LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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Seismometer Isolation for Noise Cancellation at 40m Interferometer

SURF2016 Progress Report I

Aakash Patil

California Institute of Technology
LIGO Project, MS 18-34
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project, Room NW22-295
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
Route 10, Mile Marker 2
Richland, WA 99352
Phone (509) 372-8106
Fax (509) 372-8137
E-mail: info@ligo.caltech.edu

LIGO Livingston Observatory
19100 LIGO Lane
Livingston, LA 70754
Phone (225) 686-3100
Fax (225) 686-7189
E-mail: info@ligo.caltech.edu

http://www.ligo.caltech.edu/

1 Introduction

The existence of Gravitatonal Waves, as predicted in 1916 by Albert Einstein, was succesfully detected for the first time on 14th September 2015[2]. Experiments to detect gravitatonal waves using resonant mass detectors began in the 1960s, whereas those with long baseline laser interferometers were proposed in the early 1970s. By the early 2000s, a set of initial detectors were commissioned which included TAMA 300 in Japan, GEO 600 in Germany, LIGO in United States and Virgo in Italy. Combinations of these detectors started to make joint observations on a variety of gravitational-wave sources while evolving into a global network[1]. In 2015, Advanced LIGO became the first of a significantly more sensitive network of advanced detectors to begin observations. It detected two gravitational wave events, one on 14th September 2015 and the other on 26th December 2015.

LIGO stands for the Laser Interferometer Gravitational-Wave Observatory which consists of two widely separated interferometer installations within the United States one at Hanford,Washington and other at Livingston,Louisiana. Figure 1 shows a simplified diagram of an Advanced LIGO detector. A gravitational wave propagating orthogonally to the detector plane and polarized parallel to the 4-km optical cavities will have the effect of lengthening one 4-km arm and shortening the other during one half-cycle of the wave; these length changes are reversed during the other half-cycle, and the output photodetector at the antisymmetric part records these differential cavity length variations from which we can infer information about the gravitational wave that caused this variation [2].

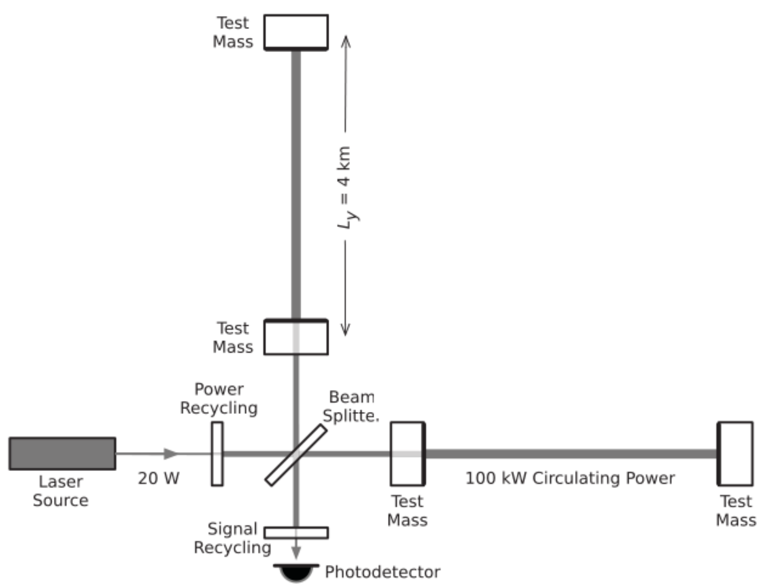

Figure 1: Simplified diagram of an Advanced LIGO detector

2 Motivation and Overview

LIGO is one of the most sensitive experiments ever built, which requires unprecedented levels of isolation from seismic noise. The seismic noise can be measured with the help of seismometers, which work on the principle of a spring mass system. For a seismometer to provide accurate readings, they must be very well isolated from the environment. Any disturbance from the environment, which comprises of thermal and electro-magnetic fluctuations among others, may lead to errors in readings and therby cause obstruction to working.
Though seismometers are made to respond to and record seismic energy, environmental factors like temperature, atmospheric pressure and electro-magnetic interference may add noise to the seismometer readings. Optimally, these sensors should be installed in an enclosure that effectively controls environmental variables such as temperature and humidity. For example, an enclosure in the form of a vault would provide better isolation to the seismometer. So, during this summer, I will develope and test an enclosure for isolating a seismometer from thermal and electromagnetic fluctuations at LIGO 40m lab. If LIGO can accurately measure and reduce its seismic noise, a greater range of phenomena will be available for study at low frequencies.

3 Objective

The objective of this summer project is the development of enclosures for the seismometer at the LIGO 40m lab so as to protect it from environmental fluctations. Insulative enclosures will be developed to isolate the instruments from external thermal and electromagnetic fluctuations. This technology will be applied to the aLIGO detectors to improve low frequency sensitivity to astrophysical events, and progress made on seismic cancellation will be used to adaptively reduce other noise sources

4 Work done so far

4.1 Temperature Measurement

Temperature measurement can be done either by thermocouples or resistance temperature detectors. Thermocouples consist of two wires of different metals connected at two points. A voltage is developed between the two junctions in proportion to the temperature difference between them. On the other hand, resistance temperature detectors(RTD) are simply resistors whose resistance is significantly affected by temperature. It is better to use a resistance temperature detector based integrated circuit for temperature measurments since they are simple in operation as well as robust in design and give accurate readings without any complex setup unlike a thermocouple which may require a cold junction arrangement for accurate readings. While selecting a resistance temperature detector type transduce IC, it is better to select one which provides an output current ptoportional to absolute temperature. Initially, I selected a RTD which needs a constant current source for giving a voltage output proportional to temperature. So for constant current source, after a few iterations, I made the electronic circuit design which is shown in figure 2. It is complicated to design a constant current source, and hence it was decided that it is better to select a temperature transducer IC which works on a specific voltage range. I selected AD592 which is a high precision temperature transducer IC which provides an output current proportional to absolute temperature [5]. Its features include high accuracy, minimal self heating and excellent linearity.

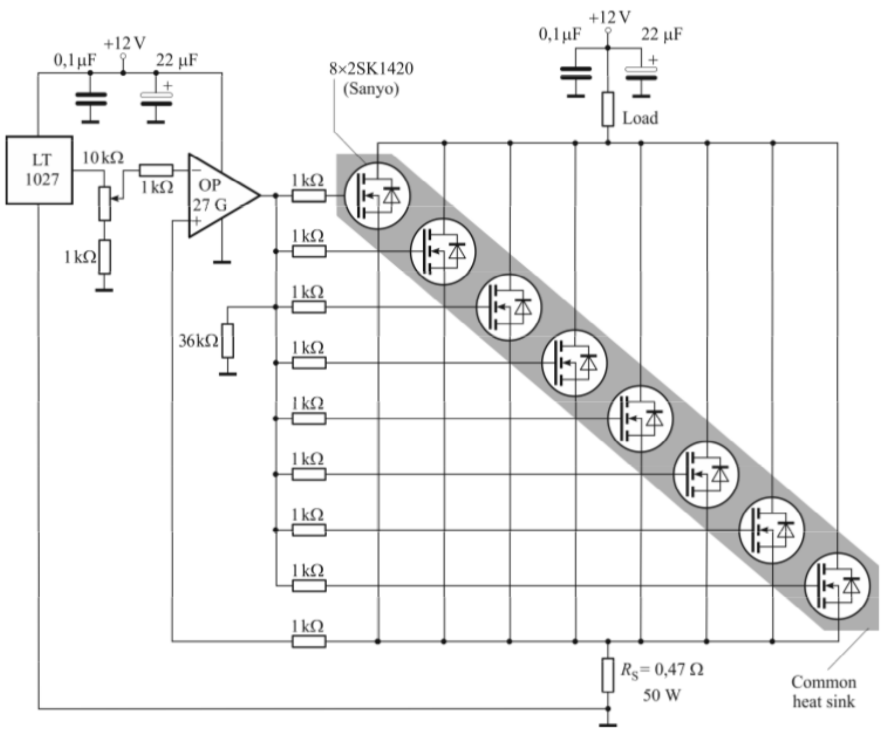

Figure 2: Electronic Circuit for a Constant Current Source

4.2 Acquiring and Storing Data

The experimental data acquision process should be digital so that data can be easily retrived and analysed as well as to integrate with the existing digital control system at the LIGO 40m lab. I have been working to use Acromag BusWorks data logger card for recording data from my experiment. Acromag BusWorks is an ethernet I/O card with 8 analog channels and 4 digital channels. Figure 3 shows the setup I am using currently which consists of the Acromag BusWorks card, Raspberry Pi Model B and a power supply.

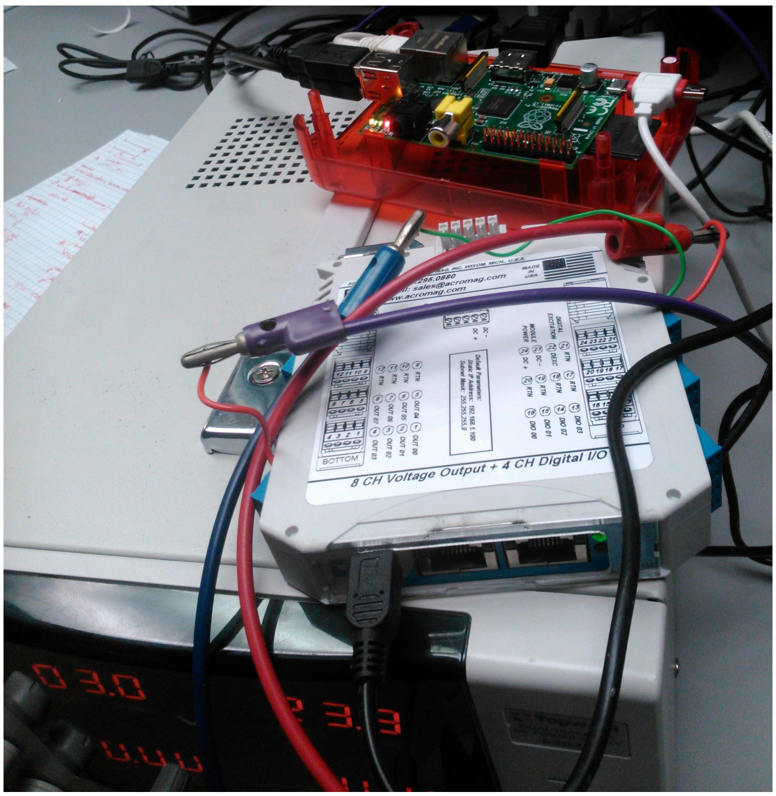

Figure 3: Photograph of DAQ Setup

First I configured the acromag busworks card using the usb configuration setup mentioned on model XT 1541-000's manual. For inital setup, a windows machine needs to be used. Initial setup consists of assigning a static ip address to this card as well as testing the channels. Since this card requires modbus TCP/IP for operation, I used a raspberry pi model B to setup and use this card over ethernet. I also installed EPICS(Experimental Physics and Industrial Control System) on raspberry pi which is a set of open source software tools, libraries and applications developed collaboratively and used worldwide to create distributed soft real-time control systems for scientific instruments such as a particle accelerators, telescopes and other large scientific experiments.

4.3 About Existing Enclosure

The existing enclosure for seismometer at LIGO 40m lab is simply a cylindrical stainless stell can placed upside down over the seismometer. It is shown in figure 4. It has more empty space between the seismometer and the internal surface of enclosure which is not desirable. Stainless steel has a thermal conductivity in the range of 16.3 to 16.7 Watts per meter per kelvin and magnetic permeability 1.260e-6 Henries per meter [3] [4].

Figure 4: Photograph of Existing Enclosure for seismometer

The rate of heat transfer by a cylinder through conduction is given by :

$$Q = \frac{2\pi kl(T_1 - T_2)}{ln(r_2/r_1)}$$

where k is the thermal conductivity of material, L is the length of cylinder, r_1 and r_2 are inner and outer radius of cylinder respectively and T_1 and T_2 are temperature on inner side and outer side of the enclosure respectively.

The attenuation coefficient of a cylinder is given as :

$$\eta = \frac{9\mu}{(2\mu + 1)(\mu + 2) - (\frac{a}{b})^3(\mu - 1)^2}$$

where μ is the magnetic permeability of the material and a and b are inner and outer radius of cylinder respectively.

Assuming an ambient temperature 298K, and the temperature inside the enclosure as 295K, as well as substituting all the values for dimesions and material properties of existing enclosure,
k=16.4 W/mK
μ=1.260e-6 H/m
L=2ft=0.6096m
b=r_2=0.5ft=0.1524m
thickness=5mm
a=r_1=0.1474m

Thus we obtain the value of attenuation coefficient=5.953584e-05 and the value of rate of heat transfer= 5.64913 kW.
For studying the variation of rate of heat transfer and attenuation with the thickness of enclosure material, I have plotted the following graphs in Figure 5 and Figure 6 for different materials which include hardened stainless steel, aluminium, pure iron and nanoperm-muMetal [6].

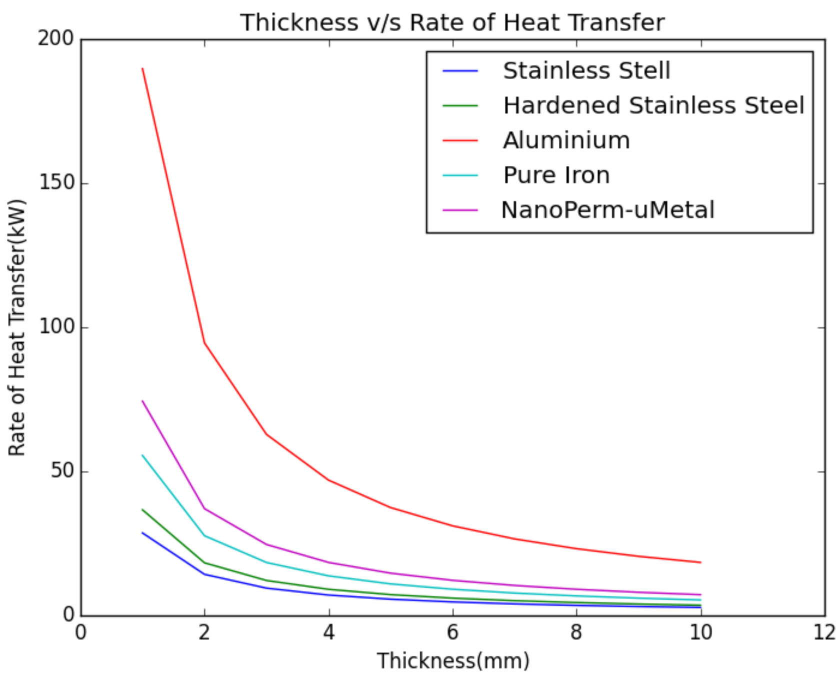

Figure 5: Plot of Thickness v/s Rate of Heat Transfer

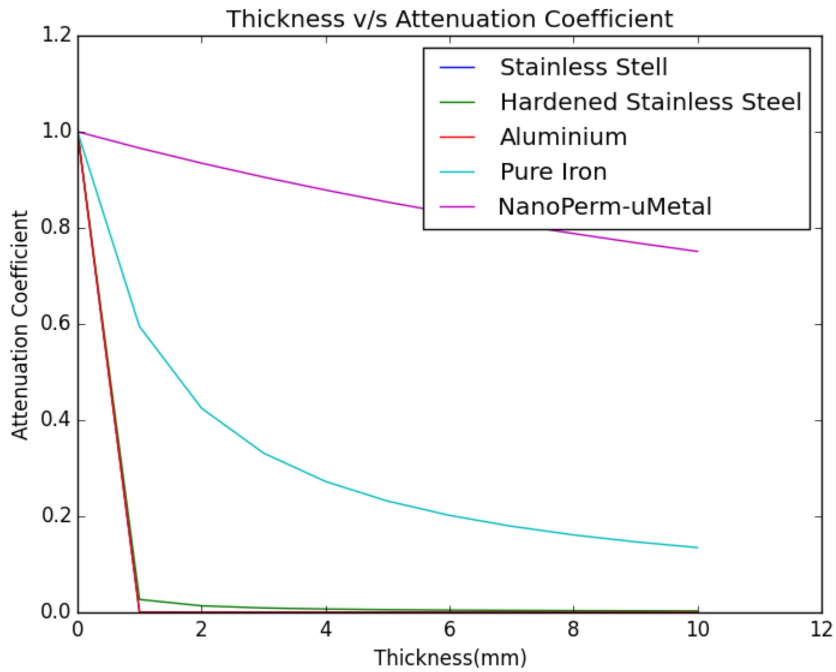

Figure 6: Plot of Thickness v/s Attenuation Coefficient

5 Future Work

1.DAQ Work
I need to test the Acromag Busworks card for acquiring data. If I don't suceed in another three days, I will try to use some other easily available DAQ card and then try to configure this Acromag BusWorks card throughout the summer.

2.Temperature Circuit
Within next few days, I will develop a differential temperature measurement circuit so that I can measure accurate temperature inside the enclosure.

3.Enclosure Design and Material Selection
I have not considered the conductive heat transfer in my calculation. So I will try to incorporate the conductive heat transfer terms while selecting material for enclosure. I am also thinking of applying some coating on the surface of this material. About new design of enclosure, I am planning to make it smaller, just enough to accomodate the internal insulation and the seismometer because it is better to leave less empty space inside the enclosure as more empty space may lead to development of air currents. Also, I will select and use a suitable insulating material in addition to enclosure material.

4.Component Placement
Sharp corners may lead to higher turbulent kinetic energy inside enclosure's free space. Hence to avoid any sharp corners and to maximize the internal surface area, I will make a proper

placement of enclosure's internal compenents. I would also like to perform a fluid and heat transfer simulation for design of enclosure and correct the design parameters if any.

References

[1] J. Houghet al. *Proposal for a joint German-British interferometric gravitational wave detector* MPQ Technical Report 147, No. GWD/137/JH(89), 1989

[2] B.P.Abbott et al., *Observation of Gravitational Waves from a Binary Black Hole Merger.* Physical Review Letters February 2016

[3] *http://www.goodfellow.com/E/Stainless-Steel-17-7PH.html*

[4] *http://www.bssa.org.uk/cms/File/SSAS2.81-Magnetic20Properties.pdf*

[5] *http://www.analog.com/media/en/technical-documentation/data-sheets/AD592.pdf*

[6] *http://www.magnetec.de/en/nanopermr-products/technical-data-nanopermr/*