Noise Analysis on a DCRC Board

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Abstract

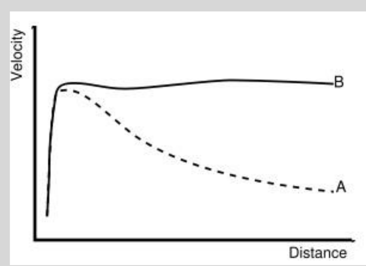
This project branches off of the Super Cryogenic Dark Matter Search collaboration (SuperCDMS) and involves analyzing the effect that environmental noise has on a Direct Control and Readout Card, or DCRC board. Sources of noise can come from lights, pumps, air conditioning units, electronics, and many other places. The method used here takes a signal measurement in a lowest possible noise environment and compares that to various situations of different noise. Once it is understood how noise affects the board, steps will be taken to eliminate those sources whether by shielding or otherwise. Ultimately, SuperCDMS will be able to use DCRC technology in its experiments and the researchers will be aware of how the signal they receive is affected by noise.

Background

The observed rotational velocity of galaxies does not match the predicted rotational velocity. The prediction is based on the mass of a star and its distance from the galactic center.

$$F_g = \frac{GmM}{r^2} = \frac{mv^2}{r}$$

$$v = \sqrt{\frac{GM}{r}}$$



Instead, the galactic rotational velocity is nearly constant with *r*, shown as line be in the plot above. This means the outer stars are moving so fast that they should be flying away from the galaxy. This suggests the existence of unseen mass that is contributing to the total mass of the galaxy and holding it together.

SuperCDMS is a nationwide collaboration working on direct detection methods of finding dark matter particles. The Supersymmetric model of physics predicts the existence of a particle that would fit the needs of a dark matter particle. Namely, this is the WIMP, or Weakly Interacting Massive Particle. The predicted mass of a WIMP is between 1 GeV/c^2 and 10 TeV/c^2 [1], and as the name suggests, it does not interact strongly with normal luminous matter. In any given second, a billion WIMPs pass through your body without making any collisions.

In order to find the WIMP, SuperCDMS uses cryogenically cooled germanium crystal detectors that will warm slightly when a particle collides with it.

Introduction

Signal processing is an important part of most functioning laboratories. In this lab, there is a dry dilution refrigerator that is used to cool detector payloads. The tool used to communicate with the detector is called a DCRC board. While the payload reaches temperatures of 20 mK, the DCRC is kept at room temperature.

So that measurements can be taken freely, the DCRC has a plug-in device called a miniBoB, or mini break-out board, that is used to simulate detector signals. Together with its Labview controller, the DCRC and miniBoB let the user analyze the signal a detector would give.

Hardware

Shown in Figure 1 is an earlier version of the DCRC board without copper shielding and Figure 2 is the DCRC as it was used in this experiment. The DCRC is a dizzying array of circuit components but the miniBoB, shown in Figure 3, is smaller and less complicated. It has eight channels in total, however, only Phonon Channel A will be discussed here.

In the Labview controls, there are toggles that switch between measuring the signal of a TES (a transition-edge-sensor) and a SQUID (Superconducting QUantum Interference Device). These coupled devices are essential to the real detectors for measuring particle collisions.

Fig 1

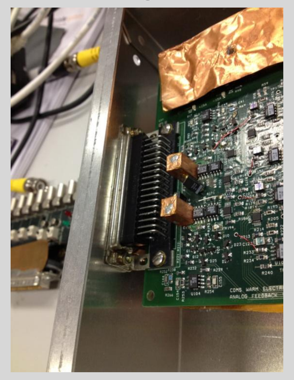
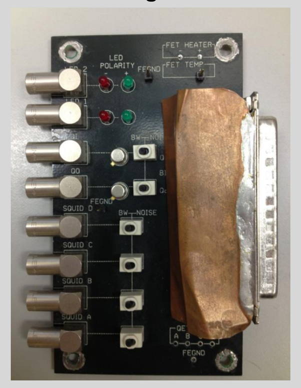


Fig 3



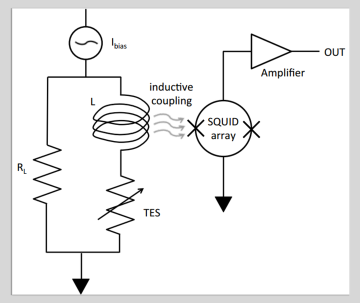


Fig 2

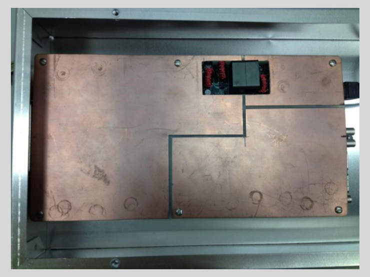
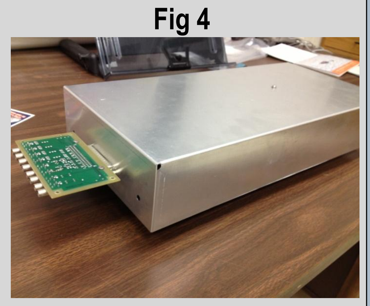


Fig 4



Data Collection

The objective was to see which combinations of conditions resulted in low noise and which resulted in high noise situations. Some of the conditions altered between measurements were:

- Location
- Shielding
- Lights
- Channel Termination
- Channel Settings

The traces are identified by their location short-hand such as 'box' which indicates the board is shielded, and 'Lon' which indicates the lights were on. A word about the locations:

- TopLSB—expected to be noisy, by electronics for lab's fridge
- TopFridge—close to where the DCRC would normally be operated when reading from a real detector
- TableNorthWall—expected to be quiet, shows a generic area away from pumps and electronics

PSD

A power spectral density, or a PSD, is essentially a time domain signal that has been Fourier-transformed such that it is then in the frequency domain. It shows the power of the signal over different frequencies.

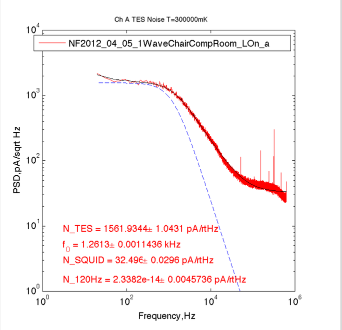
Analyzing the data in this way is effective because it is easy to see what kind of disturbances there are, whether it is 60 Hz noise and its harmonics that come from wall sockets or from somewhere else.

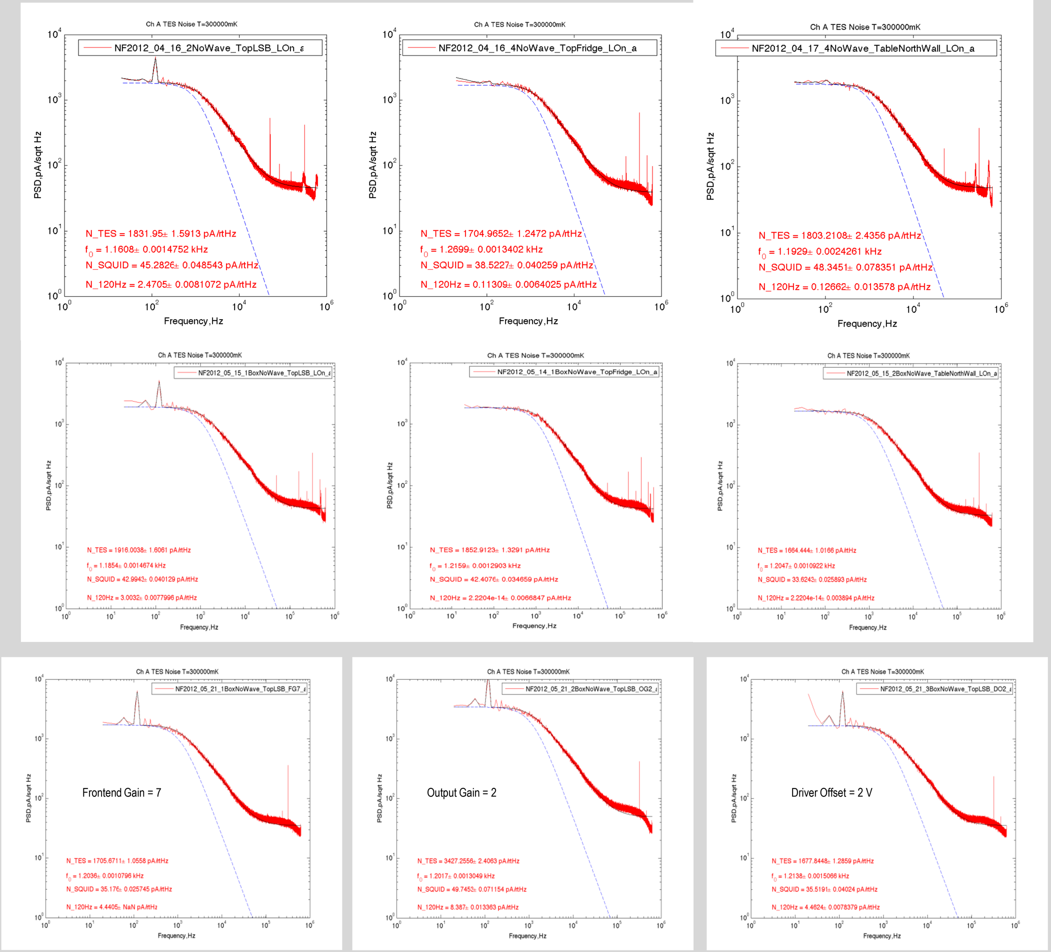
Results TES

The plots below are TES signal PSDs in units of pA/√Hz. The first plot shows a near-baseline reading, the first row shows an unshielded DCRC, and the second row shows it with shielding.

The third row shows the TopLSB location but altered settings in the Labview controls:

- FG—Frontend Gain
- OG—Output Gain
- DO—Driver Offset [V]

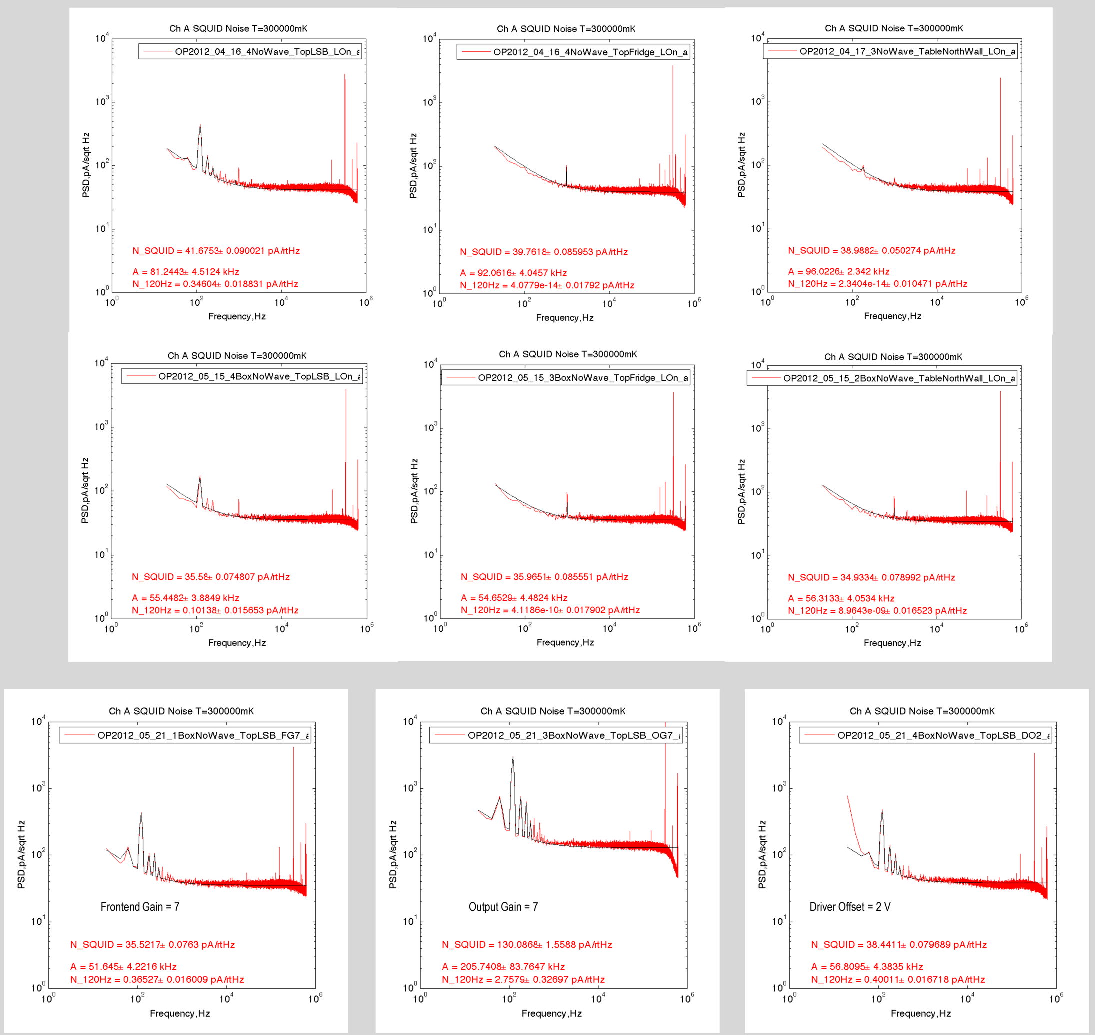




Results SQUID

The plots below are SQUID signal PSDs in units of pA/√Hz. The first row shows an unshielded DCRC in different locations, and the second row shows it with shielding.

The third row shows how changes in the channel settings affects the signal in the TopLSB position.



Conclusion

Of all the differences in conditions, the data suggests that the **largest factor in reducing unwanted noise is the location of the DCRC board and maintaining a small output gain**. In both the TES and SQUID measurements the signal was altered heavily in the form of 120 Hz noise by exposure to the electronics contained by the TopLSB location.

For the TES plots,

- TES noise dominates between 10 Hz and 1.2 kHz
- 1/f noise dominates from 1.2 kHz to 100 kHz
- SQUID noise dominates from 100 kHz to 300kHz.

The SQUIDs are not coupled to the TES in their measurement mode so,

- 1/f noise dominates from 10 Hz to 1 kHz and
- SQUID noise dominates from 1 kHz to 300 kHz.

In two of the TES plots, shielding box did not reduce the noise. In fact, the noise was increased a nontrivial amount and this occurrence warrants further investigation. The effect of raising the Output Gain from 1 to 2, raised the noise by a factor of 1.8, however, this is due to the signal simply being larger.

For the SQUID plots, the shielding box does affect the noise in the correct direction, however, it is a modest drop of only a few pA/√Hz. In the settings changes, increasing the Output Gain from 1 to 7 increased the noise by a factor of 3.4, which indicates some loss between input and output.

Because the Frontend Gain does not increase the noise threshold of the signal, it would be best increase the magnitude of the signal there.

Due to poster real-estate, it was not possible to share all the locations and conditions in the results section. As mentioned previously, the effects of ambient lighting and channel termination were also analyzed, as were there three other channel setting features.

Citations

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2. Richard J. Gaitskell. *Direct Detection of Dark Matter.* Annu. Rev. Nucl. Part. Sci. 2004. 54:315–59
3. Jeter Hall. *Detector Control and Readout.* SuperCDMS internal pages. 14 Feb, 2012.
4. DCRC Analog Schematic. 17 Feb, 2010.

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