Brasil Internship report : the helical resonator

Contribution to strontium cavity and lattice experiments

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Remerciements

First and foremost I'd like to thanks Philippe who raised *hell* to give me the chance to participate to this internship, indeed, since my application was lost in translation by computers between France and Brasil he had to find a way to get me funding to come anyway because I was considering of maybe doing a PhD in Brasil. I also like to thanks everyone from the optical group for giving me such a warm welcome. It's not an exhaustive list but I'd like to mention Romain Bachelard my french compatriot who showed me the ropes of how to go out in Sao Carlos. I'm thanks full to Michael Holynski and Paulo Hisao Moriya the two experimentalists that I worked with everyday. I don't know what I would have done without Paulo translator skills, he was a huge help to guide me along to realize my projects. I also learned a lot from my discussions with Mike and working all together with the students in this lab was not only pleasant but also very well organized. That's one of the point I'd like to stress because it's not easy to find a team that work well together and has a well thought and efficient process to welcome a new team member even for a short period of time.

Abstract

The main goal of this report is to leave a written trace of the work accomplish on the helical resonator project. During my internship I've participated to several projects : designing and putting in place compensation coils on the experiment, premisses for the build of an ultra-stable laser and several day to day tasks to help the strontium lattice experiment in progress. The helical resonator in question is meant for the next experiment where it's suppose to act as a transformer and provide the necessary voltage to supply an EOM. For the input we intend to use a 20 MHz signal to create side-bands which combine with a cavity provide us all the tools for a PDH scheme. The reflected signal coming from the cavity is used to get an error signal to feed a servo-lock loop in order to stabilize our laser.

1 Introduction

Integrating a new lab is never easy and furthermore, when you know you will spend a short amount of time among a team of experimentalists, finding the right project that will allow you to contribute in a meaning full matter is not an easy decision either. One of the main reasons for that is simple to understand: to work in a lab you have to learn ways of the lab so you kind of disturbing the actual workers, and while they're teaching you they're not working anymore. Anyway after a short period of learning my way around the lab we decided I will try to find a way to contribute to the advancement of the next experiment (the strontium cavity project) by helping putting in place an essential part of the locking scheme : the EOM that generate the side-bands for the error signal. The first step consisted in aligning a Fabry-Pérot in order to analyse the signal at the output of the EOM. The lack of side-bands, because we were not able to provide sufficiently high voltage in the EOM, gave rise to the idea of building our own transformer.
I also spend some time learning about the current experiment (strontium lattice) and we decided it would be helpful to have compensation coils to work with so I design and build three rectangular pairs of coils by winding some copper wires together. Finally while I was waiting for the mechanical workshop to finish building a much needed cylinder in copper for my helical resonator, I started checking, ordering and listing all the parts needed to build a replicate of the Steck laser for the strontium cavity experiment.

2 The compensation coils

Building compensation coils is pretty straight forward. Indeed one only need to thing about the number of turns needed to reach a desired magnetic field and the more turns you use, the less current you need to get it. Considering the fact that we wanted to put those coils in place while disturbing as little as possible the experiment, I decided to minimize the number of turns. Since I knew we will be using power supply capable of at least 10 A and that we will need to obtain fields in the order of 1 Gauss, I chose accordingly after running some quick simulations. Of course after making the first pair, we checked that with an Helmoltz configuration we could measure the predicted magnetic field and it was indeed the case. The most difficult part of this task was to manage to put in place these coils and it took 2 days of work without counting the week of re-alignment that took place after that.

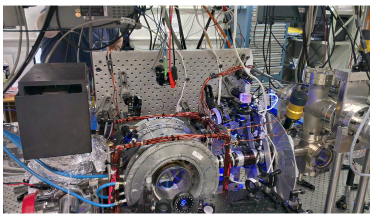

Figure 1: Compensation coils picture installed around the science chamber.

3 The Steck laser

Another project I participated in was the construction of a new ultra-stable laser following the recommendation of this paper [1]. After studying the article and the manual put in place to explain the assembly process, I started to list what we needed to build our own version of this laser. I also checked that pieces provided by the mechanical workshop were properly fabricated and fitted our specifications. When the optics ordered at Thorlabs finally arrived I had the time to check and characterize all of the six laser diodes we received in term of wavelength and power so we could choose the most appropriate ones to build our two lasers. But that's all I could accomplish on this project in the two month I stayed at the IFSC.

4 Why an helical resonator?

As I mention in the introduction there was a need for a transformer to supply enough voltage to the EOM on my main project.

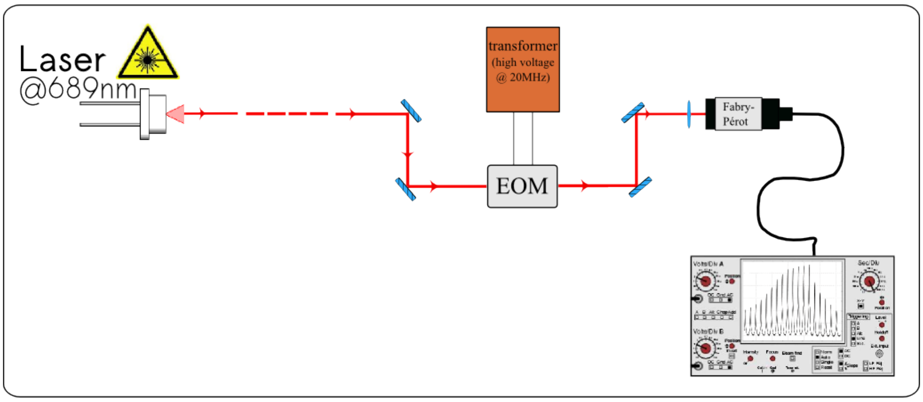

Figure 2: Layout for analysis of the EOM output: a part of the output of the red laser (dashed lines represent the optics omitted to simplify the figure) at 689 nm is used, after going through an EOM supplied with enough voltage to induce a phase shift we analyse the light with a Fabry-Pérot.

At first, I tried several ways to obtain the necessary voltage to supply the EOM at the desired frequency of 20 MHz. Either a standard transformer circuit (2 separated coils) or an auto-transformer (only one coil and a part of it is actually used as a secondary coil) failed to give enough gain to observe side-bands when plugged into the EOM.

One of the first task was to check if the EOM possessed indeed the indicated capacitance and that it didn't act as a resistor also. As reported in my lab book we could verify that the capacitance of the order of ~ 100 pF and no resistance could be measured.

We then decided to build an helical resonator like in [2] to get a better impedance matching and high factor quality for our transformer. Near to the end of my internship the workshop finished the main element of my design for an helical resonator so I was able to finish building it in time.

4.1 The apparatus

The principle idea of an helical resonator is to place the two coils in a cylindrical conductive cavity in order to reach high quality factor in a transformer. Also this scheme allow for better impedance matching through the tunable winding pitch of the antenna (the secondary coil).

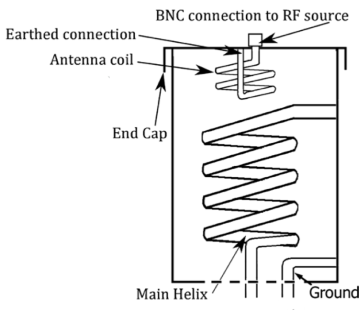

Figure 3: Helical resonator schematic.

The previous study helped us to choose the right dimensions and component to build the device. The relevant cotations are defined as shown in Figure 4.

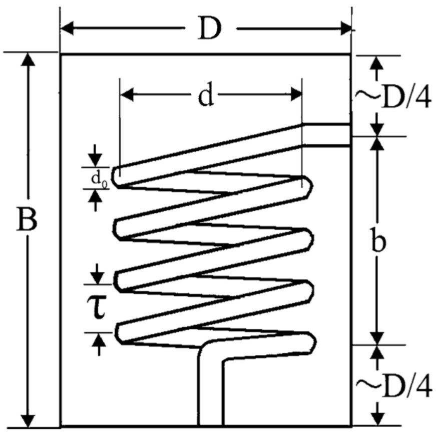

Figure 4: Notations for the helical resonator dimensions.

Since we couldn't find a copper wire of 5 mm of diameter without buying a lot of it (too expensive), as advised in the original paper, we decided to settle down for a wire of 4 mm of diameter. A thick wire is needed to have a sufficiently low resistance but also to avoid mechanical variations of the winding pitch. A diameter of roughly 4 mm seems a good compromise since it's thick enough but not so thick that we can still wind it by hand after it's akneel. The only precaution needed is to keep $\tau > d_0$ and $B \geq b + D/2$.

Another critical value is the position of the main coil. When its diameter is chosen we must build a cavity according to the specifications : first the main coil should be placed exactly at $D/4$ of each end-cap. But the cavity dimensions also play a role in the frequency at which the device should operates. Thankfully, the paper already characterized two different prototypes that show the right specifications to get the 20 MHz that we want considering that we have an EOM with a fixed capacitance and no resistance. Keeping this instructions in mind we can build our own helical resonator. The type A resonator (see Figure 5) they have build which has the best quality factor in the reference [2] seemed to suit our needs.

Resonator	A	B
Shield diameter D [mm]	108 ± 2	76 ± 2
Shield height h [mm]	120 ± 2	90 ± 2
Coil diameter d [mm]	42 ± 2	46 ± 2
Coil wire diameter d_0 [mm]	5.0 ± 0.1	5.0 ± 0.1
Winding pitch τ [mm]	9 ± 1	15 ± 1
Number of turns N	6.75 ± 0.25	4.5 ± 0.25
d/D ratio	0.4 ± 0.2	0.6 ± 0.2
Predicted frequency [MHz]	64^{+8}_{-6}	78^{+10}_{-7}
Measured frequency [MHz]	67 ± 0.5	83 ± 0.5
Predicted Q	1970^{+252}_{-374}	689^{+46}_{-115}
Measured Q	2176 ± 200	631 ± 60

Figure 5: Table giving the specifications for the two resonators tested in the original paper.

Furthermore in the paper in question we can see in Figure 6 (the figure 15 of [2]), which plot the resonant frequency against the capacitance of the trap, that 20 MHz is kind of an asymptotic value at capacitance exceeding 100 pF so any small deviation from the dimensions of the type A resonator they have build would still be perfect for us.

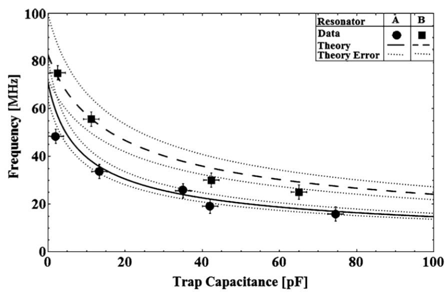

Fig. 15 The resonant frequencies of resonator A (*circles*) and resonator B (*squares*) are shown as a function of the trap capacitance they are attached to. The *dashed curves* represent the error on this calculation based on the design errors stated in Table 2. The resonant frequencies were measured for a resistance of 1 ohm; however, we note that they are actually independent of the resistance

Figure 6: figure extracted from the paper in reference [2].

4.2 Results and discussions

Here is some pictures of the different elements built according to the specifications listed before:

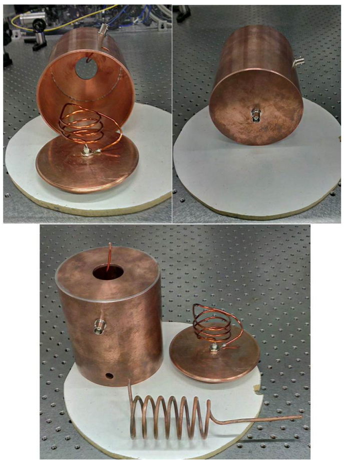

Figure 7: Picture of the helical resonator.

After some efforts I couldn't manage to obtain an helical resonator as performant as expected but while writing this report I think I may have find out the source of error : I confuse the size D of the cylinder with the size of the main coil diameter so the device is build with a distance of $\sim 13mm$ to the bases of the cylinder instead of the required $D/4 = 27mm$.
A way to quickly check if this source of error is the critical parameter preventing the device from working properly one can just remove the main coil in order to squeeze it so the winding pitch loose about $\sim 2mm$ and then, putting it in again so it's well center. The point being that the main coil is indeed at a distance of $D/4$ from each sides of the cylindric case.

5 Conclusions

This internship was very rewarding. I've learned a lot of interesting things in electronics and optics. I had the occasion to practice my english while presenting my master thesis to one of your english classes. In the end, I think I was able to contribute in an helpful manner to the experiments I worked on. It's a shame I couldn't finish my work on the helical resonator and take some data in order to put some results in my report but I heard my design actually work.
Since I left, the team tried to plug the device into the EOM and they manage to get very nice side-bands. I guess my last tests being made in a hurry in the very last day weren't made properly. I've really enjoyed my time in Brasil at the IFSC and even if I finally decided to do my PhD in France, I'm seriously considering looking for a post-doc position at USP in a few years.

References

[1] Eryn C. Cook, Paul J. Martin, Tobias L. Brown-Heft, Jeffrey C. Garman, and Daniel A. Steck. High passive-stability diode-laser design for use in atomic-physics experiments. *Rev. Sci. Instrum.*, 83:043101, April 2012.

[2] J. D. Siverns, L. R. Simkins, S. Weidt, and W. K. Hensinger. On the application of radio frequency voltages to ion traps via helical resonators. *Appl. Phys. B*, **107**:921–934, 2011.