# Doubly-locked Dual-Frequency Faraday Laser for Absolute Frequency Measurement

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***Abstract*—The Faraday laser, which is an extended cavity diode laser with a Faraday Anomalous Dispersion Optical Filter (FADOF) as intra-cavity frequency selection element, has the advantage of immunity to diode current and temperature fluctuations. For a Faraday laser working in the dual-frequency (DF) regime, it can be stabilized via frequency-locking one of the output modes to an atomic transition, or by phase-locking the beat frequency between the two output modes to a microwave reference. Here, we propose to combine the two stabilization methods, further stabilizing the two output frequencies. Such a doubly-locked DF Faraday laser, analogous to an optical frequency comb albeit with only two "teeth", can be used for absolute frequency measurement of optical signals.**

***Keywords—Faraday anomalous dispersion optical filter (FADOF), diode laser, faraday laser, dual-frequency laser, absolute frequency measurement***

## I. INTRODUCTION

The Faraday anomalous dispersion optical filter (FADOF) utilizes the Faraday rotation effect to achieve a high level of noise rejection [1, 2], narrow filtering bandwidth [3, 4] and high passband transmission. Since the FADOF only transmits light with frequency near the atomic resonance [5], it blocks out the background noise from the desired optical signal. Therefore, FADOFs are widely used in lidar technology [6, 7], optical communications [8, 9] and laser frequency stabilization [9-12].

The Faraday laser is an extended cavity diode laser that uses a FADOF as its intra-cavity frequency selection element, and it has the characteristic of only lasing on the FADOF transmission peaks, which are determined by the atomic transition. Therefore, the frequency of the Faraday laser has immunity to fluctuations of the laser diode's current and temperature [13]. When the working condition of the FADOF is tuned so that its transmission spectrum has two peaks of similar strength both within the laser gain bandwidth, the Faraday laser can achieve simultaneously lasing on two frequencies, entering the dual-frequency (DF) regime. Our group realized a DF Faraday laser, with the two output modes at transmission peaks corresponding to cesium's $6^2S_{1/2}(F = 4) \rightarrow 6^2P_{3/2}$ and $6^2S_{1/2}(F = 3) \rightarrow 6^2P_{3/2}$ transitions [14].

The two output modes of the DF Faraday laser are highly coherent, due to them sharing the same laser cavity. The beat frequency of the two output modes has narrower linewidth than each of the individual output modes, since the common-mode noise such as cavity length fluctuation is cancelled out in the heterodyne process. Moreover, like other DF lasers such as the DF He-Ne laser [15] or the DF Tm: YAG laser [16], locking the beat frequency can improve the frequency stability of the output laser frequencies, and locking one of the output frequencies, such as with modulation transfer spectroscopy (MTS), can also stabilize the beat frequency, since these frequencies are all dependent on the length of the shared cavity. Here, we propose a two-stage stabilization scheme that can achieve higher frequency stability and allows for absolute frequency measurement with a DF Faraday laser.

## II. METHODS

We propose to combine the two stabilization methods for the DF Faraday laser: after using MTS to stabilize one of the output modes, the beat frequency between output modes is then locked to a microwave frequency reference via an optical phase-lock loop (OPLL) setup. By adding the phase locking of the beat frequency as a second-stage stabilization, the DF Faraday laser can achieve a higher frequency stability than when only one stabilization method is employed.

With this two-stage stabilization scheme, the doubly-locked DF Faraday laser is analogous to a frequency comb, with the first MTS locking stage and the phase-locking of the beat frequency acting like the stabilization of an optical frequency comb's carrier-envelope offset frequency ($f_{ceo}$) and repetition frequency ($f_{rep}$), respectively. Such a doubly-locked DF Faraday laser can be used for absolute frequency measurement via heterodyne detection, since the frequencies of the two output modes are known with a precision limited by the microwave frequency reference for locking the beat frequency.

## III. DISCUSSION

Since the two output modes of the DF Faraday laser are determined by the FADOF transmission peaks, its application in absolute frequency measurement will be limited to laser frequencies close to the atomic transitions. However, with different atomic species and transitions as the FADOF's reference, the wavelength range for this application in absolute frequency measurement can be further expanded.

## IV. Conclusions

We propose a doubly-locked DF Faraday laser, which has a two-stage stabilization scheme: first one of the output laser frequencies is locked to an atomic transition via MTS, then the beat frequency is phase-locked to a high-stability microwave frequency reference. This ensures that the two output modes both have high frequency stability, and their frequencies are determined with precision, making the DF Faraday laser a good candidate for absolute frequency measurement.

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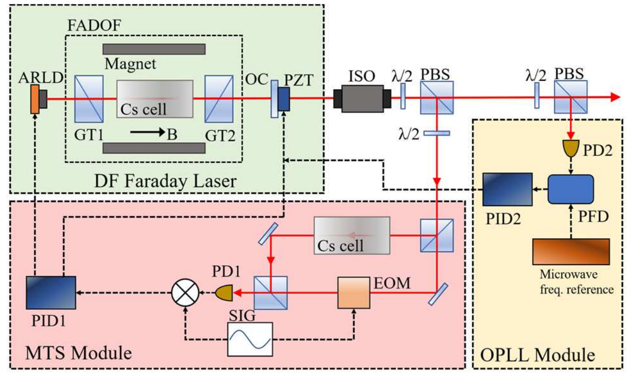


Figure 1. Proposed setup for the two-stage stabilization of the DF Faraday laser. One of the output laser frequencies is locked to the atomic transition via MTS, meanwhile, the beating frequency is locked to a microwave frequency reference by an OPLL. Such a doubly-locked DF Faraday laser can have an improved frequency stability compared to a DF Faraday laser stabilized with only one method, and can be used in absolute frequency measurement.