LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
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Frequency Stabilization of 2 Micron Lasers Using Optical Delay Self-Heterodyne Interferometry

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Note: Proposal as of Feb 2023

1 Introduction

From LIGO's observation of gravitational waves to timing experiments, laser systems are critical to modern precision measurement. Coming into particular interest to measurement is the 2050nm laser for its transparancy in atmosphere with the notable exception of carbon dioxide among other benefits [2]. As a result these lasers are prime candidates for use in LIDAR and carbon dioxide concentration measurement [6]. For the measurements to be precise, the lasers must have narrow linewidths (range of light frequencies output) to reduce noise coming from other wavelengths. Current 2050nm lasers reach linewidths around 50kHz [3]. To achieve narrower linewidths suitable for more precise measurements, a common method involves selecting out the primary frequency using a resonant cavity. These methods can achieve linewidths less than a millihertz, yet require costly precision optics [4]. This feedforward approach aims to substantively narrow the original linewidth at lower cost than the resonant cavities.

2 Approach

This work draws substantively from previous work in feedforward linewidth stabilization [1][5]. The beam from a 2050nm laser (e.g. [3]) will be split in two with the bulk of the beam being sent into a fibre-optic delay line of approximately 100m (approximately 400ns delay). While the light propogates through the delay line, the remaining fraction of the beam is sent into a delayed self-heterodyne interferometer to measure its phase error. The interferometer consists of splitting the incoming beam in half, passing one half through a delay line, and interfering the delayed half with the direct beam in a 90°optical hybrid. The light output of the hybrid is then converted into electrical signals using a pair of balanced photo-detectors. Digital and/or analog circuitry then processes this measured phase noise into a phase correction RF signal to control an acousto-optic frequency shifter at the end of the primary branch's delay line. Folowing the application of this correcting frequency shift, the resultant laser output is expected to be of a much narrower linewidth. The necessary calculations to find the phase correction involve finding the argument of a pair of voltages representing a complex number, removing a DC component, the time-integration of a linear term, and conversion of that value into the angular frequency of an RF signal. This can be done using an analog-digital converter to digitize the signals, a field programmable gate array to perform the calculations, and a direct digital signal generator to produce the RF signal, or otherwise in analog computation using operational amplifiers and associated components. The final laser output is then reassessed for phase noise using self-heterodyne interferometry as described before to quantify the reduction in noise.

3 Timeline and Goals

1. Pre-Summer Preparation: Selecting components and ordering those not on hand to allow for shipping times; Design and order preliminary PCB for analog circuitry
2. Setup laser and quantify unreduced noise / become familiar with the components
3. Assemble and begin to tune the linewidth narrowing setup utilizing digital computation
4. Once the specific calculation sequence has been implemented / tested in digital logic and the preliminary analog circuit characterized, refine and reorder PCB design if necessary
5. Quantify preliminary results in reduced noise - *Goal:* Order of magnitude reduction in linewidth
6. Assemble and tune refined analog computation circuit in noise reduction setup
7. Continue to refine and tune the digital and analog systems
8. Final assessment of noise reduction - *Goal:* sub-kilohertz linewidth, system characterised to allow for speedy implementation for use in applications

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