Optimizing The Study Of Quantum Optomechanics In Super Fluid Liquid Helium

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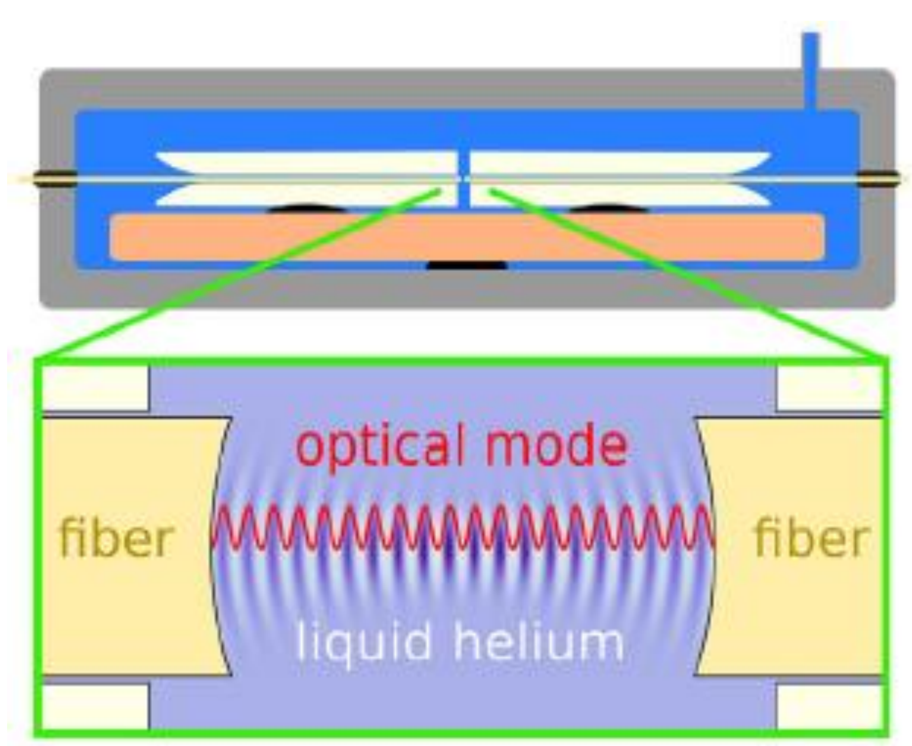
Abstract

All objects obey the laws of quantum mechanics. As an object increases in size, it appears to obey the laws of physics more classically. Demonstrating that large objects obey quantum mechanics currently requires superfluid liquid helium and lasers. When superfluid liquid helium is placed in a cavity there exists some discrete amount of energy in the form of an acoustic wave, as opposed to the classical state where this energy can take on continuous values. We study how this acoustic wave couples light from a laser when sent into cavity. As the light exits the cavity its energy has changed some amount proportional to the energy of the acoustic waves. The information gathered by the light leaving the cavity provides insight into different aspects of quantum mechanics. To optimize the study of the affected light exiting the cavity it is necessary to frequency lock two lasers used in the experiment. This is done using a feedback loop dependent on a beat frequency between two lasers. To address this concept, we use a frequency to voltage converter that produces a frequency dependent output voltage. The importance of frequency locking two lasers is to ensure the correct frequency of the light sent into the cavity.

Introduction

Optomechanical experiments have shown quantum effects in mechanical oscillators that are solids and cold gases. Currently in this research we are studying the measurements of quantum behavior in the vibrations of a volume of superfluid liquid helium coupled to an optical cavity. The purpose of this is to observe whether superfluid liquid helium obeys the laws of quantum physics. When the helium is coupled with the cavity quantum mechanics says there exists some discrete amount of energy. This exists in the form of a phonon (acoustic wave) oscillating at some frequency dependent on the cavity. To study this discrete level of energy in the helium, light from a laser is tuned to a frequency and sent into the cavity. When the photons exit the cavity, they are either red shifted or blue shifted depending on the quantum state of the helium in the cavity. This leads to the need of two frequency locked lasers to be used in the experiment. The two lasers will be tuned to specify frequencies to optimize the amount of red shifted and blue shifted photons that exit the cavity.

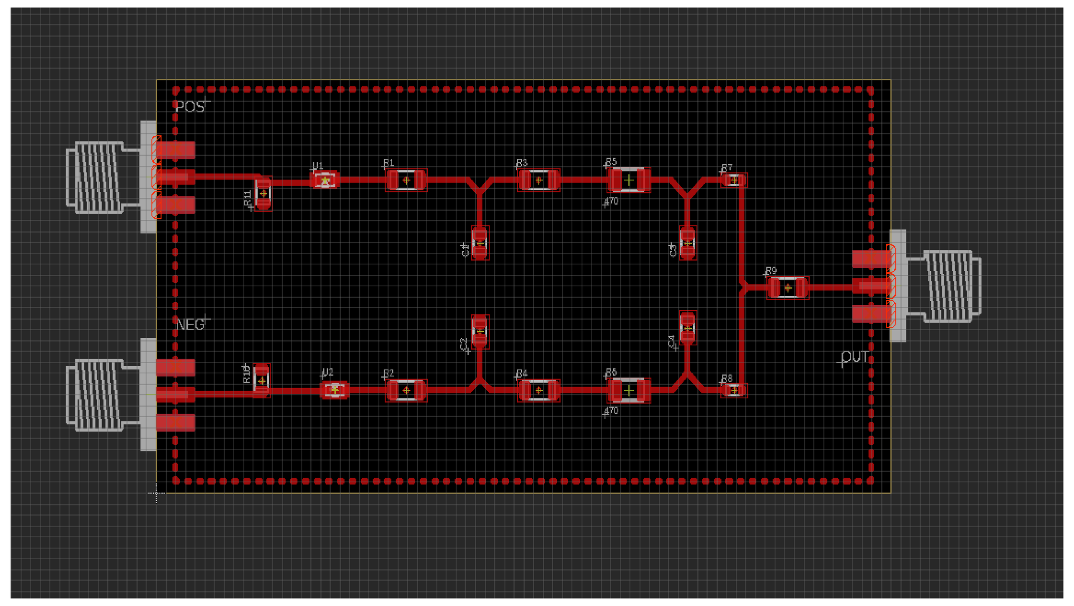


- **Figure 1**: Optical Cavity containing volume of super fluid liquid helium. Photons tuned to a specific frequency enter the cavity and interact with the superfluid liquid helium. The photons either give energy to the helium or take energy from it. The photons then exit the cavity and are then observed.

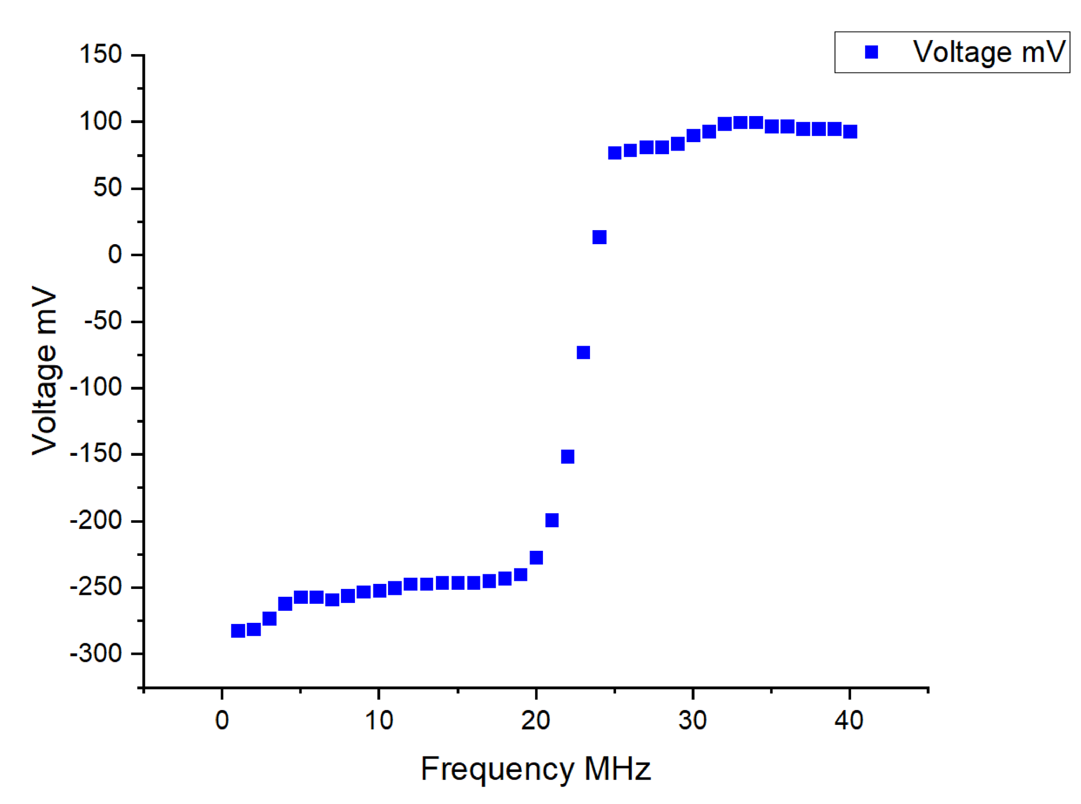
Methodology

To optimize this study, two separate slave lasers at different frequencies will be utilized. This is significant because currently a single laser is sending light to the optical cavity at a certain frequency over a 12-hour period. During those twelve hours there are many factors that cause the laser to shift in frequency thus unlocking its frequency from the optical cavity. When two lasers are used there is no need to shift frequency and keeping them locked at their respective frequencies is more stable. Then instead of taking data at two different frequencies over the course of 24-hours the lasers can be alternatively shined into the cavity, thus optimizing the study of the shifted light exiting the cavity.

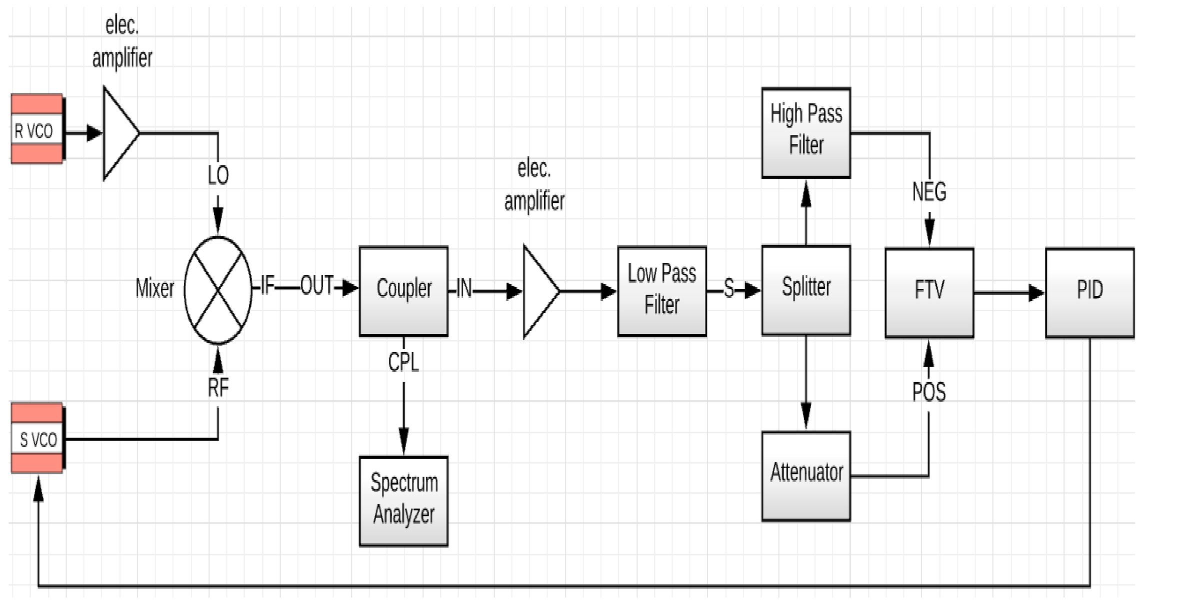
To frequency lock the lasers we create a beat frequency between the slave lasers and the reference laser. The beat frequency is then sent to a frequency to voltage (FTV) converter circuit that produces a DC voltage that is dependent on frequency of the beat signal.



- **Figure 2**: Computer drawing of frequency to voltage converter (FTV) used to create printed circuit board with surface mount devices The circuit contains two separate branches that rectify the AC sine wave into both a positive and negative voltage and then adds them together. This DC output is then used as the error signal for a feedback control loop

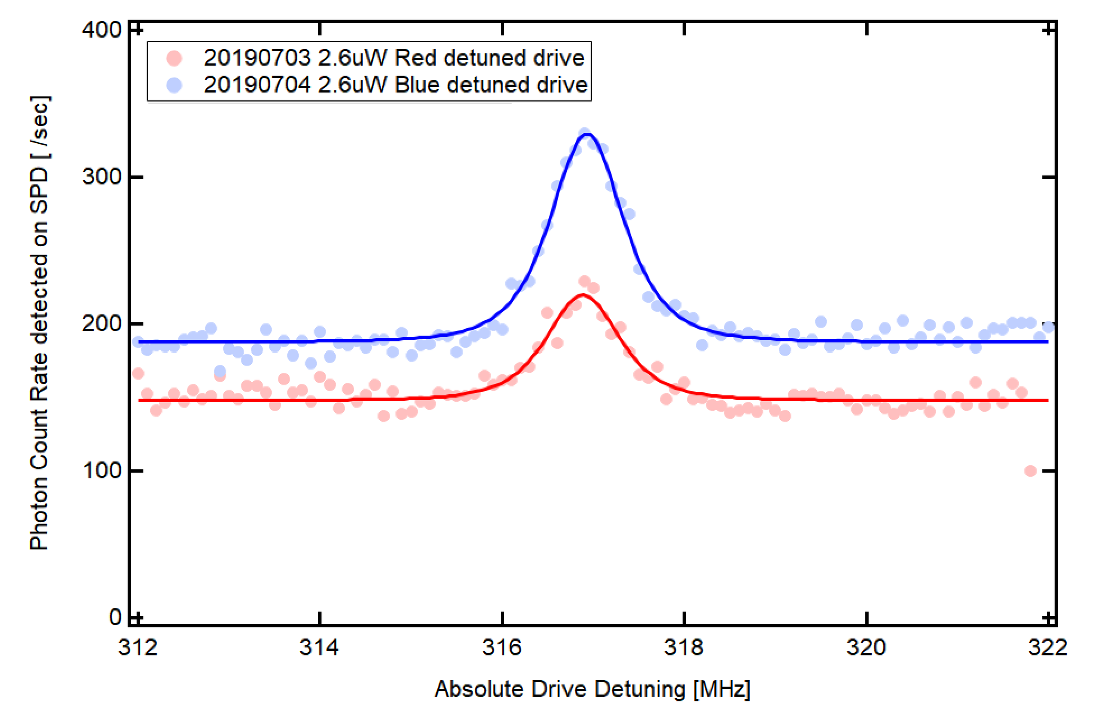


- **Figure 3**: Error signal output voltage dependent on an input frequency from a signal generator Any change in the beat frequency corresponds to a change in voltage in the error signal. It is important to have a steep slope around the zero-voltage point because this will correspond to a strong response in the error signal and an effective feedback loop keeping the frequencies of the lasers locked in the correct position.



- **Figure 4**: Schematic of feedback loop using VCO's. To keep the laser's frequencies locked to the correct frequency we have developed a feedback loop that is dependent on the error signal from the FTV. The feedback loop is being driven by two voltage-controlled oscillators (VCO). The reference VCO receives a voltage from a power supply while the slave VCO receives a voltage from the PID. The VCO's signals go to a mixer that outputs the difference of the two frequencies. This beat frequency is then split and sent to the FTV that outputs the error signal. The error signal is sent to a PID that has a set lock point of zero volts and any deviation from that results in a correction voltage to the slave VCO to keep the beat frequency locked.

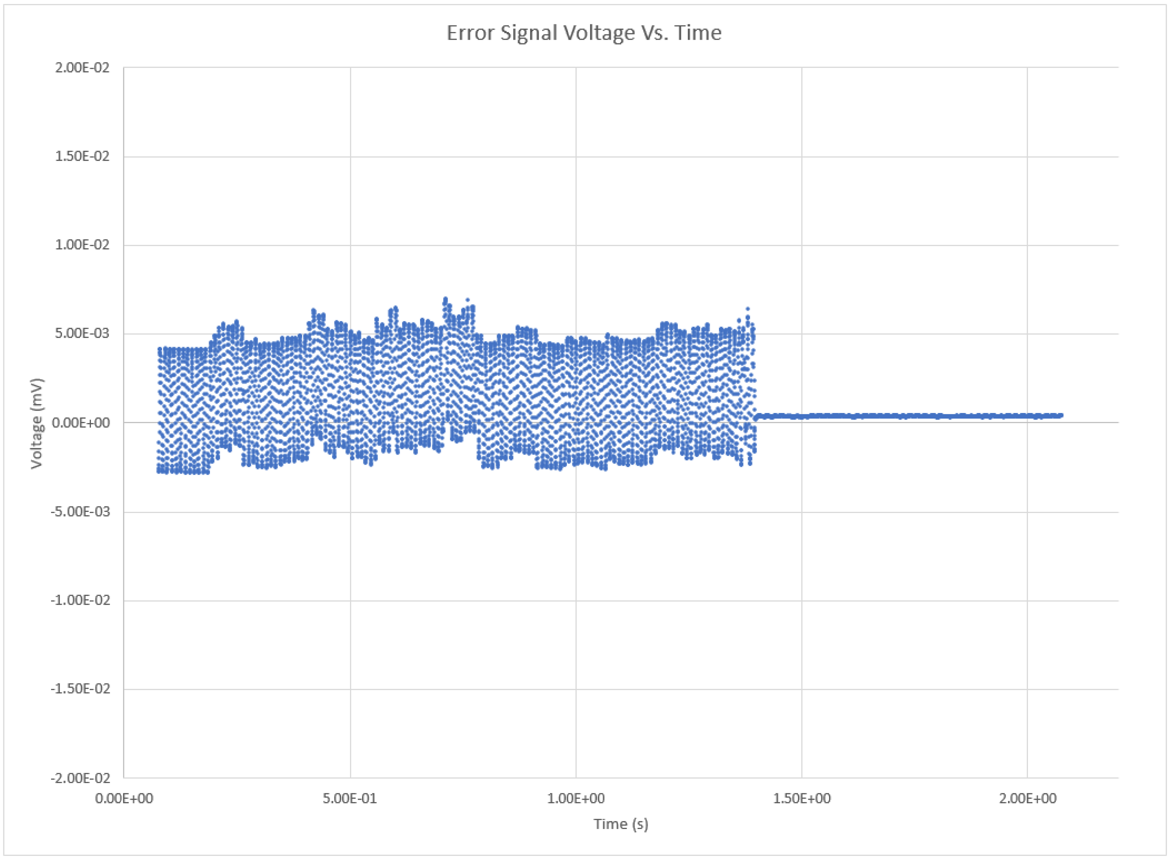
In the application of the experiment the two slave lasers will be tuned to approximately 196 THz + 316 MHz and 196 THz – 316 MHz. These frequencies correspond to the frequencies at which light will couple with the cavity and either give or receive energy from the super fluid liquid helium. When light is shined in at the higher frequency it is said to be blue detuned and will give energy to the cavity. Then the laser red detuned to a lower frequency and will take energy. This light then exits the cavity and is observed by a single photon detector and then studied further.



- **Figure 5**: Data collected shows the amount of red and blue shifted photons observed exiting the optical cavity. Classily the amounts would be the same. The difference can be explained by the laws of quantum mechanics and energy having to exist at discrete values. SPD ≡ Single Photon Detector

Results

So far, we have demonstrated that it is possible to lock two VCO's with the frequency dependent error signal from the FTV using a feedback loop and a PID. This error signal has the steepest change in voltage around 24 MHz. The reference VCO was driven with multiple types of waveforms (sine, square, noise) and when the PID was engaged to lock the error signal remained constant around 0 V therefore locking the VCO's to each other.



- **Figure 6**: This plot shows when the PID was engaged to lock. The error signal goes from an oscillating voltage that is dependent on the frequency of the input signal to a constant voltage around 0 V.

Conclusion

The next step in the optimization process is to get the FTV to operate with a signal that has a frequency of around 316 MHz. This is important because the reference laser will be tuned to approximately 196 THz. The two slave lasers will be detuned and locked 316 MHz from the reference laser. One proposed way to do this is to change the diodes currently in use in the FTV. When the FTV operates around 316 MHz many of the additional components in the feedback look can be removed. The less components in the feedback loop the less noise introduced to the error signal which will produce a stronger lock for the lasers.

References

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