Design of a Laser Frequency Stabilization for Cs Atomic Magnetometer

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An atomic magnetometer can measure weak magnetic fields with a high sensitivity $\sim fT/\sqrt{\mathrm{Hz}}$, which can be reached with a laser stabilization technique. This sensitivity can be used in axion-like field search. 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. We will develop an atomic magnetometer with Cesium vapor for detecting such magnetic fields from the axion like domain walls. The design of the laser frequency (852 nm) stabilization in the magnetometer using the dichroic atomic vapor laser lock (DAVLL) technique is presented.

1 Introduction

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 $fT/\sqrt{\mathrm{Hz}}$, 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]

$$\delta B_f = \sqrt{\delta B_{\mathrm{at}}^2 + \delta B_{\mathrm{ph}}^2 + \delta B_{\mathrm{ba}}^2} \approx \delta B_{\mathrm{at}}. \quad (1)$$

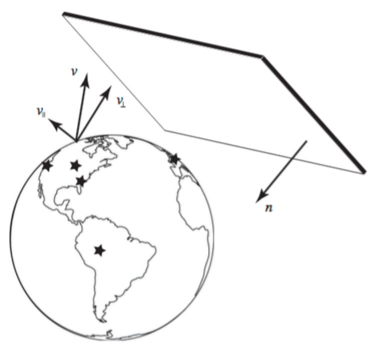

Figure 1: Schematic drawing of the global network of optical magnetometers

2 DAVLL for Cesium

The dichroic atomic vapor laser lock (DAVLL) is a laser frequency feedback system using polarization rotation by dichroic interaction with an atomic vapor [5].

The magnetic field on the Cesium vapor splits degenerated energy levels to distinguished levels have different energy and angular quantum number. Since the circularly polarized light $\sigma^{\pm}$ carries ± 1 angular momentum, the absorption light from different angular quantum numbered states can be happened by corresponding polarized light to conserve the angular momentum conservation. Such transitions have different energy levels determined by the strength of magnetic field.

The laser beam is linearly polarized initially. It means that it has an equal fraction of left and right circularly polarized lights. The frequency offset of the diode laser makes polarization bias and this causes a rotation of the polarization angle.

The D_2-transition ($6^2S_{1/2}$ to $6^2P_{3/2}$) energy levels of Cesium vapor is used [6].

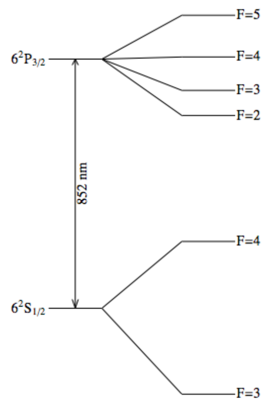

Figure 2: The Cesium D_2-transition energy level and its hyperfine levels.

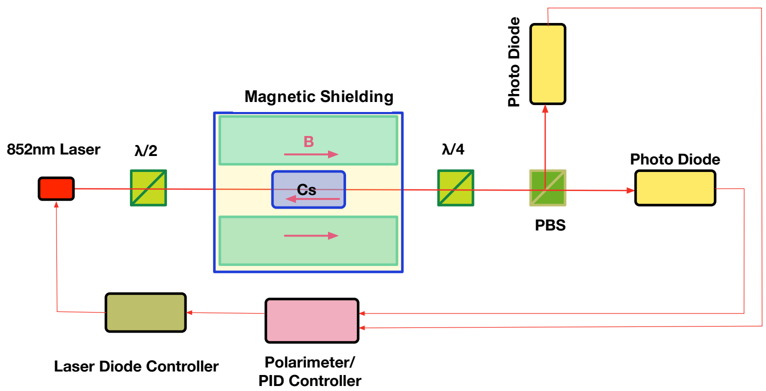

Figure 3: A schematic diagram of DAVLL system.

3 Setup

The experimental setup can be divided into two major parts; the optical and the electronics ones. The optical part generates the DAVLL signal, which is the difference between two polarization intensities. This signal can be used as an error signal for PID controller and the PID controller adjusts laser frequency of the diode laser by modulating laser diode controller. These electronics compose an automatic feedback loop for laser frequency stabilization.

3.1 Optics

The optics setup follows the schematic diagram shown in the Figure 3 and test setup is realized as in the Figure 4.

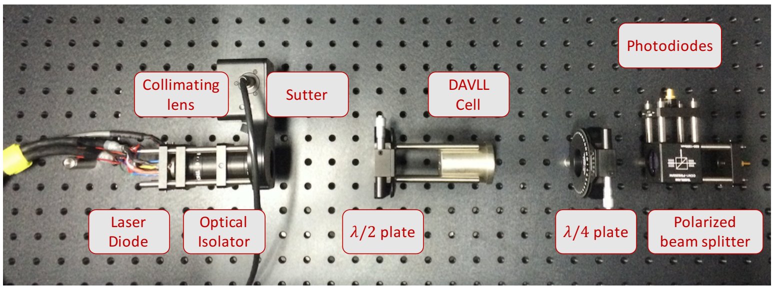

Figure 4: The experimental setup of DAVLL system.

It is used that the 852 nm laser diode (Eagleyard EYP-DFB-0852-00150-1500-TOC03-0005) for Cesium spectroscopy with operation power of 100 $\sim$ 150 mW. The current flow on the laser diode can be controlled by the laser diode controller (SRS LDC501).

The 10 mm diameter and 30 mm length of Cesium cell (TRIAD Quartz Cell) is used and wound by copper wires for applying the uniform magnetic field to split hyperfine energy levels. The magnetic field generated by the coils had been simulated and measured. The result is shown in the Figure 5. Currently, 28 G of magnetic field map is obtained and the target magnetic field is 200 G [5].

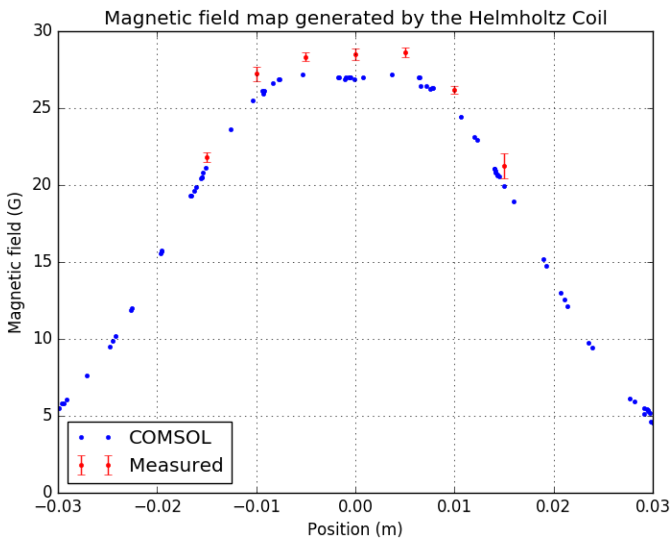

Figure 5: The magnetic field map on the Cesium cell.

3.2 Electronics

The photocurrents from two photodiodes can be converted into the voltage signal with the polarimeter board. The configuration is shown as in the Figure 6. Two photodiode (PD) inputs are copied and subtraction of them (DIFF) is generated. This DIFF signal will be used to modulate the laser diode controller via PID controller.

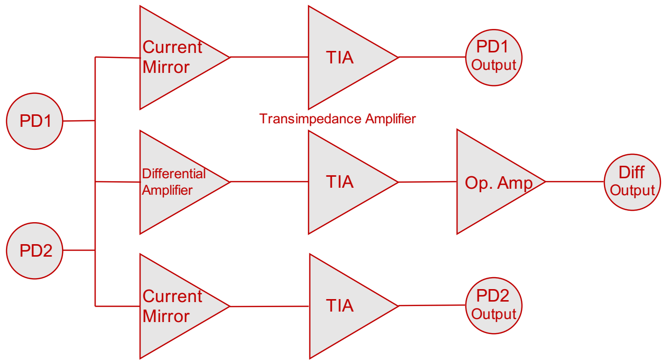

Figure 6: The scheme of the polarimeter board to generate DAVLL signal [4].

On our setup, the PCB board is on the manufacturing stage.

4 Summary

The atomic magnetometry can be used for searching axion-like field with its high sensitivity. One of the key techniques to increase sensitivity is using stabilized laser for the magnetometer. The DAVLL can be applied to stabilization. In this proceeding, the design of DAVLL system is presented and it will be installed to stabilize the laser frequency. We are planning to test laser stabilization and setup whole atomic magnetometer with stabilized laser.

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