CHARACTERIZATION OF THE STABILITY LIMIT OF AN ULTRA-STABLE LASER RESPECT TO ^{133}Cs D$_2$ LINE USING MODULATION TRANSFER SPECTROSCOPY

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Abstract: Laser frequency stabilization by Ultra-Low Expansion (ULE) optical cavities is a recent strategy to create ultra-stable oscillators, which are fundamental, among other applications, for the new atomic clocks generation based on optical transitions. In this work we describe the implementation process of an ultra-stable oscillator using a Fabry-Pérot cavity made of ULE glass and an Extended Cavity Diode Laser (ECDL). In order to elucidate the stability limit of the ultra-stable laser (USL), time variations of the frequency difference between it and the most probable transition of the ^{133}Cs D$_2$ line $\left(\left|6^2 S_{1/2},\ F=4\right\rangle \rightarrow \left|6^2 P_{3/2},\ F'=5\right\rangle\right)$ are characterized using Modulation Transfer (MT) spectroscopy.

1. INTRODUCTION

State-of-the-art laser stabilization usually involves phase-locking to a single mode of a passive ultra-stable Fabry-Pérot (FP) cavity. That has allowed a vertiginous advance of the optical clocks during the past three decades and that, in turn, has motivated an international debate about the need to redefine the second in terms of an atomic transition in the optical region in order to take advantage of such a grade of stability and accuracy [1]. In this context, spectroscopy has become a valuable tool not only for the study of atomic structure, but also for the construction of extremely stable frequency references [2].

Additionally, there are a variety of fundamental physics tests that could be implemented as application of ultra-stable and accurate optical frequencies to increase our understanding of different principles of nature, which remains unexplored.

2. EXPERIMENTAL DETAILS

The experiment started with a laser coupled to an Ultra-Low Expansion (ULE) cavity to produce an ultra-stable optical frequency. The master laser is a commercial AlGaAs, which is an Extended Cavity Diode Laser (ECDL) equipped with a low loss interference filter, 852 nm wavelength (near to Cs-133's D$_2$ line) and 20 kHz linewidth. Additionally, a commercial optical FP cavity made of ULE glass is used. The cavity has a free spectral range of 1.49 GHz and a linewidth less than 2.3 kHz. In order to stabilize the ECDL to the optical cavity, the Pound-Drever Hall technique is used [3]. Then, as shown in figure 1, the USL is used to monitor the most probable transition of the ^{133}Cs D$_2$ line $\left(\left|6^2 S_{1/2},\ F=4\right\rangle \rightarrow \left|6^2 P_{3/2},\ F'=5\right\rangle\right)$ using an Acousto-Optical Modulator (AOM$_2$) in cat´s eye configuration [4], so the laser beam is "re-locked" to the cesium D$_2$ line using Modulation Transfer spectroscopy [5]. To avoid magnetic interferences from external fields, the cesium cell is located inside a double-layered μ-metal magnetic shield.

Variations of frequency fed into the AOM$_2$ are measured to monitor the time variations of the frequency difference $\nu_{4-5} - \nu_{USL} = 2RF_2$. Due to the fact that ν_{USL} is an ultra-stable frequency, the variations of RF_2 allow us to measure the short-term stability of the ν_{4-5} optical frequency $(\delta\nu_{4-5} \approx 2\delta RF_2)$. The factor of 2 is associated to the double-pass configuration used. The measurements were taken using an external trigger signal, which is sent to frequency counter each second, and the frequency reading is sent to a PC.

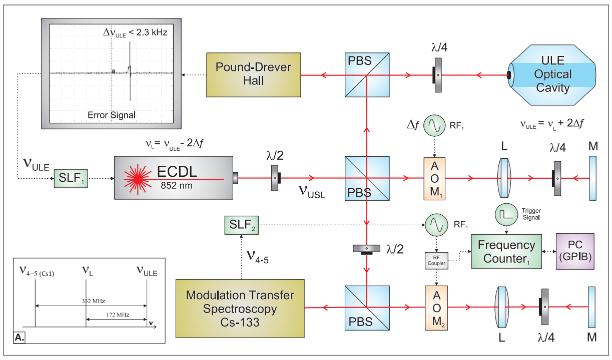

Fig. 1. *Setup to measure frequency variations between ν_{USL} and ν_{4-5}. Red solid lines represent laser's light and black dashed lines represent electrical connections. PBS: polarizing beamsplitter; M: mirror; λ/2: half-wave plate; λ/4: quarter-wave plate; L: lens; AOM: acousto-optical modulator; SLF: servo loop filter.* ***A.*** *Frequency differences between ν_L, ν_{ULE} and ν_{4-5}.*

3. RESULTS

In figure 2, the stability data of the frequency difference $\nu_{USL} - \nu_{4-5}$ are presented for different averaging times. That stability result is compared with data stabilities of standard and high performance commercial cesium clocks [6]. For averaging times smaller than 20 s, the relative stability of the USL vs. ^{133}Cs MT spectroscopy is better than high performance commercial Cs clock´s and for times smaller than 90 s, the USL oscillator present a better stability in comparison with a standard commercial Cs clock.

Although the optical cavity has features of high quality, such properties are not perfectly time invariant. Even when the frequency stability is brought to practical limits; there are slightly variations (tenths of kHz) in the resonance frequency observed in long periods of time. Also, the stability is degraded due to misalignments in the spectroscopy experiment. It is important to highlight that the measurements were taken in intervals of 1 s during 30 min. In consequence, the stability calculations are degraded as the averaging times increase due to the less quantity of information available to perform the AVAR calculations.

5. CONCLUSIONS

The stability results of the USL respect to the most probable transition of the ^{133}Cs D₂ line presented in this work are better that high performance commercial *Cs* clocks for short averaging times (smaller than 20 s).

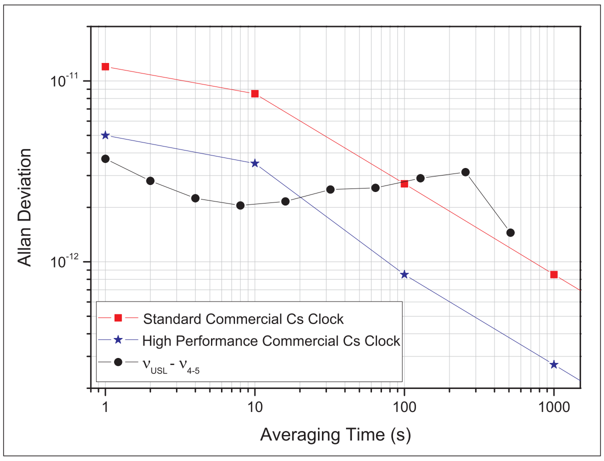

Fig. 2. *Allan deviation corresponding with frequency difference $\nu_{USL} - \nu_{4-5}$. As reference the stability results reported [6] for commercial (standard and high performance) Cs clocks are plotted.*

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