Development of an industrial two-photon Rb atomic clock for timekeeping applications

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***Abstract*— The performance of a two-photon atomic clock currently developed at CSEM in partnership with Rolex is reported. This clock, designed in view of its integration in a 19-inch rack-mount enclosure, is intended for 24/7 operation as Rolex timescales master clock. Its design, based on a standard architecture, takes advantage of the high-reliability and high-availability of telecom C-band components. Long-term stability limited to a few 10^{-15} by the cell helium permeation drift is demonstrated. A drift-removed relative frequency stability in the 10^{-15} range at 10^5 s and beyond is achieved, limited by the residual AC Stark-shift.**

Keywords—compact clock, optical clock, rubidium, atomic vapor cell, UTC

I. Introduction

Optical atomic clocks based on hot atomic vapor cells have recently gained an increased attention due to their capacity to outperform traditional microwave atomic clocks in terms of frequency stability and accuracy while keeping a limited size, weight, and power consumption budget. Among the possible atomic transitions, the Rb two-photon transition at 778 nm offers a particularly interesting combination of intrinsic stability, reduced complexity, and high reliability, which makes it an interesting candidate for the next generation of compact clocks with a broad range of applications in metrology, telecommunication, radioastronomy, and navigation.

Here is reported on the performance of a two-photon atomic clock currently developed at CSEM in partnership with Rolex. This clock, designed in view of its integration in a 19-inch rack-mount enclosure, is intended for 24/7 operation as the master clock of the Rolex timescales [1].

II. Clock Design

The clock design is based on a standard architecture [2]. It takes advantage of the reliability and availability of fibred telecom C-band components: a 1556 nm narrow-linewidth continuous wave (CW) laser is used as local oscillator. The laser light is amplified with an EDFA and frequency-doubled to address the $5^2S_{1/2} \rightarrow 5^2D_{5/2}$ two-photon transition of ^{87}Rb. This transition is probed in a Doppler-free configuration within an evacuated glass-blown cell. The wavelength of the laser is controlled by electro-optic modulation (EOM) and synchronous detection with a PMT of the 420 nm fluorescence light arising from the atomic deexcitation path. A 100 MHz repetition rate self-referenced fibred frequency comb finally transfers the stability of the locked optical reference is to the RF domain.

To ensure the frequency stability of the clock, the AC Stark shift is reduced by control of the incident light power, and the residual amplitude modulation is cancelled by feedback on the EOM DC offset. These functions are realized by a dedicated FPGA which is also used to frequency lock the CW laser to the atomic transition and could ultimately be used to control the frequency comb.

III. Performance Assessment

The frequency stability of a laboratory version of the system reported here is shown in Figure 1. While the short-term frequency stability is limited to $1.6{\cdot}10^{-13}$ at 1s, due to the fluorescence shot-noise, the long-term frequency drift is limited by the cell helium permeation drift ($4.0{\cdot}10^{-15}$/day). A linear drift-removed relative frequency stability in the $1{\cdot}10^{-15}$ range above $3{\cdot}10^5$s is nevertheless measured, limited by the residual AC Stark-shift and by the stability of the maser used as reference.

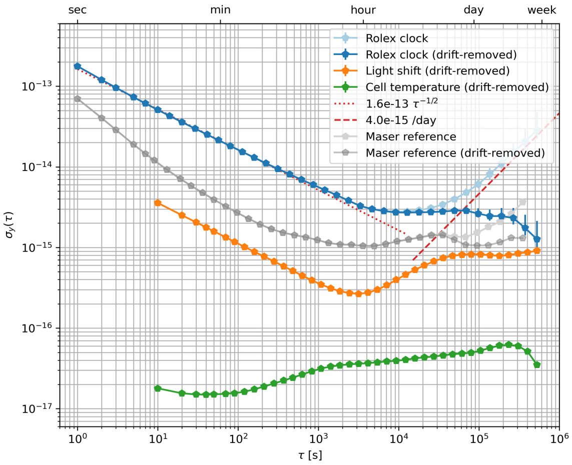

Figure 1: Measured frequency stability of the two-photon laboratory clock prototype

The measured time interval error (TIE) reported in Figure 2 is compared with the specifications of clocks typically used in UTC. The short-time TIE is in the same order of magnitude as an active hydrogen maser. The linear frequency drift removed TIE above $3{\cdot}10^5$s is below 200 ps. These measurements thus confirm the potential use of this clock as master clock in a timescale as foreseen in the project.

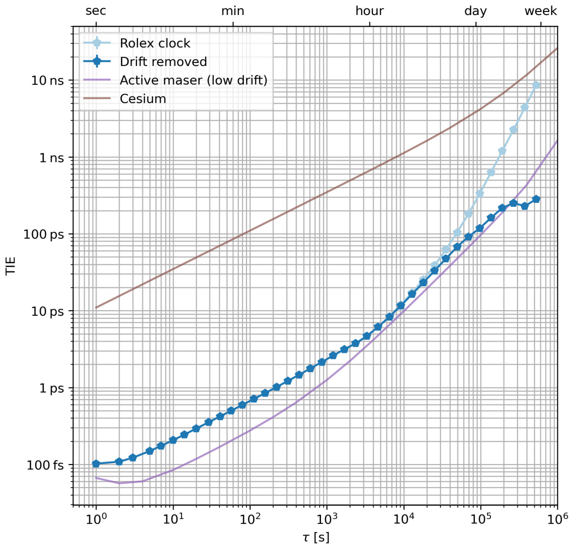

Figure 3: Time interval error (TIE) of the laboratory clock prototype and comparison with the specification of clocks typically use in UTC

IV. PROTOTYPE INTEGRATION

In view of the development of an industrial system, a first step of integration was realized. A clock prototype, reported in Figure 3, was developed in the form of a bay comprising three 19'' 3U racks:

- A commercial self-standing rack (COMB) composed of a frequency comb system including its own control electronic,
- An atomic reference rack (ARU & FPU) composed of the CW laser, the fibred elements, and the atomic reference,
- A control electronic rack (CONTROL) including the power supply, current sources and the control of the CW laser, the fibred system and the atomic reference.

Preliminary measurements of this pre-industrial system show results equivalent with the laboratory prototype reported above. This first industrialization step paves the way for integration of the full system in a single 3U rack including the atomic reference, the frequency comb and the control electronic in a single enclosure.

V. CONCLUSION

A rubidium two-photon atomic clock with state-of-the-art long-term performance and with a potential for integration in a single 3U rack has been presented. This clock will be used in the Rolex timescales as a master clock. Its long-term time stability potential (< 300 ps at 1 week) makes it a good

Figure 2:Integrated clock prototype

candidate for participation in the realization of UTC. Work in this direction is currently ongoing in collaboration with Rolex and the Swiss national metrology institute METAS.

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