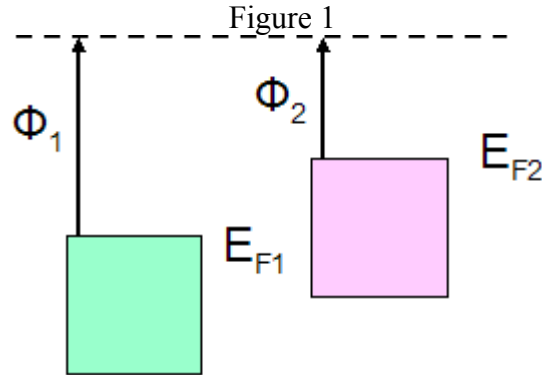


Vacuum Kelvin Force Probe Research
Richard Williams
August 1st 2008

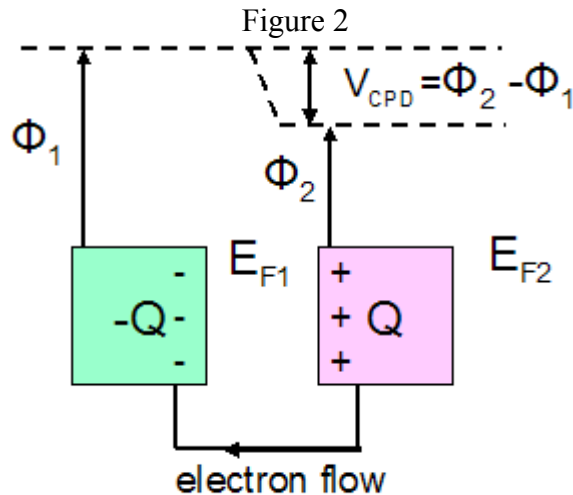
Introduction

Kelvin Force Probe Microscopy is an analytical method to measure the contact potential difference between a reference material and a sample which depends on the work function of the materials being studied^[1]. The contact potential difference is measured as the difference in work function of the reference material: the tip of the Kelvin Probe, a non-contact vibrating capacitor used to measure work functions; and the sample material^[2]. The work function of a material is defined as the minimum energy required to remove an electron from the bulk of the material and is measured in electron volts, the work function is also known as the Electrochemical Potential^[3]. Figure 1 shows two conducting specimens where ϕ_1 and ϕ_2 are the work functions of the materials and E_{F1} and E_{F2} are the Fermi levels of the respective materials.



Two disconnected conducting specimens.

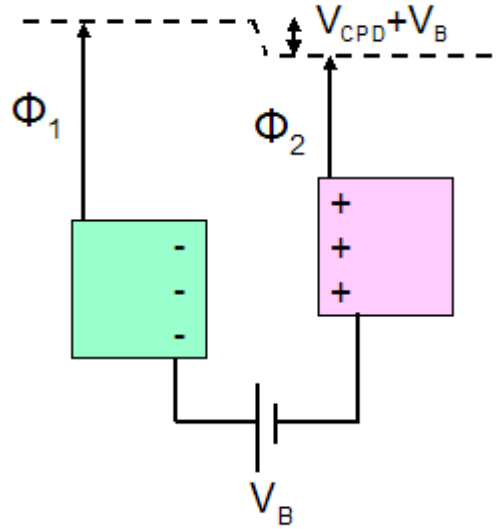
Once the specimens are brought into electrical contact the Fermi levels equalize and the contact potential V_{CPD} is produced. The direction of the electron flow and the resultant contact potential is shown in Figure 2.



Conducting specimens are connected and the contact potential is produced.

The contact potential difference is measured as the difference in work functions when the tip and sample are brought into electrical contact^[4]. The inclusion of an external backing potential V_B is used to favor one electrode over the other, the effect of which is shown in Figure 3.

Figure 3



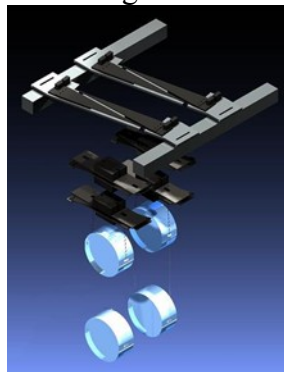
Specimens with external backing potential to favor one electrode.

The equation for capacitance for the vibrating tip and the sample can be written as $Q = C(V_{CPD} + V_B)$.

Motivation

The purpose of this research is to measure the contact potential difference at different locations on a sample. This research will further understanding about how charge distributes on surfaces of certain materials which can be quite useful in the building and designing of Laser Interferometers such as LIGO and VIRGO. The optics used in LIGO are subject to feedback techniques to keep the optics in line in order to detect gravitational waves, such techniques include magnets to move the optics back into position if disturbed and frame structures to prevent the optics from flailing wildly. Examples of the suspended optics and the frame structures are given in Figures 4 and 5 respectively.

Figure 4



LIGO Monolithic Suspension

The suspension shown in Figure 4 is used courtesy of University of Glasgow.

Figure 5



Optic Frame Structure.

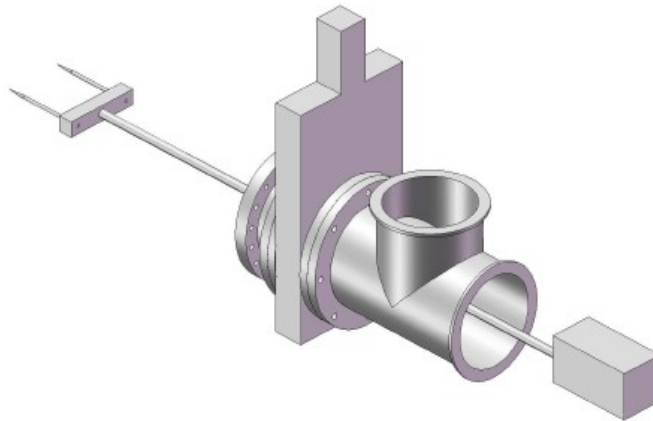
The optic frame structure in Figure 5 is used courtesy of Caltech. Any motion could send the optics toward the frame structure and if an accumulation of charge were on the surface of the optics, they would stick to the frame structure and the entire detector would have to be stopped in order to prise the optics away. This proves to be quite a nuisance in the detection of gravitational waves. The use of Kelvin Probe Microscopy can determine how charge accumulates on the materials used to make the optics used in the detectors.

Experimental Setup

The Vacuum Kelvin Probe experimental setup requires a 3-axis stage setup to move a sample up to the Kelvin Probe and then perform a 2D scan. The first hurdle was to design the vacuum chamber to house the stages and probe. Upon arriving in Glasgow the main chamber was already built but there was still the issue of loading samples. The lid to the main chamber would have to be removed to place a sample into the chamber, due to the size of the chamber this would prove to be a very laborious activity. In order to make loading and removing a sample easier and less costly, time wise, a sample loading chamber had to be designed. A separate chamber added to one of the ports on the main chamber could be used to place and remove samples without having to remove the heavy lid to the main chamber, the sample could then be pushed into the main chamber onto the 3-axis stages.

The sample loading chamber was designed with the CAD program Solidworks®, incorporating a gate valve and sample loading rod. The gate valve is used to keep two separate vacuums, one in the main chamber at a pressure around 1×10^{-7} Torr and the other in the sample loading chamber at a pressure of approximately 1×10^{-3} Torr. The sample would be loaded into the sample loading chamber with the gate valve open, the system would then be pumped down to 1×10^{-3} Torr at which point the gate valve would be closed. Once the main chamber was pumped down to 1×10^{-7} Torr the gate valve would be opened and the sample pushed into the main chamber with the sample loading rod, the design is shown in Figure 6.

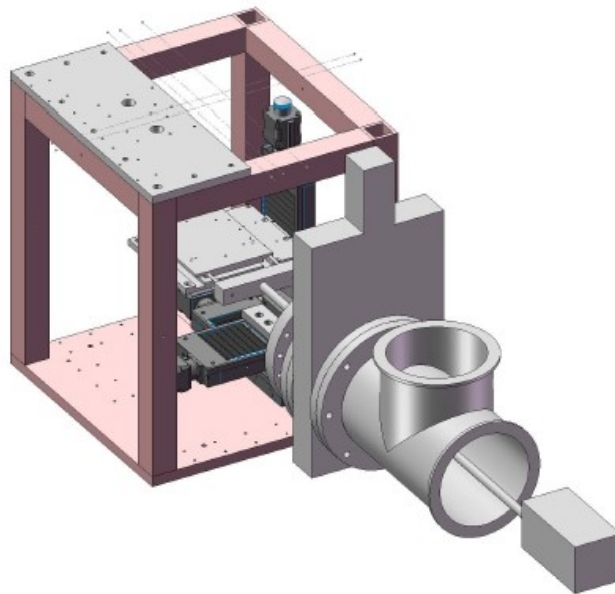
Figure 6



Sample loading chamber with loading rod.

The sample would be placed on a top stage and loaded onto the fork end of the loading rod through the top port, once the main chamber reached the proposed pressure the fork would push the stage and sample into the main chamber and onto the 3-axis stages. This mechanism is shown in Figure 7.

Figure 7

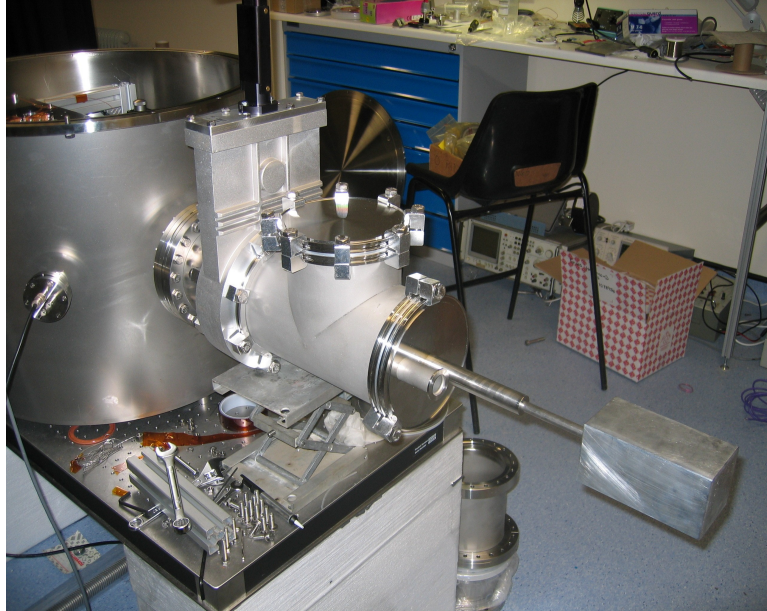


Sample loading chamber loading sample stage onto 3-axis stages.

The designs shown in Figures 6 and 7 are missing an end piece through which the sample loading rod would enter the sample loading chamber. The end cap was designed with careful consideration of O-rings and dynamic seals. Given the size of the rod and the type of seal required to maintain the desired pressure in the sample loading chamber an O-ring size can be determined and the grooves in which to

place the O-rings are determined by the cross-sectional area of the O-ring and the amount of compression the O-ring would undergo due to the vacuum. Figure 8 shows the completed vacuum set up with sample loading chamber and end piece, the end piece consists of a flange with two rods protruding from it. The sample loading rod is loaded through one and the other is used to connect a pump and valve so that the vacuum in the sample loading chamber can be changed without affecting the vacuum in the main chamber.

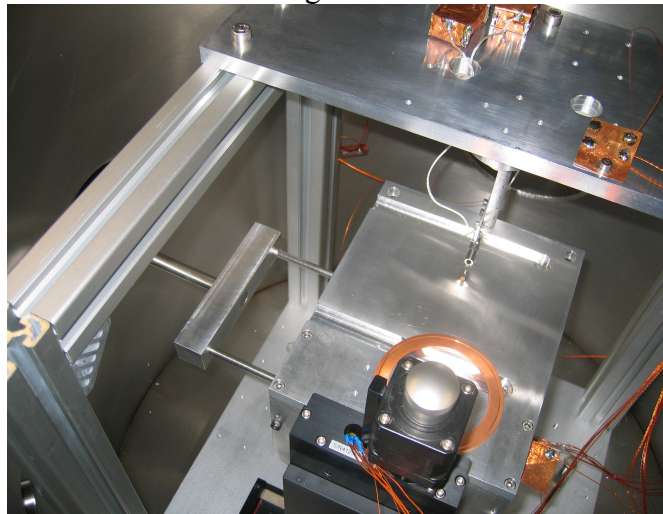
Figure 8



Completed sample loading chamber.

The Kelvin Probe was mounted on the frame with the 3-axis stages directly below as shown in Figure 10.

Figure 10

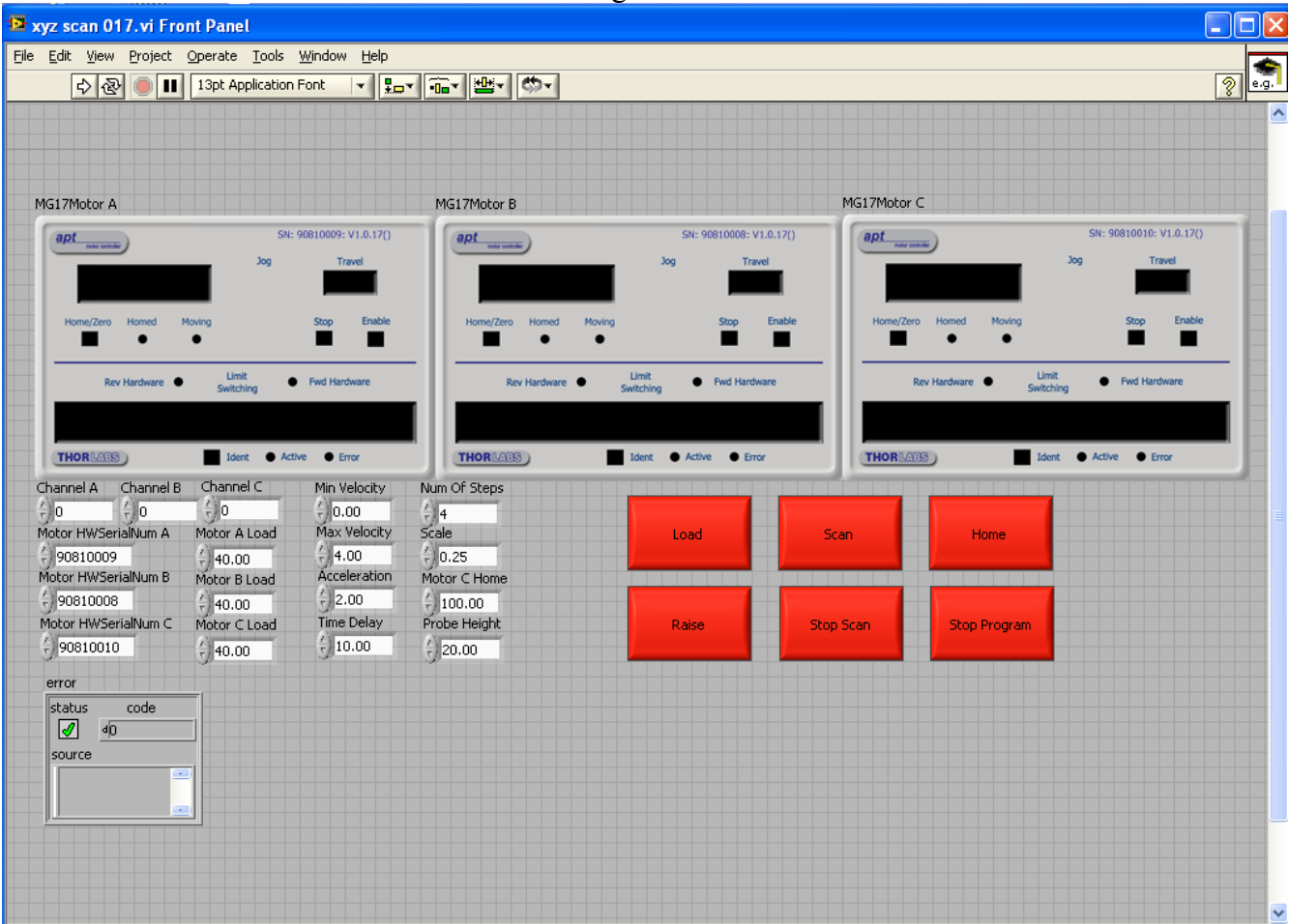


Kelvin Probe mounted above 3-axis stages with Sample Loading rod in main chamber.

The next step was to create a program in LabVIEW® to automate the 3-axis stages. The program would need several features including: a predefined loading position to receive the sample; the ability to raise

the sample to the Kelvin Probe; and perform a 2D scanning motion. Figure 11 shows the program interface.

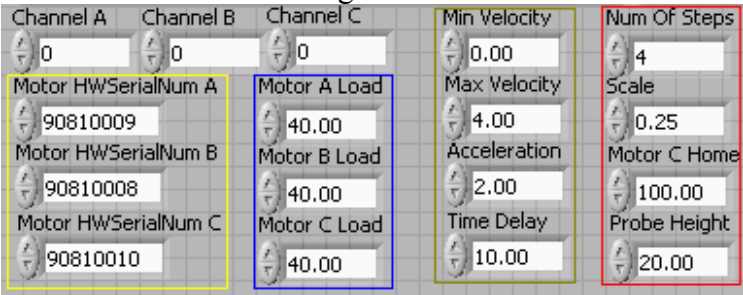
Figure 11



LabVIEW Program Interface.

The program shows an Active-X control for each stage as wells as six buttons to perform the necessary operations. Figure 12 shows the dialog boxes that can be used to customize the operations of the program if needed.

Figure 12



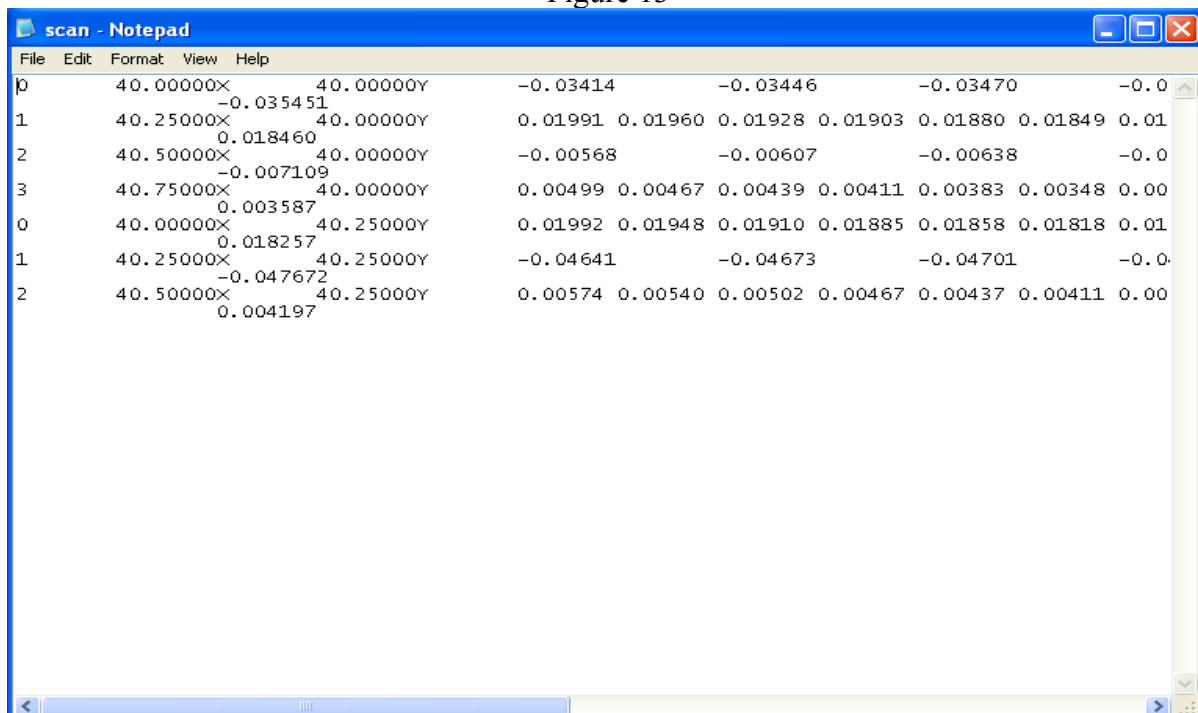
Input options.

The options in the yellow rectangle labeled *Motor HWSerialNum* allow the user to define the serial numbers for each of the three stages used. The options in the blue rectangle define the load position in

millimeters of each stage used in the Loading operation. The green rectangle contains options for controlling the velocity and acceleration of the stages as well as a time delay feature, the time delay is used during the 2D scan to pause the stage motion for taking measurements with the probe. The red rectangle has options to define the number of iterations of the 2D scan (*Num of Steps*), the scale of each movement in millimeters, as well as the *Probe Height* option to raise the Z stage towards the Kelvin Probe.

The program prompts the user to save a .txt file of the data acquired from the Kelvin Probe which records the X and Y position of the stages and ten voltage readings per position, from this the user can easily see any change in charge and the location of that charge on the surface of the sample, and example of the output file is show in Figure 13.

Figure 13

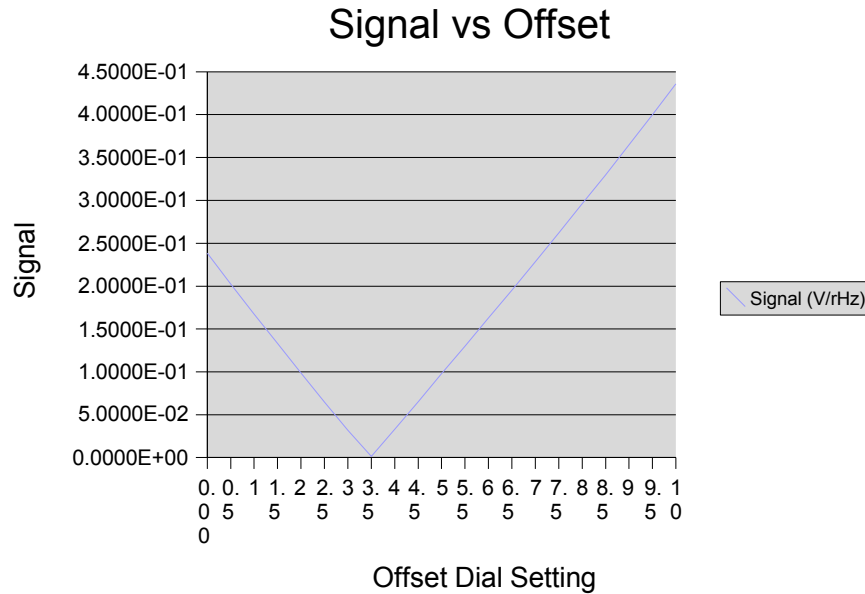


Example output file from 2D scan.

Results

The first test of the Kelvin Probe and Control box brought about a few questions. The Control box has an offset dial that ranges from 0 to 10 (-5V to 5V) that reduces the backing potential so that the probe measures just the contact potential, to see how this dial worked the signal in V/rHz of the Kelvin Probe at resonance was compared to the setting of the offset dial using a Spectrum Analyzer. Figure 14 shows the results which take the form of what appears to be an absolute value function.

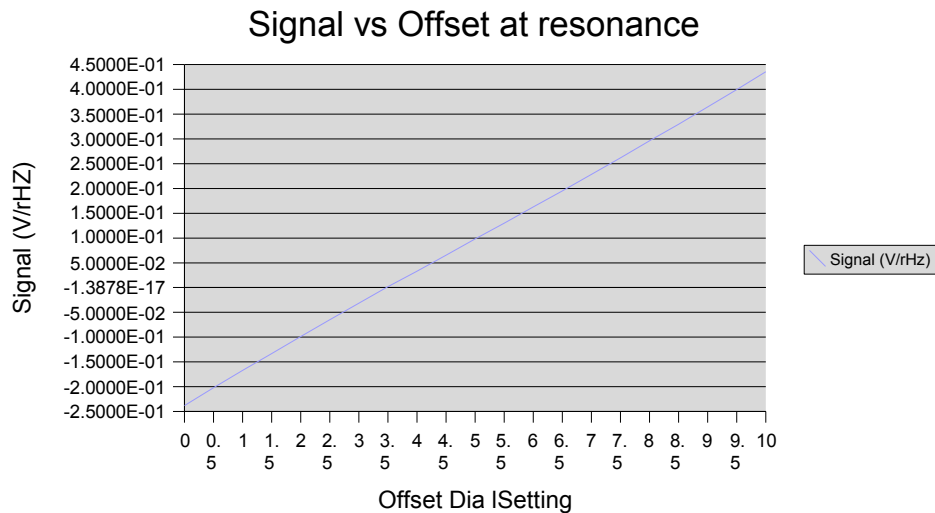
Figure 14



Signal at KFP resonance vs Offset dial setting.

Figure 13 brought about the question of what is the gradient of the signal at resonance versus offset, the data was converted from an absolute value function to a linear function and graphed in Figure 15.

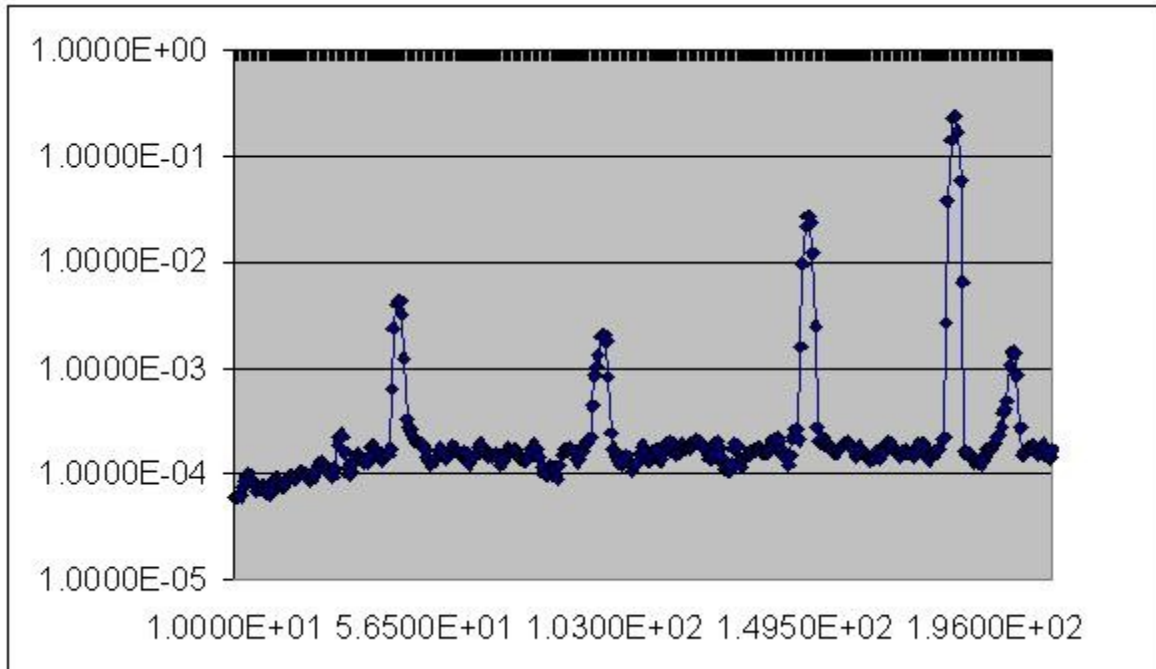
Figure 15



Signal vs offset as a linear function.

The gradient was determined to be approximately 6.72×10^{-2} V/rHz / Vdial. This gradient can then be used to evaluate how noisy the signal coming from the Kelvin Probe is. Taking data from the Spectrum Analyzer for one of the offset settings shows the signal coming from the Kelvin Probe where the largest peak is the resonance frequency of the probe. Data taken for the offset dial at 0 is shown in Figure 16.

Figure 16

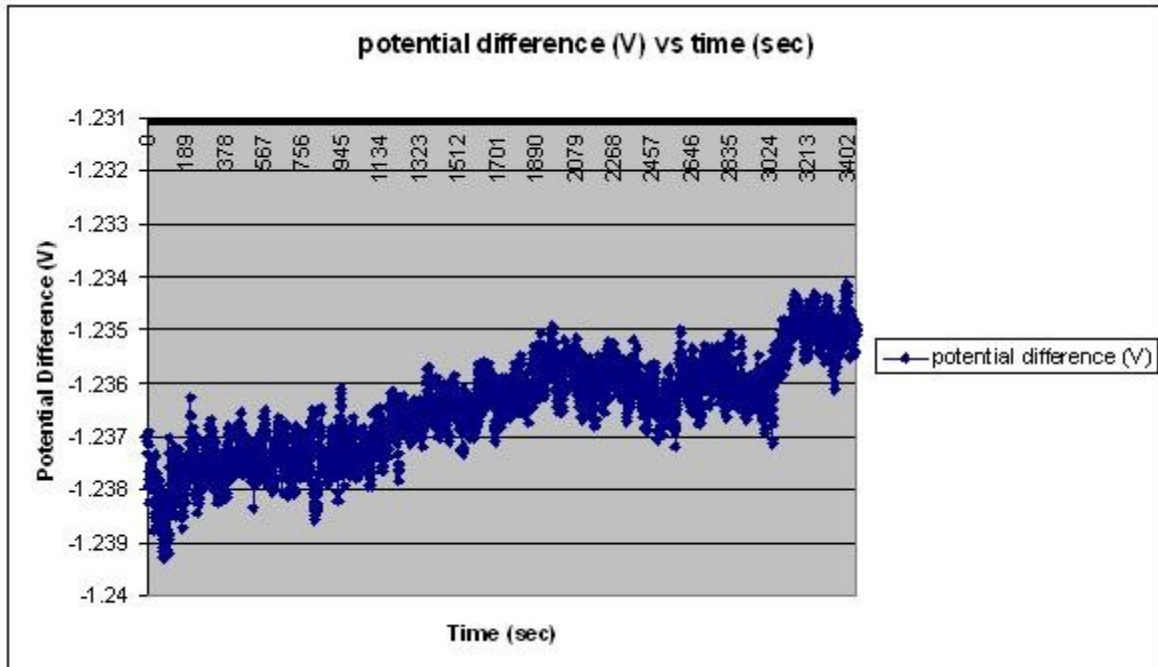


Signal from Spectrum Analyzer with Offset dial set to 0.

Below the obvious peaks the signal is quite noisy, by taking one of these points and dividing by the gradient the noise sensitivity is determined to be approximately $2.4 \times 10^{-3} \text{ V/rHz} / \text{rHz}$. For 1 second this yields a noise sensitivity of approximately 2.4 mV which according to the Kelvin Probe manual is within the realistic range of operation.

The Kelvin Probe is a piezo driven vibrating Gold tip, the work function of Gold is easily found in reference. The stage that samples rest on is made of Aluminum, the work function of which is also readily available in reference materials. Knowing both of the work functions between the materials one can predict the readings from the Kelvin Probe to determine if the probe is working properly. The first readings taken with the Kelvin Probe were of an Aluminum sample for a period of approximately 1 hour. This test was taken to see how the readings would change during time and results are shown in Figure 17.

Figure 17

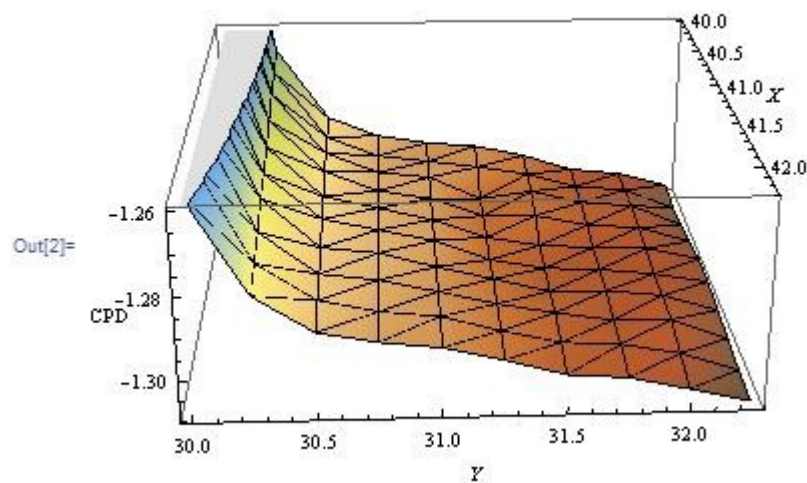


Gold-Aluminum CPD reading over time.

The Kelvin Probe is designed to take quick readings for short amounts of time as long readings could deposit charge on the sample, from the data presented in Figure 17 there is slight drift as time progresses. The contact potential difference changes as time goes on which would support the information stated previously.

Prior to leaving Glasgow a preliminary 2D scan was taken on a 2.25mm x 2.25mm square of Aluminum. The program records the X and Y position of the stages and takes 10 readings with the Kelvin Probe at each position, the average contact potential difference at each position is shown in Figure 18.

Figure 18



3D Plot for Gold-Aluminum 2D scan.

From the plot in Figure 18 it is clear that the contact potential difference between Gold and Aluminum was different at different locations on the Aluminum.

Conclusions

Preliminary tests with the Kelvin Probe show promise. Although it was believed there were problems with the probe such as too noisy of a signal, after further investigation it is true that the probe is working within factory specifications. The data presented in Figures 17 and 18 show why this project is important, whether it be due to time or other means charge accumulates on objects and in different locations. It is important to those in the field of detecting Gravitational Waves that the behavior of charge on the suspended optics is known and methods to combat it's accumulation are perfected.

Future Plans

This assignment was the preparation and calibration of a Vacuum Kelvin Probe system. The measurements taken and presented are just preliminary measurements, with future work being on silica samples such as those used in the LIGO suspended optics. From these tests more experiments on how to better clean the optics will arise, such methods as Plasma Cleaning or UV light exposure.

References

- [1] <http://www.kelvinprobe.info/technique/technique.html>
- [2] <http://www.kelvinprobe.info/>
- [3] Giles Hammond, Research with a Vacuum Kelvin Probe, Thermal Noise Meeting 29 November 2007.
- [4] <http://www.kelvinprobe.info/technique/theory.html>