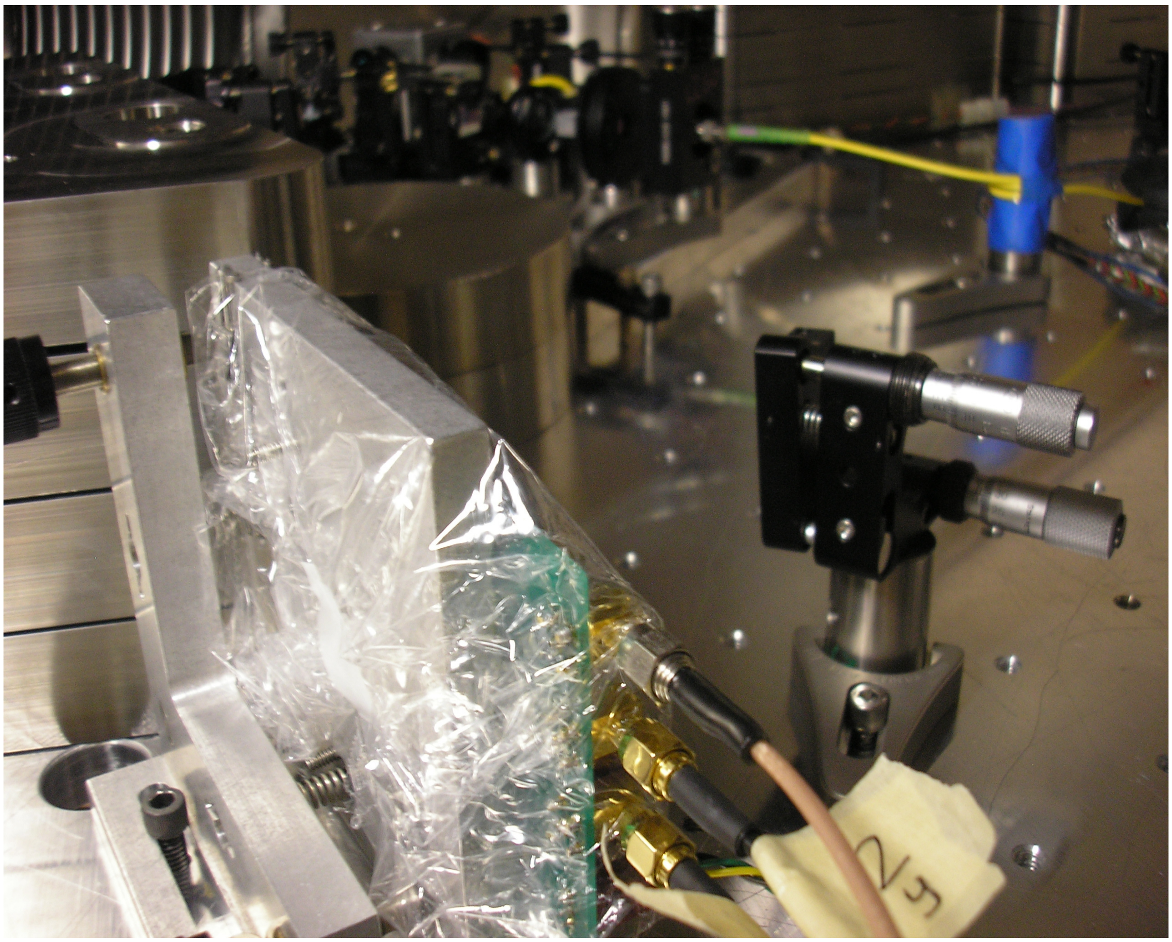
SPI POINTING STABILITY



Stanford University
Ginzton Laboratory
End-Station II

LIGO-E1000449

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I. Introduction

A quad photo detector (QPD) was installed in a HAM (Horizontal Access Module) Chamber for the aLIGO (advanced Laser Interferometer Gravitational Wave Observatory) program. The quad photo detector is intended to monitor the SPI's (Seismic Platform Interferometer) stability. In order to comply with the advanced LIGO specifications, the pointing stability measurements were plotted against the HAM requirements for the advanced system.

II. Setup

A) Directing the Beam

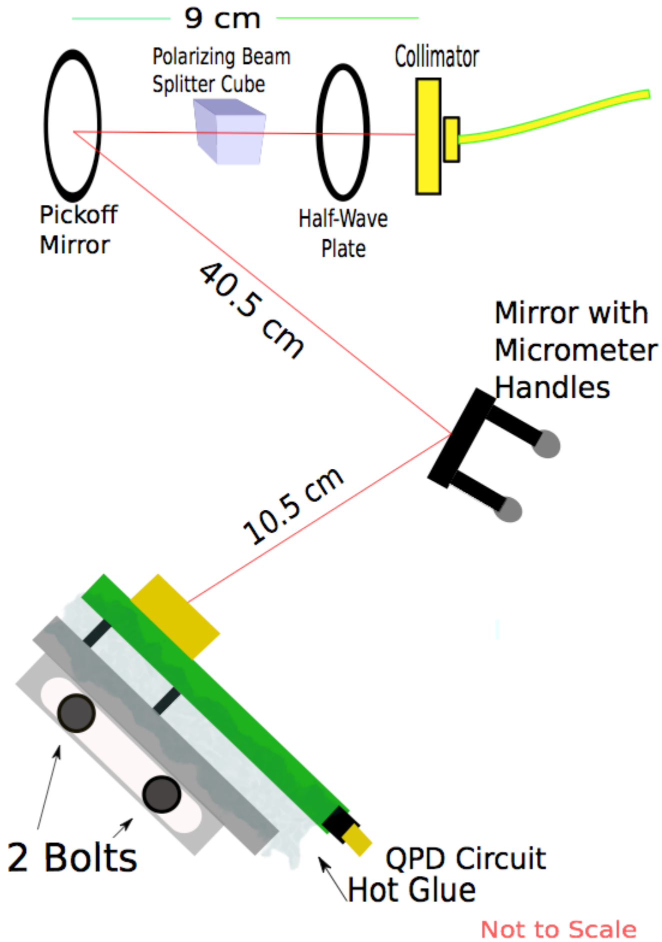
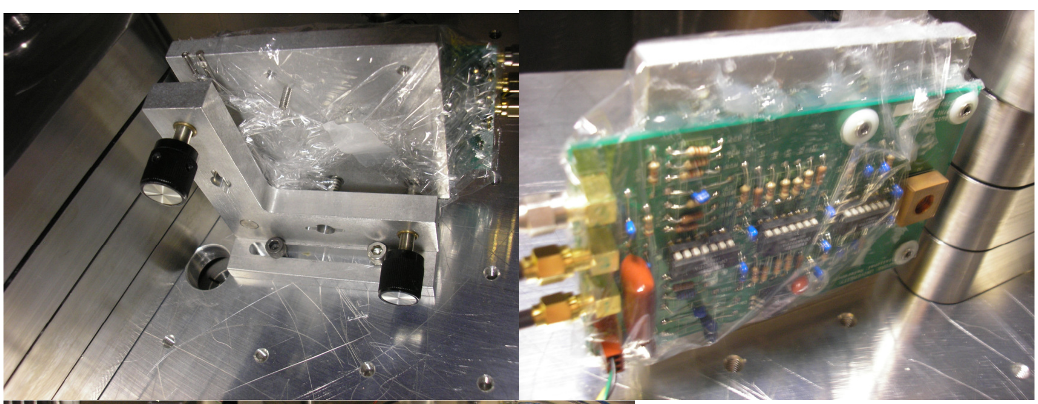


Figure 1: Setup
This diagram illustrates the setup on the optics table. The patch cord hooks up to the collimator. From there it proceeds through the half-wave plate and the polarizing beam splitter cube. The pickoff mirror then splits the beam into the SPI and towards the QPD. It is supposed to pick off 10% of the beam, but we have been obtaining lower power output than expected. The QPD circuit board is anchored to the table by being bolted and glued to a mount. The mount is then bolted to the table. The laser fiber was attached to the collimator with epoxy. The fiber was wrapped around a post before connecting to the collimator

B) Anchoring the Mount

Initially, the mount for the QPD circuit was anchored to a plate that was then bolted onto two construction cubes placed on pedestal. The pedestal was anchored to the optics table using a fork and one bolt. The circuit board was very unstable as a slight push on the edge farthest from the bolts would cause the board to vibrate. In an attempt to improve the stability of the mount, the circuit board was bolted to a more stable mount. Again, it was attached using four bolts, but hot glue was used to fill all of the gaps. Now, the board is much more stable and does not budge at all. Also, the mount allows for two bolts without the use of the fork, so it is bolted directly to the table. Saran wrap was placed around the circuit (the QPD remained open, so as not to allow for any interference) to prevent air currents from affecting the setup. Finally, aluminum foil was placed around part of the beam path to further minimize the air currents.



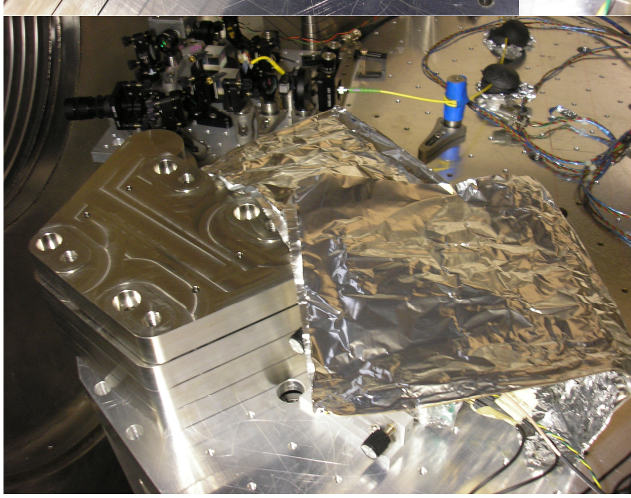
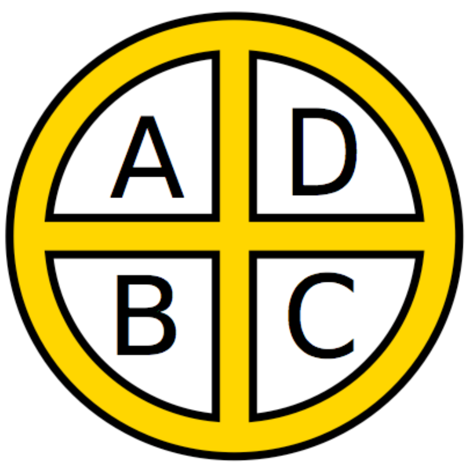


Figure 2: QPD Circuit
Images of setup. Rear, frontal, and overhead views. The first two images show the mount setup. The image on the left is an overhead shot showing the aluminum foil shielding.

C) Recording Data

The QPD circuit has SMA outputs for the X, Y and sum channels. See the illustration of the QPD for how X, Y, and sum signals are recorded. Power is fed to the circuit through a flange in the chamber. Using SMA to BNC connectors, the signals are fed out of the chamber and into the computer's Data Acquisition System (DAQ). Currently, the X and the Y signals are hooked up to circuit which provides a gain of 22. (with the option of setting the gain to 10.4 or 37.7). The gains are labeled on the circuit. It also converts the double input signal from the BNC to a single output for a LEMO connector. The LEMO connectors are then fed into two of the DAQ channels. The sum channel is fed directly into one of the DAQ channels, occasionally going through an SR560 with a preset gain of 20 so it can match the X and the Y signals. The data is then collected using the get_data function in MATLAB. The data is then analyzed and processed in MATLAB. Data was also collected using the SR785 and compared to the DAQ system data, but ultimately the final setup is and will continue to be connected to the DAQ system.



<u>Figure 3: QPD Detector</u>

X Signal = (A + B) − (C + D)
Y Signal = (A + D) − (B + C)
Sum Signal = A + B + C + D

The sum channel has a lower gain than the x and the y channels, so its values are less.

III. Calibration of the QPD

The X and the Y signals were calibrated in order to determine the change in radians per volt. This way, it is possible to correlate the change in voltage to a displacement of the beam. Using the micrometer knobs on the mirror, the position of the beam was changed on the QPD and the signal was recorded in volts using an oscilloscope. Below is the table of the data obtained.

Sum Signal (mV)	X Signal (mV)	X Micrometer Reading (mm)
76	920	3.90
82	860	3.95
84	700	3.98
88	580	4.00
94	360	4.03
96	260	4.05
94	-20	4.08
94	-120	4.10
92	-400	4.13
90	-560	4.15
88	-720	4.18
86	-820	4.20

Table 1: Data for the X Calibration

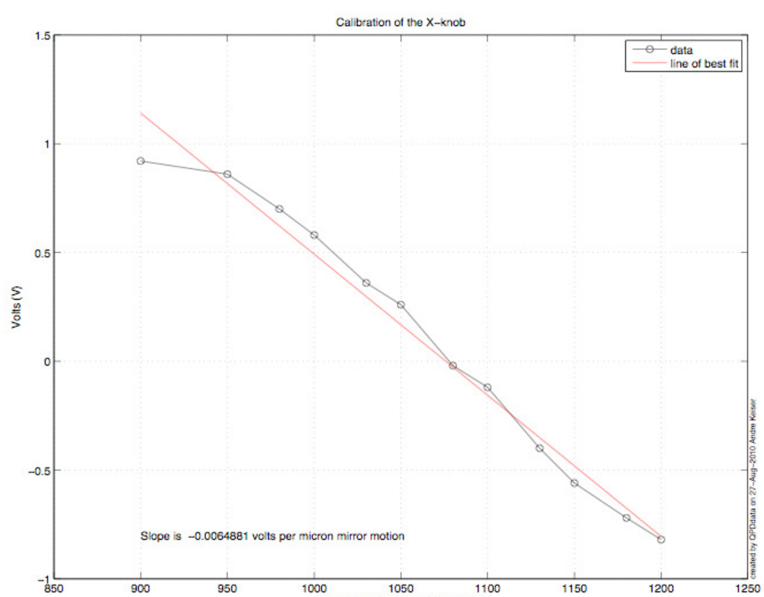


Figure 4: Plot of Volts vs. Microns for the X

Calibration. The slope of the line of best is -0.0064881 volts per micron mirror motion.

Sum Signal (mV)	Y Signal (mV)	Y Micrometer Reading (mm)
76	960	3.65
88	820	3.60
88	520	3.55
90	340	3.52
92	200	3.50
100	-20	3.47
94	-160	3.45
92	-380	3.42
90	-500	3.40
88	-640	3.37
82	-740	3.35
72	-840	3.30

Table 2: Data for the Y Calibration

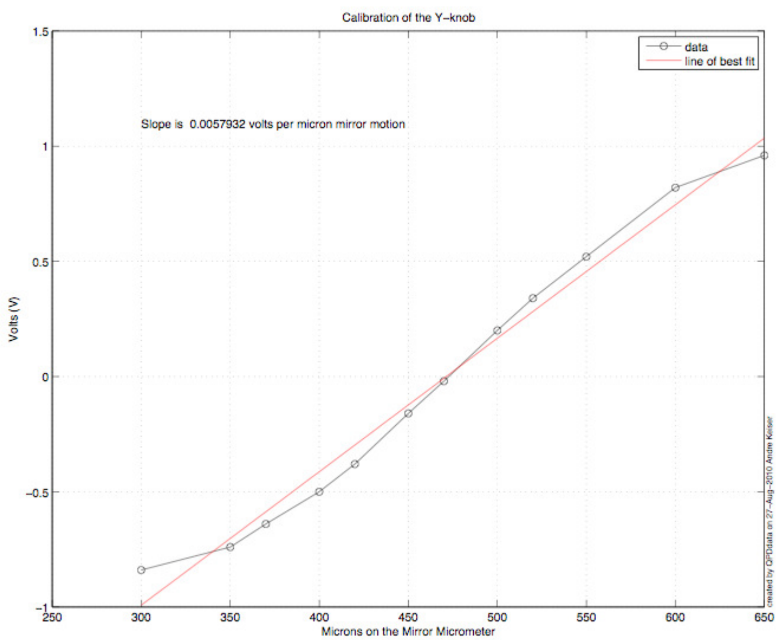


Figure 5: Plot of Volts vs. Microns for the Y Calibration. The slope of the line of best is 0.0057932 volts per micron mirror motion.

The calibrations are within 10% of each other, which seems reasonable. After the volts per micron of mirror motion fractions are calculated, the fraction is converted into radian per counts using the Borkspace gain (1605 counts per volt), the length of the laser, and the angle of reflection of the beam on the micrometer mirror. I used the small angle approximation for the angle of reflection. Note that if the angle of the mirror changes by θ, the angle incident on the detector will change by 2θ. The gain stage from the electronics box is also taken into account (currently, both the x and the y signal are set to roughly 22).

IV. Data

A) Validity of the data

The next step after running the calibration scripts is to examine the data and determine if it is fitting. The best way to go about this is to plot the time series (counts vs. seconds) and to look for unexpected spikes or humps in the data set. These spikes or humps could occur for a variety of reasons. Temperature cooling is possibly an issue as the data seems to oscillate in regular intervals of 3 hours. Noise issues were also addressed, but some still remain (such as the spikes at intervals of 1 Hz, probably due to some coupling of the power supply). For example, I was able to track down that the L-4C readout boxes caused spikes and humps at 18 Hz, 30 Hz, and 36 Hz. These were unplugged from the power supply and data was recorded, Improvements were seen at these frequencies, even though we are more interested in lower frequencies.

B) Time Series

The final data st was recorded during a period where the watchdog did not trip and the damping loops remained on throughout the entire time series. Below are the results. The average number of counts is removed from the time series.

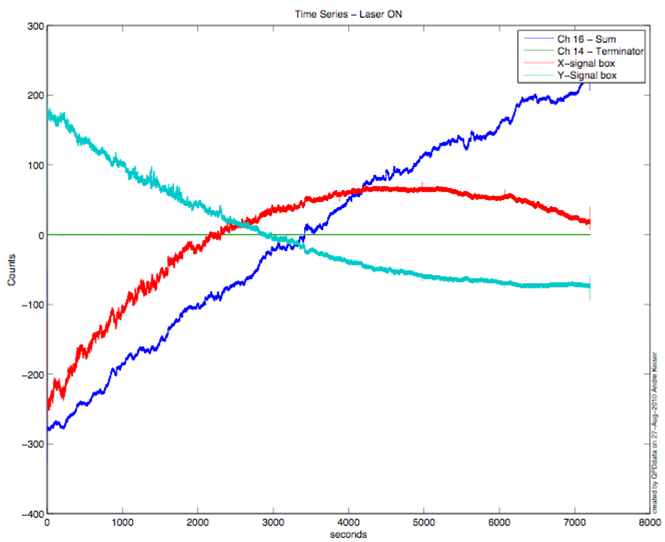


Figure 6: To the left is the complete time series for the final data set. The x and the y signals take 3000 seconds to stabilize. A probable cause is temperature stabilization.

To compensate for the temperature stabilization, part of the data was cropped. There was still over one hour of data, enough to look at lower frequencies.

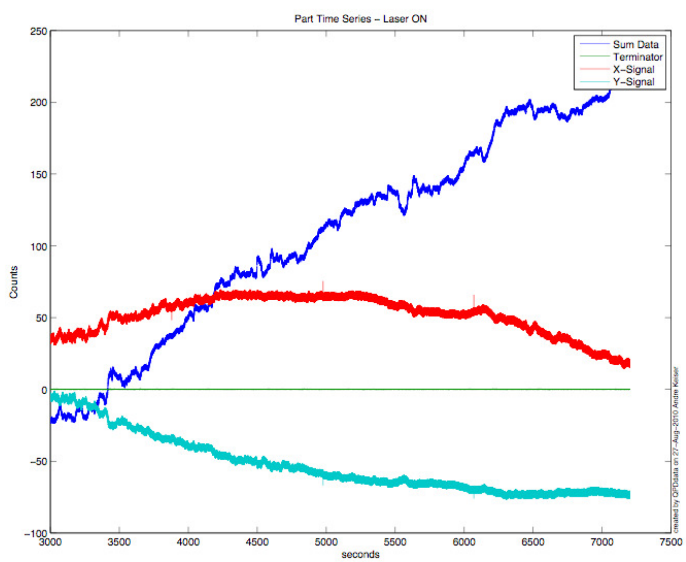


Figure 7: Here is the time series that was ultimately examined. The sum signal increases as the x and y signals stabilize. There are few minimal spikes in the data.

B) Data

The angular amplitude spectral density (radians/√Hz) was computed using MATLAB's power spectral density function (pwelch) and by multiplying the result by the previously determined radians/count constant. The goal for the ASD was to beat the second corner of the HAM requirements curve (a cue of 2.2^-10 at 0.6 Hz). The latest data set beats this requirement by a factor of 3.5 for the x signal and slightly less for the y signal. The terminator was placed on the DAQ system.

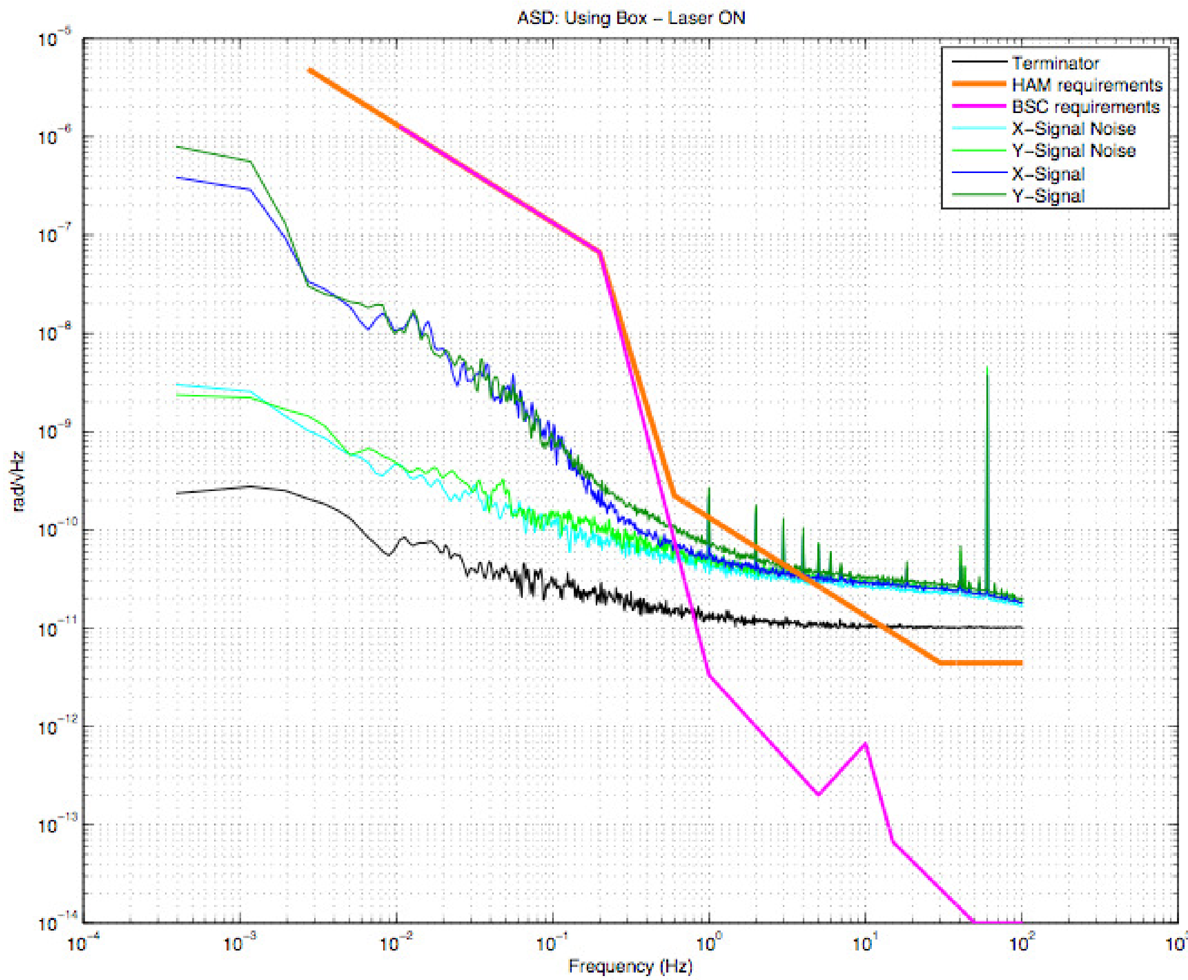


Figure 8: BSC requirements were plotted for reference. The noise measures all the electronics noise. The same data was taken, but with the laser fiber disconnected before the flange. The noise floor matches up with data where it crosses the HAM requirements curve at about 4 Hz.

C) Mount Comparison and Improvements

The new mount improved the ASD plots significantly, especially for the x signal, which was very unstable before the mount was bolted down tightly and glued. The saran wrap most likely limited air currents and also improved the data, but it was never tested with the old mount to determine the exact cause of the previous instabilities. The aluminum foil shielding was tested on the old mount and it improved the data slightly.

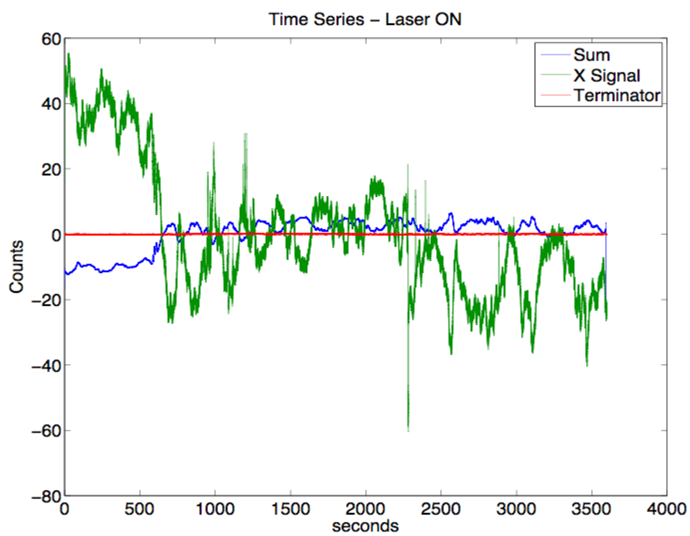


Figure 9: Here is an example of a time series before all of the improvements were made. Note how the data oscillates more and various spikes in the data appear.

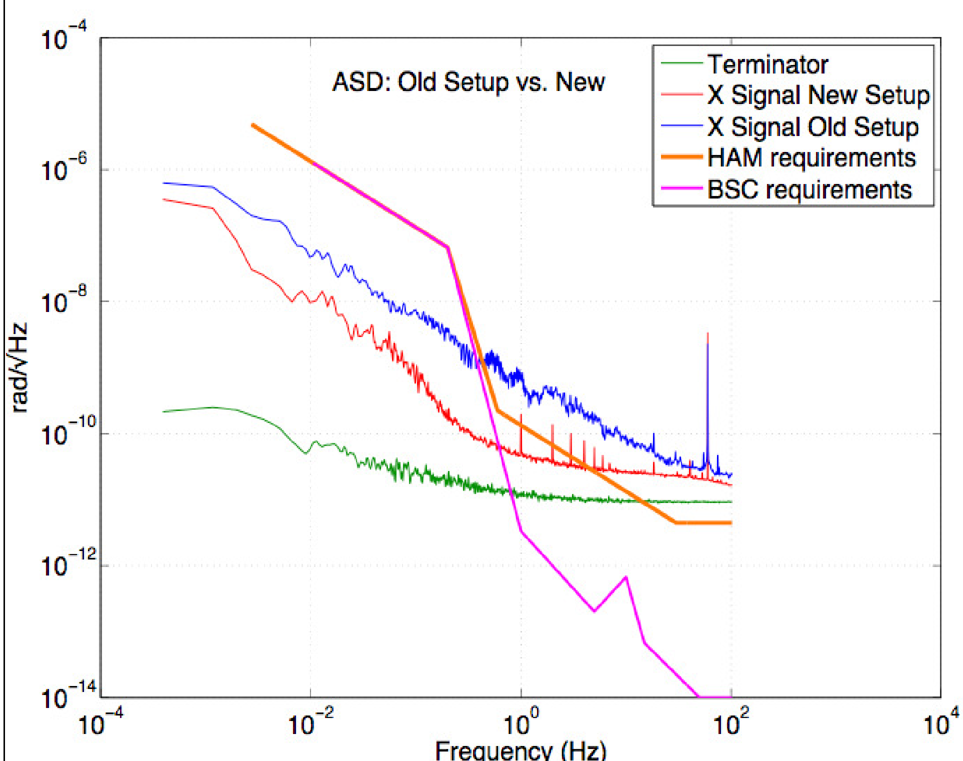


Figure 10: ASD plot comparing the two setups. Various improvements were made between the two data sets including the new mount, epoxying the fiber and tracking down noise problems.

V. Conclusion

The new and improved set up was ultimately able to beat the second corner of the HAM requirements curve, which was our initial goal. However, the system still seems to be limited by the electronics noise at higher frequencies and this could be improved upon. I designed a new QPD circuit to help improve the noise. It is uploaded to the ELOG. Many other improvements could be made.

It would be interesting to turn on the vacuum and take another data set to compare to the current one. Previously, the vacuum improved the results by a few factors. However, the table has been quite chaotic in the past few weeks, so I was not able to test it with the new setup.

It is sometimes difficult to tell what actually improved the system because problems were encountered in the installation, but many were eventually fixed. The new sturdier mount certainly improved the data and epoxying the fiber seems to have helped too.

A next step would be to track down the cause of the spikes at 1 Hz intervals, which are coupled into the power supply. These are showing up in all of the SPI data. Also, a larger QPD would help with the calibration of the system and hopefully improve the consistency of the data.

The data continues to be inconsistent over long period of times. It was necessary to crop out the first 3000 seconds of the data set because of a large oscillation. We believe this may be due to temperature oscillations because we monitored the temperature sensors and they seem to fluctuate fairly regularly in a period of three hours. It would be beneficial to investigate this further and determine what the exact cause of fluctuations is and then address the problem. Ideally, the data would have few unpredicted alterations so that there would be no need for cropping the time series.