Report of activities: Winter Internship 2014 (Jun-Sep)

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São Carlos - SP

2014

Introduction

In this document is presented different activities developed in the Strontium Lab at IFSC (USP) under the direction of Philippe Courteille between June and September of 2014 during my winter internship there. All of the activities here presented were related with the experiments in course now in Strontium Lab.

Characterization of a Fabry-Perot cavity

A Fabry-Perot cavity is a device constructed of two opposite mirrors with a piezo-electric material in one of the mirrors and a photo-detector there. To characterize a Fabry-Perot cavity it can be done with the FSR (Free Spectral Range) and the $FWHM$ (Full Width Half Maximum) in the signal of the photo-detector on the cavitiy.

A blue light was aligned to the cavity, after that a saw-tooth triangular signal was connected to the piezo, it had a frequency $f = 10.96Hz$ and amplitude $A \sim 5V$ and it was generated with a signal generator.

The input and the output signal, on the piezo and the photo-detector respectively are connected to an oscilloscope as shown in the figure 1.

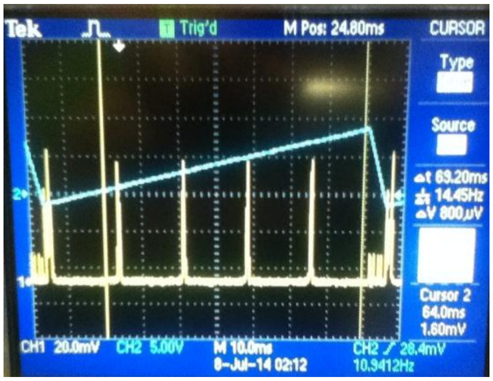

Figure 1. *Imput signal on the piezo-electric material (Blue) Saw-tooth signal. Output signal on the photo-detector (Yellow).*

Using the oscilloscope it is possible to measure the FSR and the $FWHM$ as is shown in figure 2 and with this two quantities is obtained the finesse $\mathcal{F} = FSR/FWHM$ of the cavity.

$$\mathcal{F} = \frac{18.80ms}{254.0\mu s} = 74.0$$

The finesse of a cavity can be calculated in terms of its physical properties

$$\mathcal{F} = \frac{\pi R^{1/2}}{1 - R} \approx 99.8$$

Where $R = 0.969$ is the reflectivity of the mirrors for blue light.

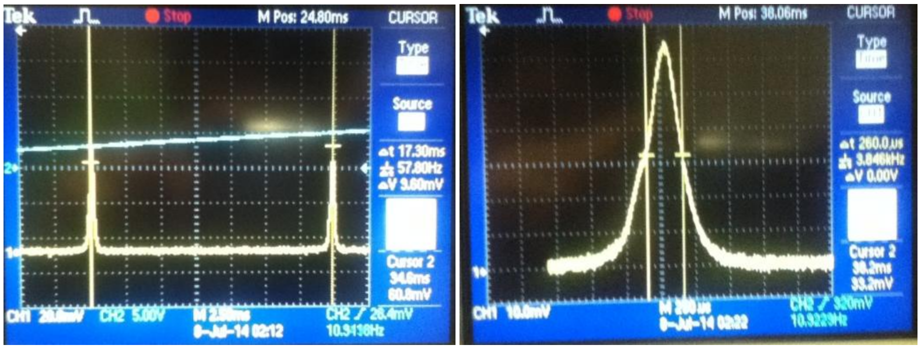

Figure 2. *Measurement of the FSR and the FWHM in the output signal in the photo-detector of the cavity*

Construction and characterization of a "summing" circuit

There was needed a circuit that sums two voltages to provide a voltage of approximately $15V$ to a VCO for the red spectroscopy.

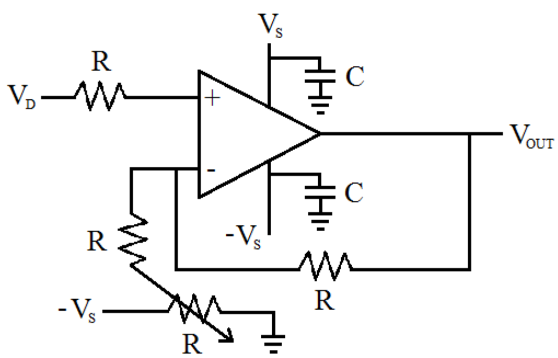

Figure 3. *Scheme of the circuit that sums V_D and V_S.*

We check the response of the circuit to see if it was linear.

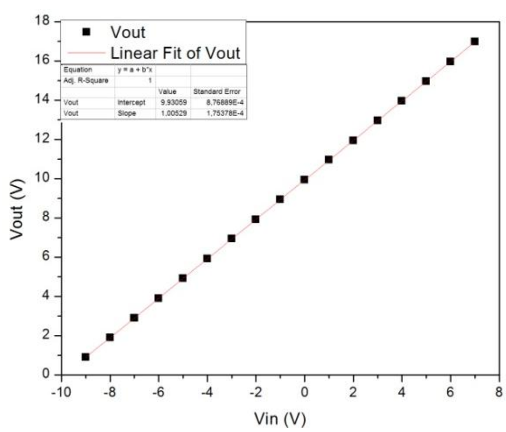

Figure 4. *Linear response between the output and input signals of the circuit. $V_D = V_{in}$ and V_{OUT} respectively.*

Characterization of a VCO

A VCO (Voltage-Controlled Oscilator) is a device that converts a voltage into a frequency, we used a ZOS-100 minicircuits VCO.

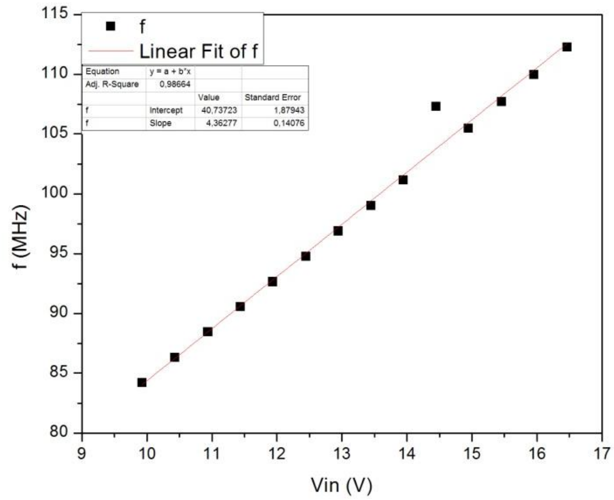

Figure 5. *Linear response of the frequency on the VCO.*

Measurement of the FSR of a He-Ne Laser

We coupled a He-Ne Laser to an optical fiber with an efficiency of approximately 80%. We can estimate the $FSR \equiv \delta = c/2L \approx 600MHz$ where c is the velocity of light and $L \approx 25cm$ is the distance of the cavity of the laser.

Let's assume that the beam emitted by the laser is a 2-mode light E_1 and E_2 practically equal, the intensity I can be written as

$$I \sim |E_1 + E_2| = \left|E_{10}e^{i\omega_0 t} + E_{20}e^{i(\omega_0+\delta)t}\right|$$

$$= {E_{10}}^2 + {E_{20}}^2 + E_{10}E_{20}(e^{-i\delta t} + e^{i\delta t}) \approx 2{E_{10}}^2(1 + \cos \delta t)$$

where ω_0 is the fundamental frequency of the laser.

This can be used to calculate the Free Spectral Range of the laser using a spectrum analyzer and looking at the frequency because it has to be 1-mode.

The optical fiber is connected to a photodiode (FDS02 minicircuits) and the voltaje in the output is connected to a spectrum analizar showing a SINGLE peak that changes in the time (sometimes $\delta = 653.48MHz$, sometimes $\delta = 654.00MHz$) with a frequency of minutes. The important thing is that is shown that is a good approximation to consider that the laser is 2-mode, the FSR was measured in a precise way in good accordance with the estimation made above and the fluctuations of this frequency can be understood in terms o knowing that the dependence on the temperature of the physical properties of the cavity of the laser. This result is show in figure 6.

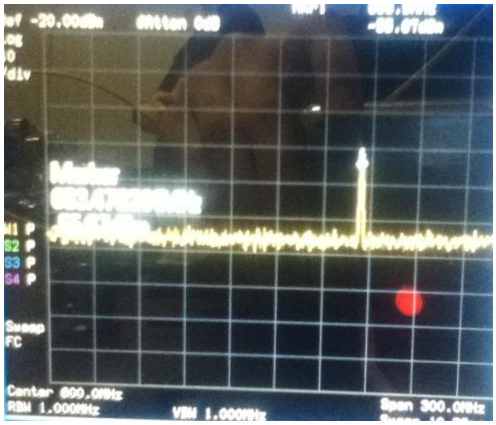

Figure 6. *Signal of the photodiode at the spectrum analyzer showing a single peak at the frequency* $\delta = 653.48 MHz$.

Threshold for the Steck-Laser

In this part the goal was to reach the minimum possible value of the current in the diode laser of the Steck-Laser to get it lasing, in order to do that first we align as good as possible the cavity of the laser, we connect a triangular signal ($50mV$ from peak to peak with an offset of $100mV$) to the modulate the current on the diode laser which had an offset current of $40mA$. Also we know that $120mV$ correspond to $5mA$ in the current on the diode. After that with a photodiode and an oscilloscope we compared the input signal of the laser (triangular signal) and the output on the photodiode. At the beginning the response of the diode is linear with respect to the triangular signal so we change the alignment of the cavity in order to see a non-linear response on the photodiode signal at some value of the input current.

The maximum current on the diode is

$$I_c = (40mA) + \frac{5mA}{120mV}(100mV + 50mV) = 46.25mA$$

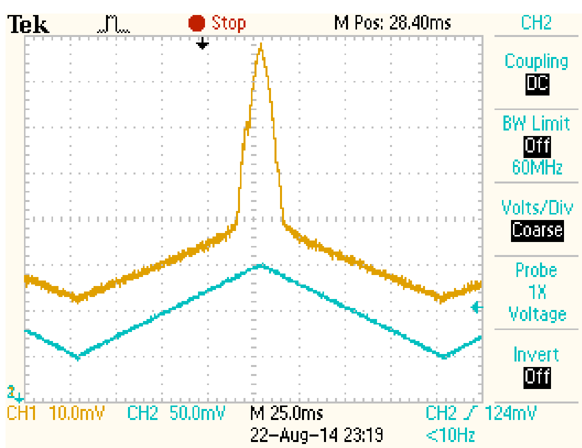

Figure 7. *Input signal on the diode laser (Blue) and response signal on the photodiode after the laser cavity (Yellow). Threshold of the Steck-Laser.*

Pound-Drever-Hall Signal (PDH)

The PDH technique is a powerful approach to the stabilization of the frequency of a laser by means of locking to a stable cavity and it is used in a lot of very precise measurements such as gravitational wave detectors, time measurement standards and atomic physics. It is really important to have a stable (low linewidth) laser and PDH technique provides a good mechanisms because all lasers' instabilities are due to temperature vibrations, mechanical imperfections, current and voltage fluctuations or atomic transition widths.

The idea is to modulate the frequency on the light emitted by the laser, so it would have a carrier frequency and two sidebands and it is directed into a Fabry-Perot cavity. The reflected light is directed to a high speed photodetector (it is important to know that the reflected signal would have a phase shift carrier component). The reflected signal is mixed with a local oscillator, which is the same that had been used to modulate the frequency so is in phase with that, and after everything the resulting signal (PDH signal) gives a measure of how far the laser carrier frequency is off resonance with the cavity and may be used as feedback for stabilization. The resulting signal is connected to a PID Controller which converts it to a voltage that can be used to lock on resonance the laser with respect to the cavity. The scheme of the montage for this technique is shown in figure 8.

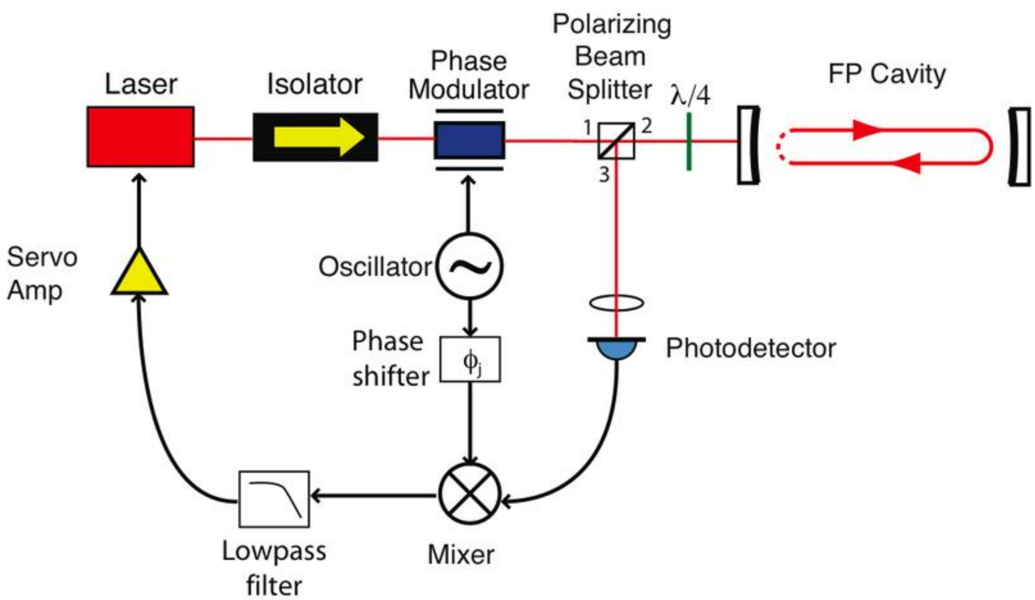

Figure 8. *Scheme of the montage for the PDH technique. (Isolator and Lowpass filter are for getting a better signal).*

In Strontium Lab was carried out this experiment to create a PDH signal and lock a laser that will be used to make a gravimeter using ultra-cold strontium atoms and the principles of Bloch Oscillations. The local oscillation was developed with a synthesizer in range between 30 to $150 MHz$.

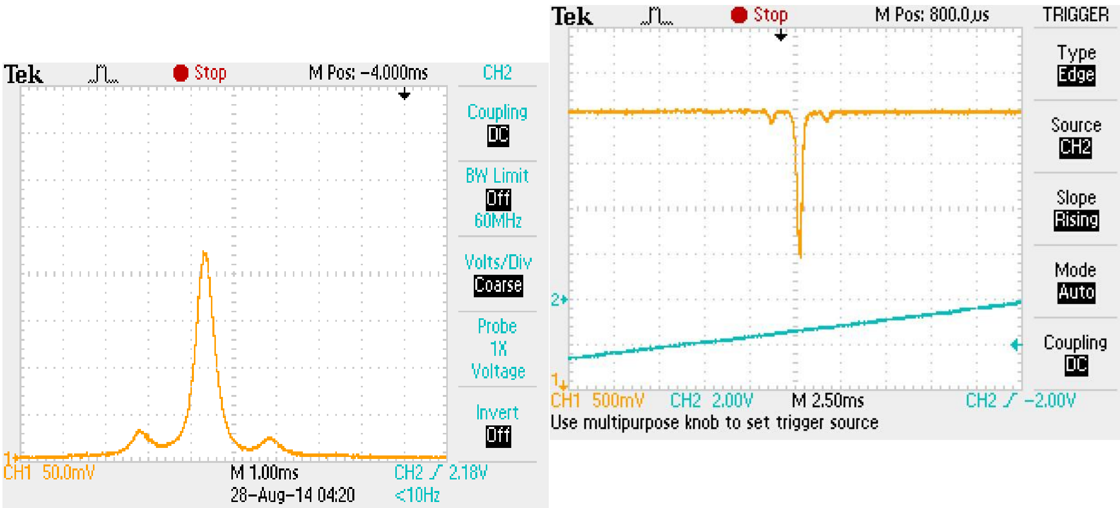

Figure 9. *Transmitted and relected signal (on the Fabry-Perot cavity) with sidebands made with a local oscillation of* $25mA$ *and a frequency* $80MHz$*.*

In the following figure is shown the PDH signal that we got for different values of the modulation frequency.

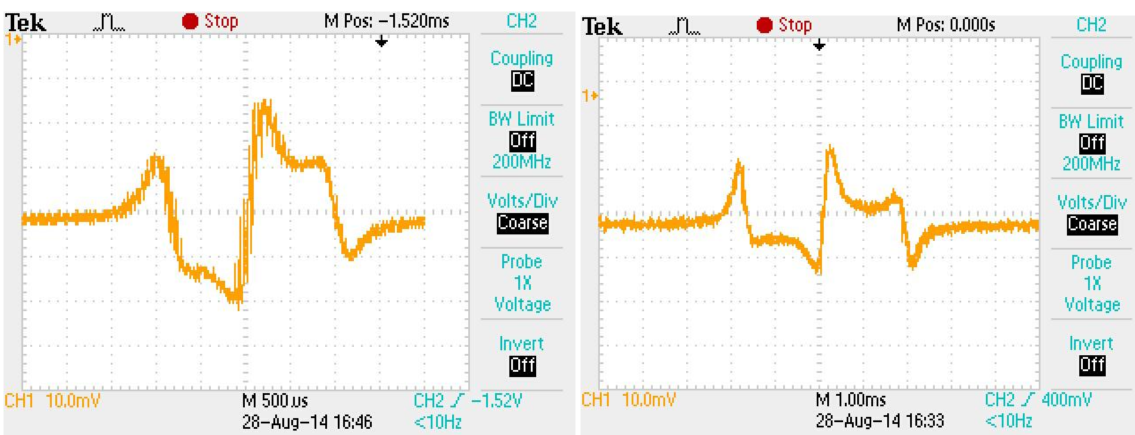

Figure 10. *PDH signal with for* $50MHz$ *and* $100MHz$*.*

We can see that for both modulation frequencies the PDH signal is well defined and looks pretty good. After getting this signal, it is possible to get it to the PID controller and lock the laser in resonance with he cavity.