LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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Implementing A Frequency Control Loop for the 40m Prototype Arm Length Stabilization System

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1 Introduction: The LIGO Detector

Gravitational waves are a component of Einstein's theory of General Relativity, which have not, as of yet, been directly observed. The detection, observation and characterization of these waves are the primary goals of the LIGO detector.

The waves manifest themselves with disturbances in spacetime, causing miniscule changes in length. These modulations, when detected, are on the scale of $10^{-18}m$ [?]. With independent variables on such a small scale, it is necessary to employ a highly sensitive instrument–in this case, a laser interferometer, diagrammed in Figure ??.

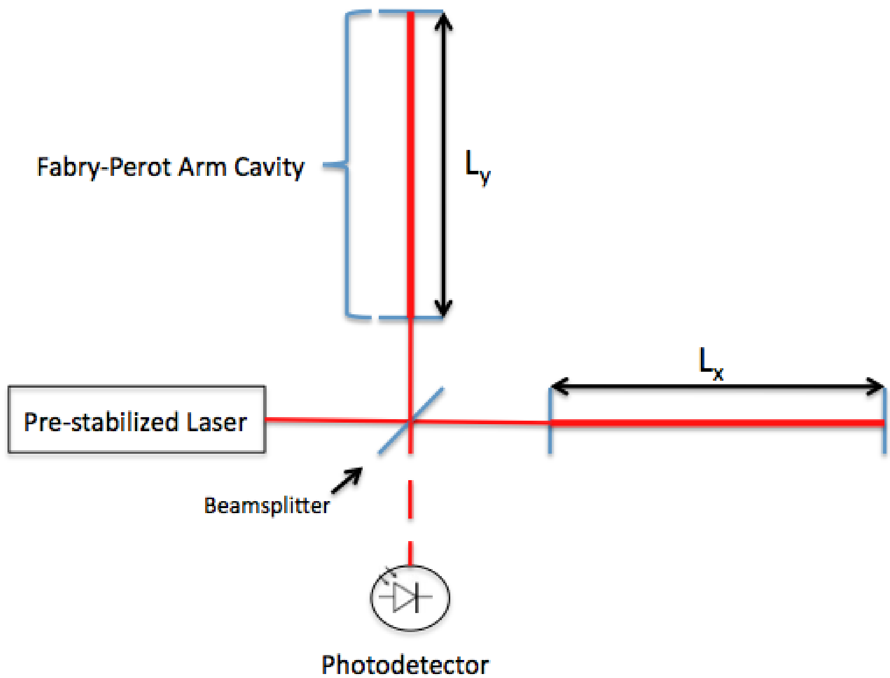

Figure 1: Laser interferometer with Fabry-Perot arm cavities.

Since the laser light is perfectly in phase with itself when it enters the arm-cavities, the only thing that could shift the phase difference between beams is a difference in arm length $(L_x - L_y)$. Thus, we can observe changes on the scale in which we need to. Measurements are taken by way of observing interference patterns produced by the recombined beam.

The Fabry-Perot arm-cavities, as opposed to the more traditional simple arms, allow us to generate greater arm lengths, and thus increase sensitivity, which increases in proportion to arm length.

In addition to the Fabry-Perot arm cavities, the detector implements power recycling cavities at the vertex of the detector, which effectively amplify the optical power of the PSL, improving the shot noise level [?]

2 Arm Length Stabilization (ALS)

In order to operate such a sensitive interferometer, we must know and control the degrees of freedom of the Fabry-Perot arm cavities. In order to do so, we make use of a frequency doubled auxiliary laser (AUX) system, which operates at baseline 536 nm. The AUX frequency can vary, as it is locked to the arm cavity length by a Pound-Driver-Hall locking servo. Using this frequency as the measurement of the arm cavity length, it is then possible to bring the PSL into lock with AUX, and thereby, the arm cavity length. The length detection scheme is described below, v and δv referring to the baseline frequency, and change in frequency, and L and δL referring to the baseline length, and change in length.

$$\frac{\delta v_a(t)}{\overline{v}} = -\frac{\delta L(t)}{\overline{L}} \text{ [?]}$$

In this system, an AUX beam is injected through the Fabry-Perot arm cavity, then combined with the frequency doubled prestabilized laser (PSL) to beat with each other, and is fed into a photodiode which acts as an input to a delay-line frequency discriminator (DFD). The DFD functions to create a linear error signal, which is then used to correct the arm cavity length through servo controlled end test masses (ETM) [?].

3 Problem

The problem here lies within the offsetting system used to keep the AUX laser locked with the arm cavity length. The laser cavity actuators can only respond at $5\frac{MHz}{V}$ with a range of $\pm 10V$, while the arm cavity length can fluctuate on a length scale corresponding to a frequency range well beyond that of the laser cavity actuators [?]. It is clear that we are in need of another method of control, with a greater range.

When we sense a beat frequency >100MHz, we encounter difficulty, since we are outside the ALS system's effective working range. This is where the proposed new servo comes into play. Using a separate sample of each beam, (AUX and PSL) we will use their beat frequency to generate a digital error signal, which will be fed into a digital PID loop, and used to actuate the temperature control of AUX, in order to bring it back into within the working range of the ALS system.

We implement a temperature actuator, which will control the temperature of the crystal within the laser, yielding a controllable range of roughly $1\frac{GHz}{V}$. This servo will respond to signals below about 1 Hz.

4 Preliminary Design and Working Principles

In principle, the temperature actuator will modulate the temperature of the laser crystal when there is a signal of frequency below 1 Hz. Changing the temperature of the crystal changes its physical dimensions, and thereby modulates its frequency in proportion.

We will take beam samples of the AUX and PSL, and recombine them at the vertex of the detector. The combined beam will then enter a photodiode. This signal will enter a frequency counter, which will then give a remote readout of the beat frequency, and then go on to the digital PID loop, which will eventually go through the DAC to actuate the temperature control servo, and bring the AUX frequency back within a workable range.

This design is show in Figure ??.

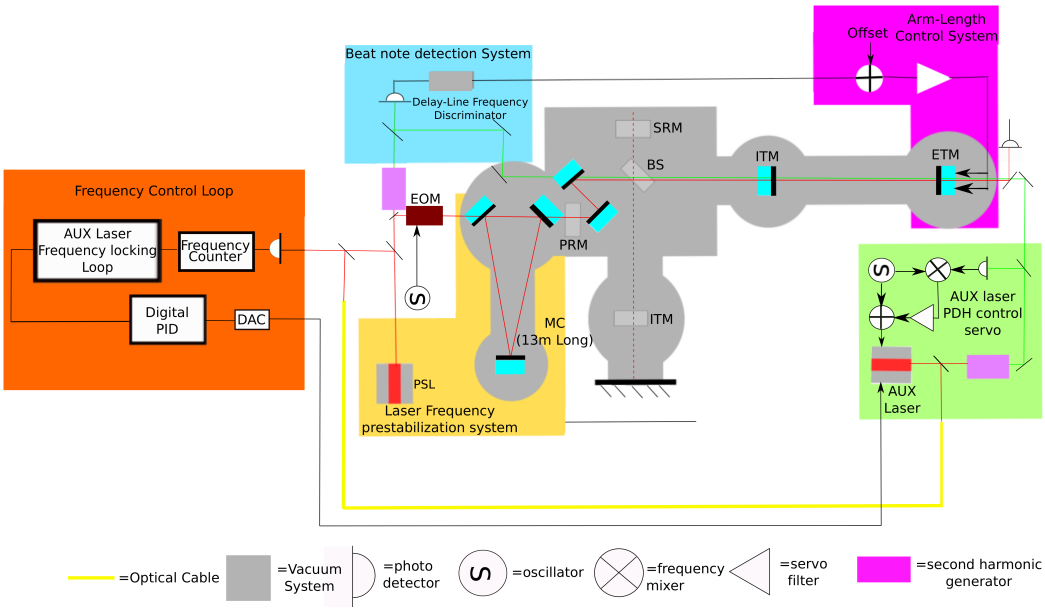

Figure 2: Schematic of interferometer with proposed AUX laser frequency locking loop

5 Important Steps in Construction of the Servo

First, we must build an optical setup to detect the frequency difference between AUX and PSL. This involves picking off a sample from each of the PSL and AUX. AUX will be run through fibers to the detector vertex, where it will be combined with the PSL.

The beam will then enter a frequency counter, and an ADC in order to generate a digital signal corresponding to the beat frequency. This part will also involve a remote readout of the beat frequency.

We will then design the digital PID loop, which will then be installed and output a digital corrective signal. This signal will then go through a DAC, and go on to actuate the temperature control to adjust the AUX frequency.

6 Timeline

Table 1: Timeline

Week 1-2	Contruction of Beat-Note Setup
Week 3-5	Design and Construction of PID Circuit
Week 6	Installation of PID Circuit
Week 7-10	Troubleshooting of System

References

[1] http://www.ligo-wa.caltech.edu/ligo_faq.html

[2] Kiwamu Izumi *Multi-Color Interferometry for Lock Acquisition of Laser Interferometric Gravitational-wave Detectors* Department of Astronomy, The University of Tokyo

[3] Masaki Ando *Power recycling for an interferometric gravitational wave detector* Department of Physics, Faculty of Science, niversity of Tokyo