Diode Laser Stabilization Using Pound-Drever-Hall Technique

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Abstract

Diode laser at 657 nm is locked by the Pound-Drever-Hall technique to a resonance of an optical Fabry-Perot cavity. We have measured the absolute linewidth of the laser by the beatnote measurement of the two lasers stabilized independently, and the stability relative to the cavities are estimated by a spectral analysis of the error signal obtained. In these measurements only the low frequency corrections were applied to both lasers, and absolute linewidths below of 1MHz and relative stability of about 120 kHz were obtained. We discussed details of the utilization of a new reference cavity made of a special glass (ULE), and of the cares taken for the minimization of the noise sources.

I. Introduction

The possibility of using cold atoms as references in precise measurements of time and frequency facilitated the accomplishment of a new generation of atomic clocks involving optical transitions in the visible [1], which are better than its predecessors in stability, reliability and precision. In this work we describe our recent progress towards the development of a local oscillator with quality factor around 10^{12} in the visible (657 nm). This oscillator is used in the transition $^1S_0$ - $^3P_1$ of the Calcium atom, which has a natural linewidth of about 400 Hz. Since this atomic transition is very narrow, a very stable diode laser is necessary, with absolute stability very close to the natural linewidth for times up to one second. It's then necessary to lock the laser in a reference cavity using the Pound-Drever-Hall technique [2] for we reach these required stabilization level, and the different types of noise sources in the frequency of the laser must be minimized or canceled. The most critical noises are mechanical, thermal and electric ones. To eliminate each one of those noise sources, we should use different actuators, which will be described in the next section. In the section III we presented the measurements of the linewidths by heterodyning two independent systems, with a beatnote signal involving the two lasers locked independently to the quartz cavities. The relative stabilities were also measured in comparison to the reference cavities. We discussed some noise sources that disturbed the lasers and our efforts to eliminate them. The general conclusions of this work are presented in the section IV.

II. Experimental Setup

Two commercial diode lasers were used in extended cavities and in the Littman configuration (at grazing incidence), with active controls of temperature and injection current. These controls allow fine-tuning the laser frequency around the atomic transition $^1S_0$ - $^3P_1$ of the Calcium atoms. Besides, the optical feedback of the extended cavities tends to narrow the laser linewidth by passive stabilization.

A typical Pound-Drever-Hall stabilization scheme is represented in the Figure 1, which is used to lock the laser to a reference cavity through the frequency modulation (FM) of the laser. The modulation frequencies used were 12 MHz and 30 MHz, respectively for each one of the two lasers constructed. Two lenses L_1 and L_2 in Fig. 1 were used to mode-match the spatial profile of the lasers into the reference cavities. A polarizing beamsplitter (BS) and a $\lambda/4$ plate are used to separate the reflected beam from the incident laser beam. These reference cavities are made of a special glass of ULE (Ultra Low Expansion) and have finesses of about 10^5. When the laser carrier is in resonance with the cavity, the induced sidebands are outside the bandwidth of the cavity resonance and therefore are reflected. Detection of this reflected light with a fast photodiode (P.D.) allows the derivation of an error signal, which is analyzed and sent to a passive filter (high pass) and to the injection current of the semiconductor laser, where we can make faster corrections with small amplitudes. The error signal is amplified by a "loop-filter" and goes to a piezoelectric transducer PZT, which is used to control the feedback mirror of the extended cavity in the Littman configuration. Then we have high frequency corrections made in the laser current source, and low frequency corrections in the mirror of the extended cavity.

The noise sources coupled to the reference cavity will be transmitted to the laser, disturbing its stability. These mechanical and thermal noises can be minimized by careful design, but never completely eliminated. To prevent the thermal noises we placed the reference cavity inside of a high vacuum camera (10^{-8} mbarr) using an ion pump. The camera and the ion pump are enclosed inside of a metallic box with acoustic isolation. The metallic box is on a commercial table with passive stabilization of high performance. The laser is coupled to the reference cavity using an optical fiber in the attempt of avoiding the transmission of mechanical noises.

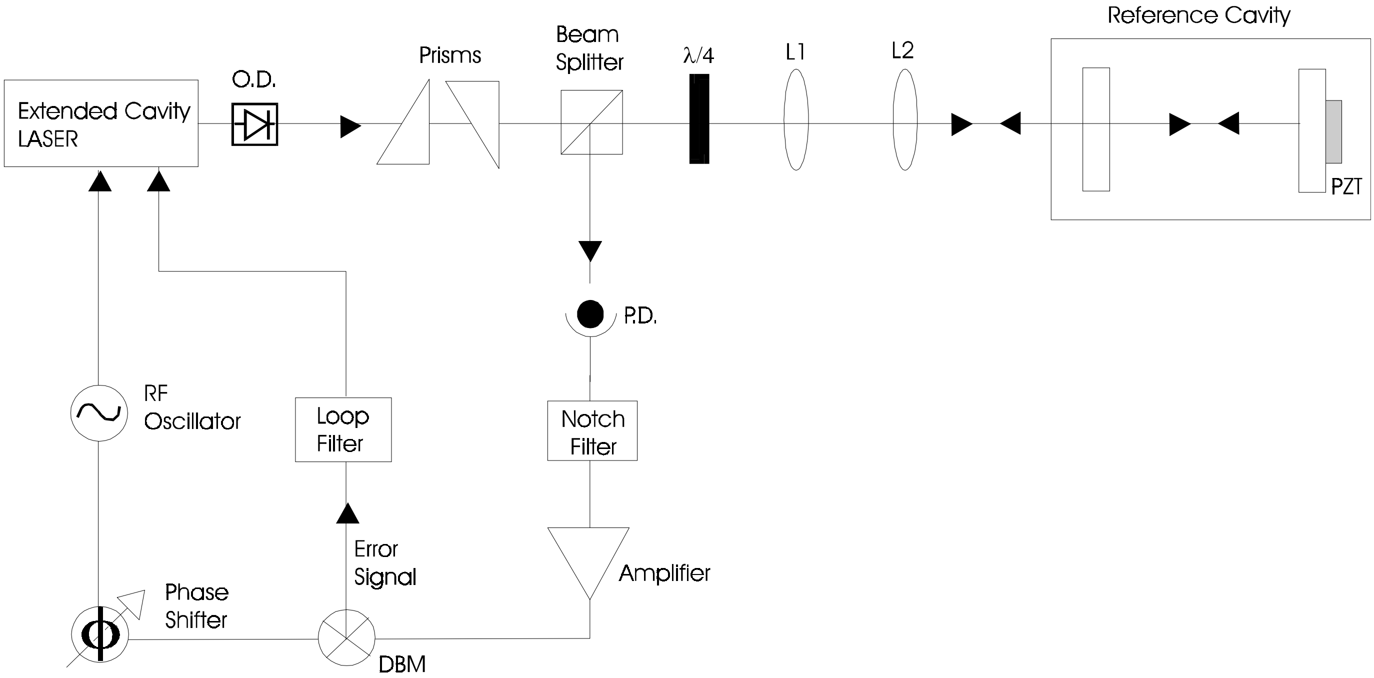

Figura 1. Experimental setup of frequency stabilization for a diode laser, using an active locking technique to the Fabry-Perot cavity, by the Pound-Drever-Hall error signal. O.D. = Diode optical, DBM = double-balanced mixer.

III. Results and Discussions

We made two independent systems with the same diode laser (Hitachi HL-6501MG, maximum output power of 35 mW). With both independently stabilized lasers we could measure the absolute linewidth by a beatnote measurement between the two lasers. To see the beatnote between the two lasers we used a fast silicon photodetector (up to 9 GHz) and a spectrum analyzer (HP8562A). The signal obtained has a full width at half maximum (FWHM) that is the sum of the individual linewidth of the lasers.

With the free-running lasers (unlocked), the beatnote measurement has a FWHM of about 10 MHz in 300 milliseconds. As the used lasers are of the same model, we hoped have similar linewidths for both lasers. In this case, we have about 5 MHz for each one of the linewidths. When we just stabilized the low frequency part of one of the lasers, we see the linewidth of the beatnote goes to 5 MHz. Stabilizing the two lasers sees a narrowing of the beatnote linewidth for less than 2MHz in 300 milliseconds (Fig. 2). This allows us to obtain absolute linewidths below of 1 MHz for each one of the lasers. When the laser is locked to the reference cavity, a fast measurement of the fluctuations in the error signal can be used to estimate the stability of the laser relative to the cavity. Using the signal transmitted by the cavity, we could determine the relative stability frequency of the laser about 120 kHz. These measurements were made with the lasers stabilized in two quartz cavities of lower finesse (615), without any isolation of the several noise sources and besides we just executed the low frequencies correction. The high frequency corrections for both diode lasers are been provided and a system with one high finesse ULE reference cavity and isolation was recently completed. The next step is lock one of the diode lasers to a resonance of this cavity in order to achieve a reduction of the linewidth.

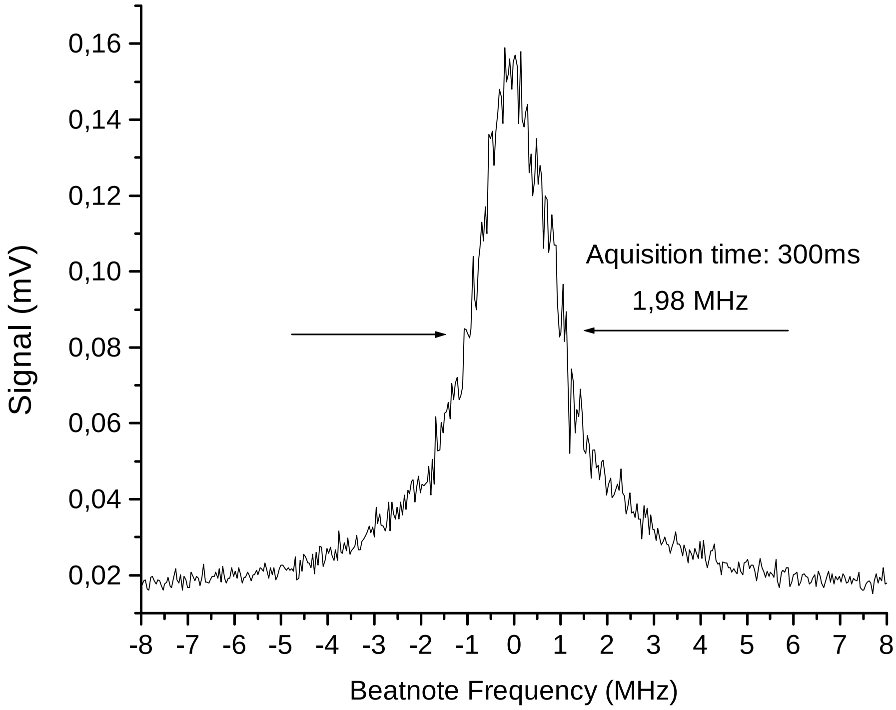

Figura 2: Beatnote signal between the two stabilized diode lasers, locked independently to resonance of two Fabry-Perot cavities by the Pound-Drever-Hall technique.

IV. Conclusions

In this work we presented our progress towards the development of a laser local oscillator for a Calcium optical frequency standard. Two diode lasers at 657 nm, used in Littman configuration, were locked by the Pound-Drever-Hall technique to resonance of two optical reference cavities. The absolute linewidth of the lasers was measured, below of 1 MHz for 300 milleseconds, and a relative stability of about 120 kHz could be estimated. This preliminary measurement was made using two quartz cavities with low frequency corrections and could be considered satisfactory, because an appreciable reduction of the laser linewidth was obtained and we could learn about the experimental details of this stabilization technique. A system with reference cavity made of a special glass and isolation of noises was completed, and the optimization of the lock scheme with optical feedback combined with electronic feedback will also be investigated for reduction of the laser linewidth.

Acknowledgments

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