Laser Stabilization for the GRAVITES Experiment

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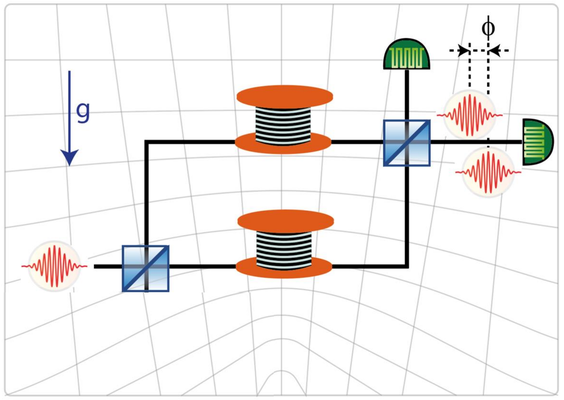
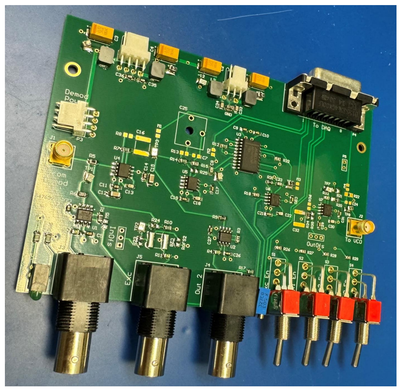
Background & Introduction



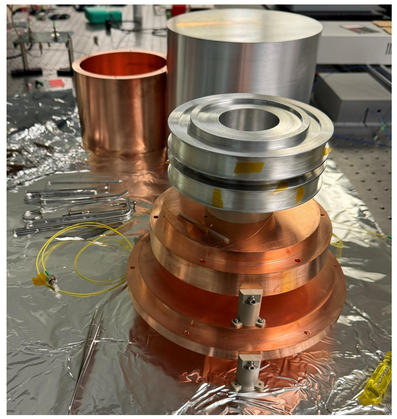
- General relativity and quantum mechanics are well-established theories
- Combining the two has been an unsolved problem for a long time
- The predictions of each theory have been verified many times
- Physicists have been unable to conduct experiments that incorporate aspects of both theories simultaneously
- Photons are sent through a Mach-Zehnder interferometer
- Each interferometer path is kept at different heights above the ground
- The photon's wavefunction is spread across two different gravitational potentials
- We expect to observe a phase shift due to gravitational time dilation

Servo Board



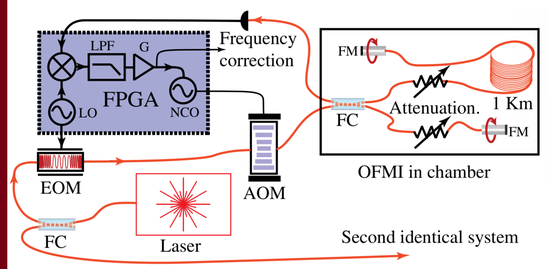
- Has 4 stages of op-amps
- First stage is an amplifier with a gain of 20 dB
- Second stage is an amplifier with a gain of 20 dB and an integrator with a corner frequency of 1 kHz
- Third stage is a variable gain amplifier and an integrator with a corner frequency of 1 kHz
- Final stage is a voltage follower which provides a lower output impedance

Thermal Isolation



- The Michelson interferometer is thermally isolated using chambers that act as a pair of thermal low-pass filters
- There is a copper layer and an outer aluminum layer separated by plastic stands
- The copper plates have a high heat capacity (C) while the stands have a high thermal resistance (R)
- The resulting time constants are $\tau_1 = \sqrt{C_1 R_1}$ and $\tau_2 = \sqrt{C_2 R_2}$ which are on the order of tens of hours

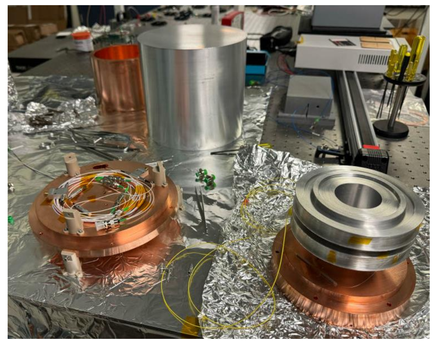
Pre-stabilization Setup



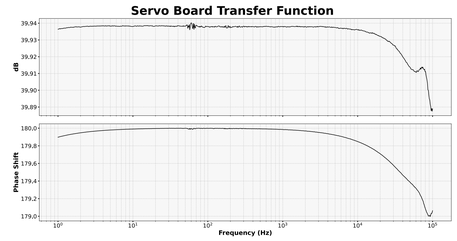
McRae, Ngo, Shaddock, Hsu, and Gray, "Frequency stabilization for space-based missions using optical fiber interferometry," *Opt. Lett. 38,* 278-280 (2013)

- Modulate the laser's phase with an electro-optic modulator (EOM) using the local oscillator signal
- Send the light to the interferometer
- Detect the interference pattern with a photodetector

- Mix the detected signal with the local oscillator signal
- Pass the mixed signal through a low-pass filter to generate an error signal
- Feed the error signal to an acousto-optic modulator (AOM) to correct laser frequency fluctuations

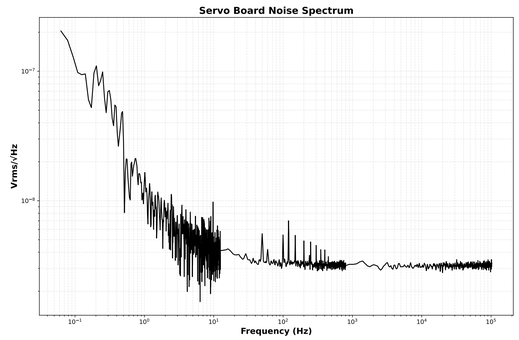


Servo Board Characterization



- Due to the first two stages having 20 dB of gain the overall gain of the board is 40 dB
- The phase is shifted by 180 degrees due to the use of two inverting amplifiers

- We found the input referred noise to be about 10^{-7} Vrms/√Hz at 100 mHz
- This is below the expected shot noise of our photodetector



Conclusion & Next Steps

- We successfully locked the laser in the pre-stabilization setup by implementing a feedback control system
- Next, we hope to assemble the vacuum chamber to improve the thermal and acoustic isolation of the optical fiber Michelson interferometer
- The GRAVITES group will continue testing the setup and gathering data to plan for the final iteration of the experiment

Acknowledgments & Contact

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