second.

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