Design of a Laser Frequency Stabilization for Cs Atomic Magnetometer

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ABSTRACT

An atomic magnetometer measures very weak magnetic fields with high sensitivity. A sensitivity in the range of $\sim fT/\sqrt{Hz}$ can be reached for instance with a laser stabilization technique. With such high sensitivity, this system can be used in both fundamental physics and its applications such as measuring biomagnetic field or geophysics. An atomic magnetometry can also be applied to axion dark matter search. Dark matter is usually stable and does not couple to ordinary matter. When the gradient of an axion domain wall interacts with the spin of a magnetometer, a very weak extraordinary magnetic field is generated and can be measured by the atomic magnetometer. We will develop an atomic magnetometry system with Cesium vapor for detecting exotic transient magnetic fields from the fluctuation of axion like domain walls. The laser frequency (852 nm) in the system can be stabilized using the nonlinear magneto-optics effect called dichroic atomic vapor laser lock (DAVLL). We will present the design of the Cs atomic magnetometry including DAVLL setup.

GNOME

- The geographically separated, synchronized optical magnetometers with high sensitivities could detect domain walls generated by an axion like field with a coupling to the spins of ordinary Standard Model particles [1][2][3].
- The global network of optical magnetometers for exotic physics (GNOME) uses this method that can measure the transient event of encountering between the Earth and gradient of such domain walls interacting with spins of paramagnetic stable alkali metal like 133-Cesium or 87-Rubidium [1][2].
- Especially, Cs possesses one stable isotope and it is more affordable relatively than Rb [4]. Also, M_x magnetometer using Cs reached high sensitivity around $fT/\sqrt{Hz}$, which can be realized only with high stabilization of a laser [2][4].
- The frequency detuning of the probe light can reduce both the photon shot noise δB_{ph} and the fundamental noise δB_{ba} due to Stark effect by quantum fluctuation of the light [2].
- Then the fundamental sensitivity limit δB_f is able to be determined by the atomic shot noise δB_{at} [2].

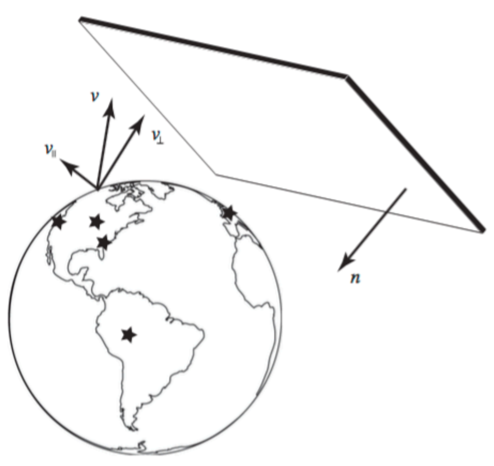

Figure 1. Schematic drawing of the global network of optical magnetometers [1].

$$\delta B_f = \sqrt{\delta B_{at}^2 + \delta B_{ph}^2 + \delta B_{ba}^2} \approx \delta B_{at}$$

DAVLL FOR CS

- The dichroic atomic vapor laser lock (DAVLL) is a laser frequency feedback system using polarization rotation by dichroic interaction with atomic vapor [5].
- Zeeman split in the D_2-transition energy levels of Cs gas [6]

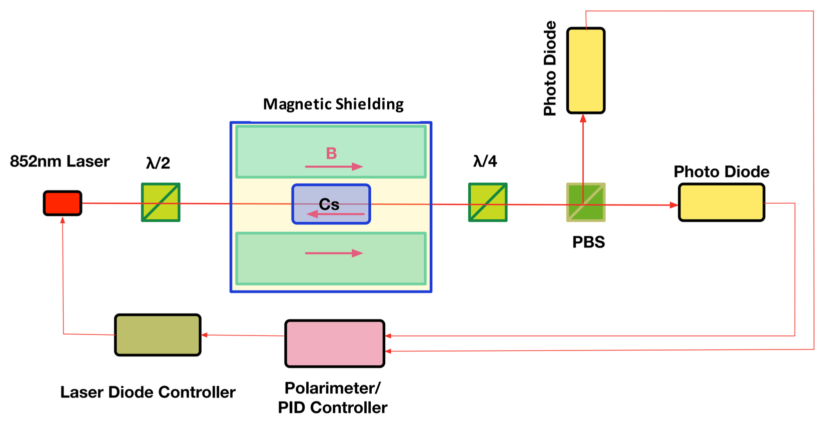

Figure 2. A schematic diagram of DAVLL system. The incident linear polarized laser into the Cs cell is rotated to have elliptical polarization if frequency was off from desired level.

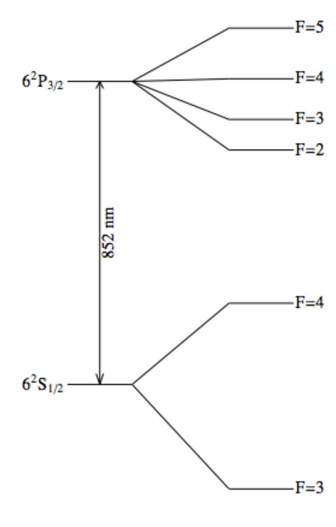

Figure 3. The Cesium D_2-transition energy level.

- An ellipticity or a polarization difference (DAVLL signal) [7]
- The temperature and current adjustments on the Laser Diode Controller
- Two operational modes locking laser frequency [6]

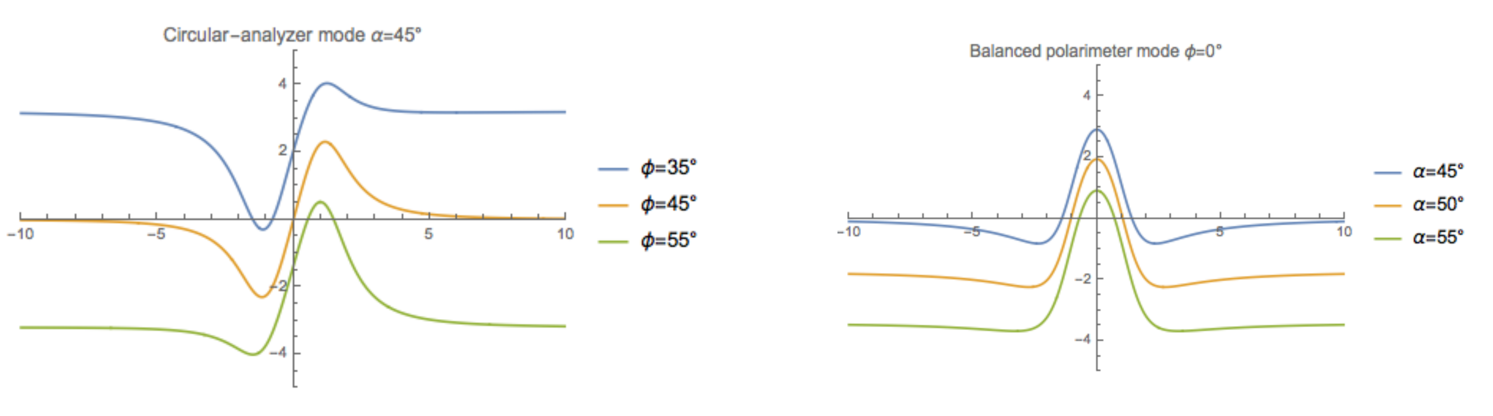

Figure 4. An expected signal of polarization rotation with respect to the frequency offset in a circular analyzer (left) and a balanced polarimeter (right) modes in unit dimensions. Both can be applied to lock the laser frequency [6].

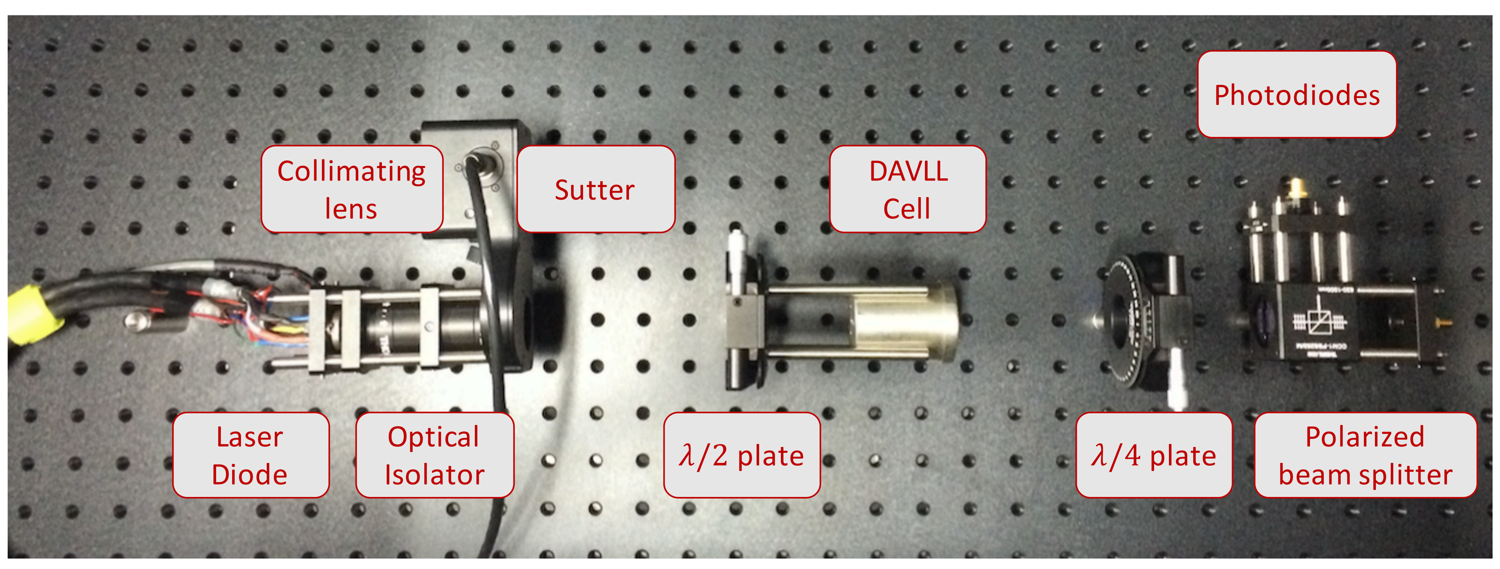

Figure 5. The experimental setup of DAVLL system.

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SETUP

Laser diode and controller

- 852 nm diode laser for Cs spectroscopy
- The operation range:
  100 ~ 150 mW

Figure 6. Laser diode controller (left) and laser diode (right).

Cs cell and coil

- 30 mm long Cs cell (ϕ = 11 mm)
- 3-D printed cell holders
- Target magnetic field: 200 G
- Compared with simulation

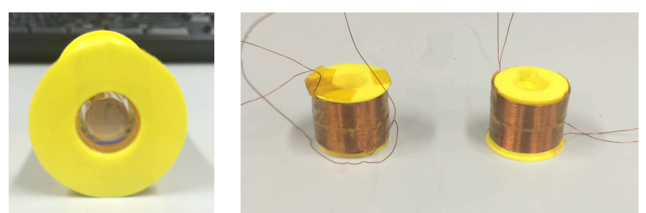

Figure 7. The 3-D printed Cs cell holder (left) and coil winding (right).

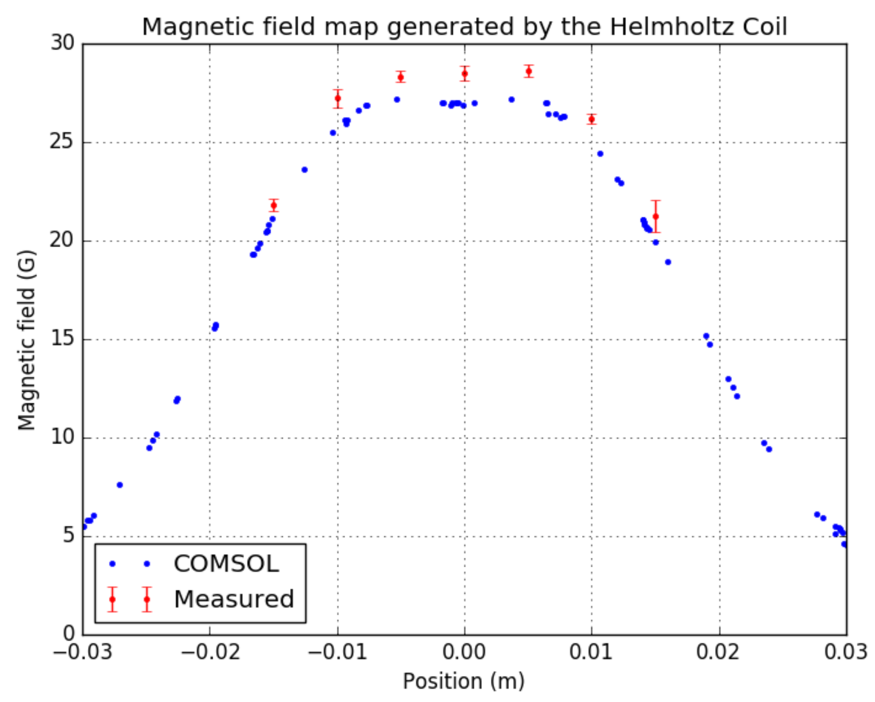

Figure 8. Magnetic field map comparison.

Magnetic shielding

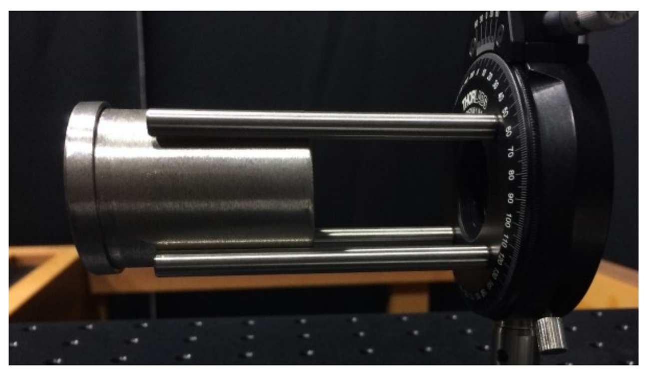

Figure 9. mu-metal shielding for Cs cell.

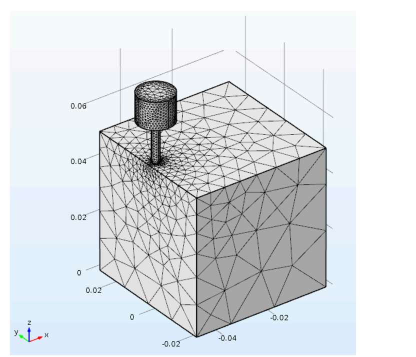

Figure 10. Magnetic shielding simulation model
* Thanks to University of Nevada.

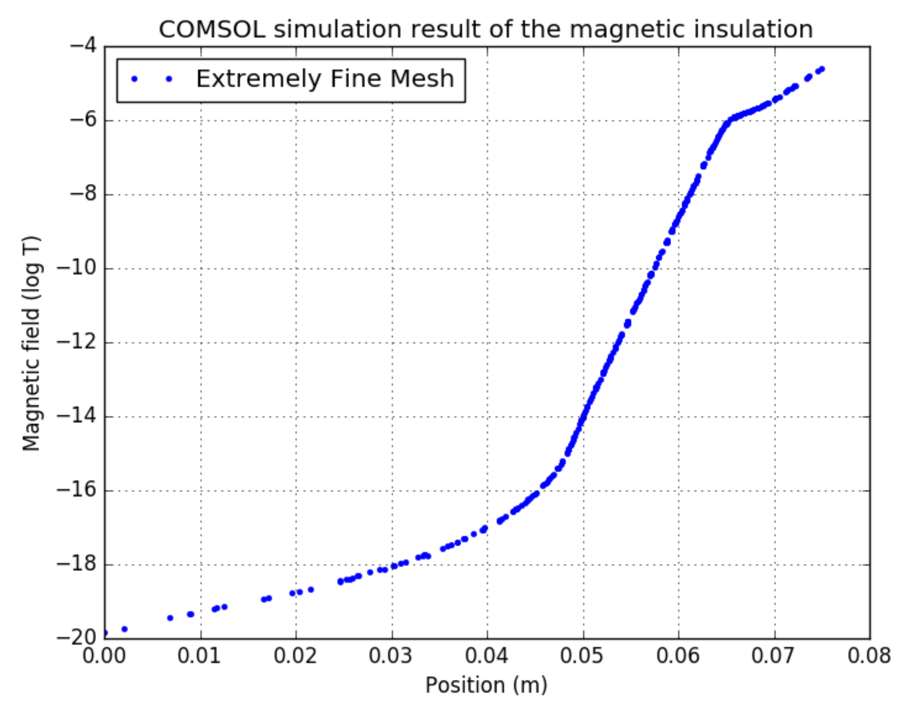

Figure 11. Magnetic field map from the circular guide to the shielding box.

Polarimeter Board

- Differential amplifier PCB Board
- Generating DAVLL signal
- Manufacturing now

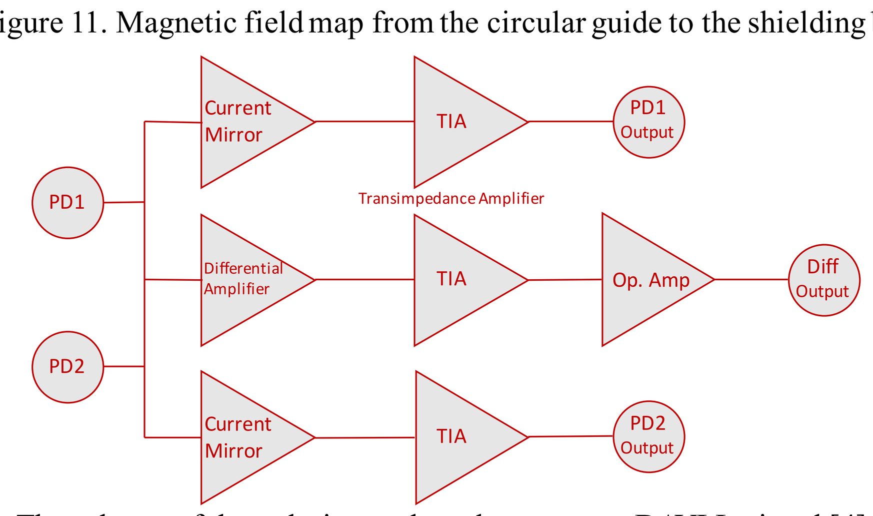

Figure 12. The scheme of the polarimeter board to generate DAVLL signal [4].

FUTURE PLAN

- The DAVLL system are to be installed to stabilize the laser frequency.
- The laser frequency stabilization with DAVLL system will be tested.
- The DAQ for monitoring DAVLL signal will be designed with Labview.
- The system will be extended to magnetometer for searching axion like particles.

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