Automated Laser Frequency Re-stabilization

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Abstract

Lasers have an enormous array of applications in science research today, from interferometry to atom traps, and often the stability of a laser's frequency is essential to the success of an experiment. Various techniques have been developed for stabilizing a laser's frequency, one of which is the Pound-Drever-Hall (PDH) technique, popular in atomic and optical physics. This technique uses an electronic feedback mechanism to "lock" the frequency of an unstable laser to the resonance frequency of a separate, more stable optical cavity. With this technique, researchers can steady their laser's frequency to a stability near that of their reference cavity. This mechanism can fail at times due to too much environmental noise, requiring the researcher to manually re-engage the lock. My project focuses on solving this problem by creating an addition to the PDH mechanism that automatically detects a faulty lock and relocks the laser to the reference cavity.

Prospectus

Since their invention in the mid-1900s, lasers have become one of the most prolific tools in science research and industry today. Lasers have an incredible array of applications, from uses in surgery to audio recording; in physics, lasers are commonly employed in mechanisms for precision measurements such as interferometers for gravitational wave detection [1], spectrometers [2-3], and optical fiber sensors [4]. The precision of these mechanisms is often closely associated with the frequency stability of the lasers involved.

There have been a number of different techniques developed for stabilizing laser frequencies, the most popular of which is the Pound-Drever-Hall (PDH) technique [5-7], put forth in 1983. The technique works by "locking" the frequency of the unsteady voltage-controlled laser in question to the resonance frequency of a more stable optical reference cavity. In order to achieve lock, the laser light is first sent into a phase modulator which tacks on two "sideband" frequencies to the original laser "carrier" frequency. This light, now consisting of three distinct frequencies, is directed at the reference cavity, which reflects more of the light if the laser frequency is far from the cavity's resonance frequency and less if the laser frequency is near the cavity's resonance frequency. By monitoring the way the reflected sidebands interfere with the reflected carrier frequency using photodetectors that measure the total reflected light's power and performing some transformations to this power signal, we can obtain an "error signal" that tells us how far away from the resonance frequency the laser frequency currently is. This error signal can then be fed into a high-speed PID feedback loop [8] which acts to push the laser's frequency toward the reference's resonance frequency upon detecting any discrepancy between the two.

At times, the feedback loop can drop the laser frequency lock due to physical noise such as a bump to the optics table or a ground tremor. The PDH loop's sensitivity to environmental noise depends on the specific components employed (i.e. photodetector quality, PID box quality, etc.), and certain setups can lead very fragile frequency locks that may drop during experiments. I seek to improve the robustness of these PDH systems by implementing a microprocessor control component into the PDH scheme.

The processor will fit into the PID section of the locking mechanism and monitor the error signal of the laser frequency without impeding the performance of the feedback. When it detects that the error signal no longer shows frequency lock, it will disengage the feedback loop and take control of the laser-controlling PID output, running a correction signal to bring the laser frequency close enough back to lock such that the original PID negative feedback can then be re-engaged to pull the laser frequency all the way back to full lock.

As stated earlier, each PDH system is unique and thus requires its own specific tolerances and correction signals. In order for the relocker to be useful then, it must have the versatility to be able to automatically adapt its detection and correction functions to the target PDH. This capability will come in the form of user-input settings that give the relocker the relevant PDH information it needs to adjust its correction signal and detection ranges for optimal operation in that specific PDH. This customizability will increase the relocking system's applicability to many different experiments.

With this automated re-stabilization technique, experiments relying on PDH frequency-locked lasers will be sturdier to environmental noise shocks to the system, making for more reliable and robust experimental setups.

Bibliography

[1] Abbott, B., et al. "Detector description and performance for the first coincidence observations between LIGO and GEO." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 517.1 (2004): 154-179.
[2] Wójtewicz, S., et al. "Line-shape study of self-broadened O 2 transitions measured by Pound-Drever-Hall-locked frequency-stabilized cavity ring-down spectroscopy." Physical Review A 84.3 (2011): 032511.
[3] Cygan, A., et al. "Pound-Drever-Hall-locked, frequency-stabilized cavity ring-down spectrometer." Review of Scientific Instruments 82.6 (2011): 063107.
[4] Gatti, D., et al. "Fiber strain sensor based on a π-phase-shifted Bragg grating and the Pound-Drever-Hall technique." Optics express 16.3 (2008): 1945-1950.
[5] Drever, R. W. P., et al. "Laser phase and frequency stabilization using an optical resonator." Applied Physics B 31.2 (1983): 97-105.
[6] Black, Eric D. "An introduction to Pound–Drever–Hall laser frequency stabilization." American Journal of Physics 69.1 (2001): 79-87.
[7] Nickerson, M. "A review of Pound-Drever-Hall laser frequency locking."
[8] Razavi, Behzad. Design of analog CMOS integrated circuits. Boston, MA: McGraw-Hill, 2001. Print.

Timeline

Date	Objective
By November 1	▪ Build and test customization interfacing circuit ▪ Develop code for relocking customization
By December 1	▪ Test system in PDH systems and optimize
By January 1	▪ Build fully developed relocking box containing interfacing circuit and microprocessor
by February 1	▪ Write code breakdown chapter and interfacing circuit chapter
By March 1	▪ Write operation chapter and possible improvements chapter
By April 1	▪ Finalize thesis ▪ Submit and defend