Laser Intensity and Frequency Stabilization Implemented on a Miniature CPT Clock Breadboard

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***Summary*—We developed and implemented a miniature electro-optical bench for the stabilization of a dual-frequency laser beam for high-contrast CPT interrogation of cesium. Preliminary results of optical intensity and wavelength simultaneous stabilizations give respective noise reduction of 15 dB and 60 dB at low frequencies. These performances are in line with targeted clock stability of 5×10^{-13} at 1 s.**

***Keywords*—compact clock; noise reduction; cesium; CPT.**

I. Introduction

In order to further reduce the volume of atomic clocks while keeping high performances needed for on-board applications, recent studies focused their work on Coherent Population Trapping (CPT) of cesium, showing impressive frequency stability at both short and long time scales [1].

We propose to implement a highly compact set-up for a CPT clock based on a miniature electro-optical bench and a disruptive dual-frequency dual-polarization Vertical External Cavity Surface Emitting Laser (DF-VECSEL) that generates directly two eigenmodes at 852 nm separated by 9.192 GHz [2] with perpendicular polarizations needed for Lin per Lin interrogation [3]. The targeted relative frequency stability at 1 s of integration time is below 5×10^{-13}. Extensive studies of the power stabilization function of the bench has been done for both short and long time scales and interactions with a dual-frequency laser beam were described [4]. Here we present and discuss preliminary characterizations of simultaneous optical power stabilization and wavelength locking of the laser within the complete miniature electro-optical bench.

II. Experimental set-up

The miniature electro-optical bench, designed and developed with the company Kylia, provides all the functions needed for the laser beam stabilization within a low volume of 10 L (Fig. 1).

First, the laser is protected from back reflections with a single dual-polarization optical isolator. Second, the optical power stabilization is done by adjusting the transmission of an acousto-optic modulator (AOM) as described in [5]. Third, saturated absorption spectroscopy using a shielded cesium gas cell generates an error signal [6] to lock the wavelength of the laser onto the D_2 line. Forth, a fast photodetector converts down the optical beat note at 9.2 GHz between the two polarization modes into the radiofrequency domain for comparison to the local oscillator. Last, a third AOM pulses the laser intensity for Raman-Ramsey interrogation and the beam is extended to match the diameter of the Cs cell. These functions are implemented on a single silica board with free-space miniature optical components. Optical alignments and adjustments have been carefully optimized and fixed with robust bonding technics to guarantee a high mechanical stability.

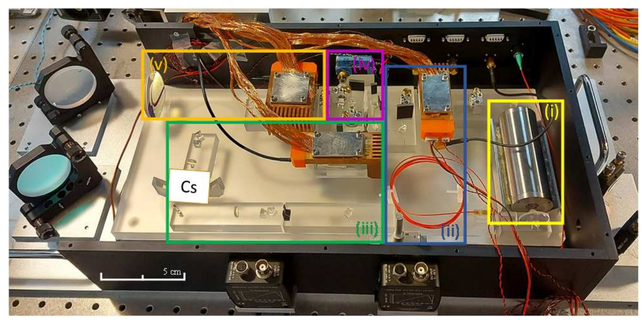

Fig. 1. Miniature electro-optical breadboard. The power consumption of each AOM is 1 W. The dimensions are 9.5 × 25 × 43 cm^3.

As a first step and before integrating the dual-frequency laser, preliminary characterizations of the stabilization loops performances are conducted using a monomode distributed feedback (DFB) laser source providing few mW of optical power (Fig. 2).

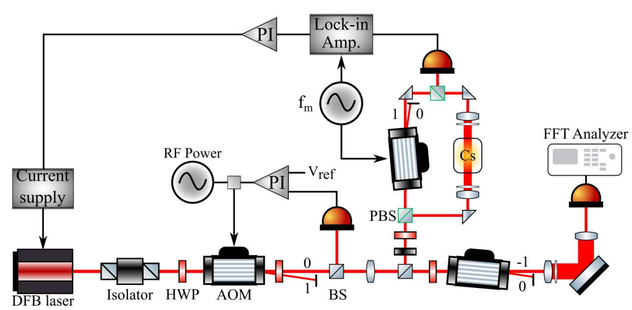

Fig. 2. Intensity stabilization and frequency locking set-up. HWP: half-wave plate, BS: beam splitter, PBS: polarization beam splitter.

III. RESULTS

The optical wavelength locking technique consists in applying a correction on the current supply of the laser. The frequency noise is measured through power spectral density of the error signal of the servo loop (Fig. 3). A drastic reduction of 60 dB is observed for low offset frequencies when the loop is closed, down to a noise floor of 40 dBHz²/Hz. For offset frequency above 500 Hz, the noise increases and an excess of noise appears at 30 kHz, the cut-off frequency of the servo loop.

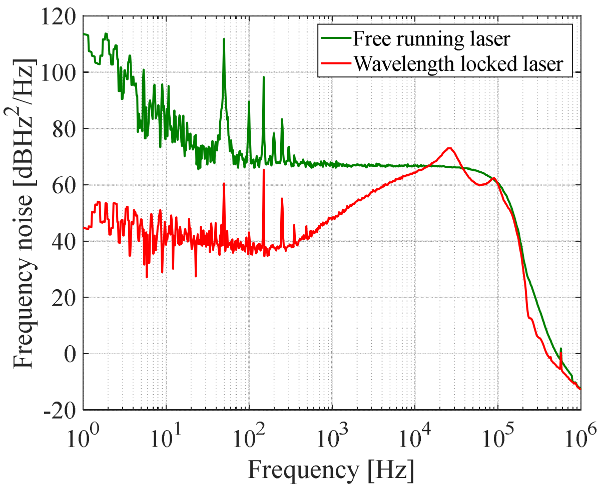

Fig. 3. Frequency noise of the laser when the wavelength locking is applied.

The wavelength locking operates simultaneously with the optical power stabilization. This second function adjusts the optical transmission of an AOM to maintain a photodetected signal to a reference voltage level. In the loop, the relative intensity noise (RIN) of the laser naturally reproduces the reference voltage RIN across the full bandwidth of the servo loop. Fig. 4 presents the RIN measured out of the loop, just before the atomic resonator. When the optical power stabilization loop is closed, a reduction of the RIN of 15 dB is measured at an offset frequency of 100 Hz. The noise then reaches a floor of -156 dB/Hz between 1 kHz and 10 kHz, close to the noise of the reference voltage. For offset frequencies below 50 Hz, stray light and mechanical perturbations prevents the transfer of the reference voltage stability out of the loop. For offset frequencies above 20 kHz, the stabilization loop cut-off generates an excess of noise with a peak at 200 kHz. The simultaneous operation of the wavelength locking generates a 3 dB bump at its cut-off frequency (30 kHz), where the gain of the power stabilization loop lacks gain.

Contributions of the laser intensity noise and frequency noise to the clock frequency Allan deviation are estimated through AM to FM and FM to FM processes. The calculations are reported in TABLE I. When the laser is stabilized, these contributions are 10 times smaller than targeted stability of 5×10^{-13} at 1 s.

TABLE I.
CALCULATION OF LASER NOISES CONTRIBUTIONS TO ALLAN DEVIATION

Noise	**Allan deviation at 1 s ($\times10^{13}$)**
Intensity noise	0.57
Frequency noise	0.10

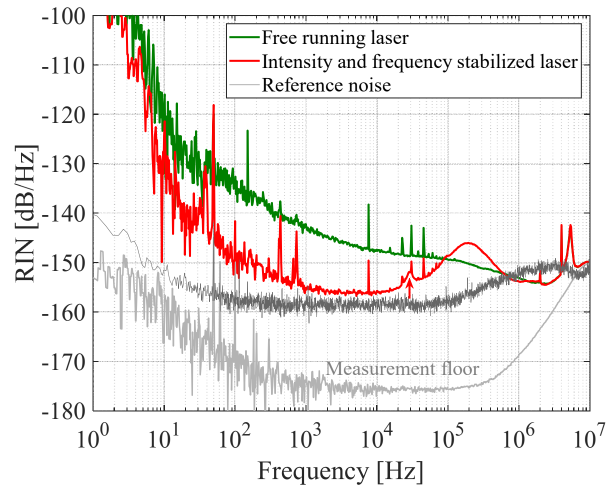

Fig. 4. Relative intensity noise of the DFB laser when both intensity and wavelength stabilizations are applied.

IV. CONCLUSIONS

We developed a miniature electro-optical bench for the stabilization of a laser beam for CPT interrogation of Cs atoms. We demonstrated the simultaneous locking of both the optical power and the optical wavelength of a monomode DFB laser with performances comparable to noise reduction obtained in state-of-the-art clock laboratory set-ups.

These promising results paves the way to the implementation of a complete highly compact clock system that will be presented at the conference, using either two phase-locked DFB lasers or a single DF-VECSEL.

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