Design of ultra-low noise coaxial cable in cryogenic setup

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Introduction

The Cryogenic Dark Matter Search (CDMS) experiment measures the energy of incident particles through an array of germanium crystals cooled to 50mK. To probe low energies, its setup is low temperature and low noise. This poses challenges for the charge readout circuit, which depends on a JFET amplifier which runs optimally at 150K [1]. All cables need to be coaxial, but a 40MΩ resistor in the amplifier circuit amplifies microphonic noise on them. To avoid this, CDMS uses cables with vacuum dielectric. This requires rigid shielding, which requires a bulky copper "tower" with temperature stages to get the signal to room temperature. This project aims to design a coaxial cable that is flexible (removing the need of a tower) and impervious to microphonics.

Motivation

Logistical

The tower is bulky, so large amounts of cooling power are required to maintain temperature stages. This limits the ability of the experiment to scale, since scaling the size of the tower increases the amount of copper that needs to be heat sunk.

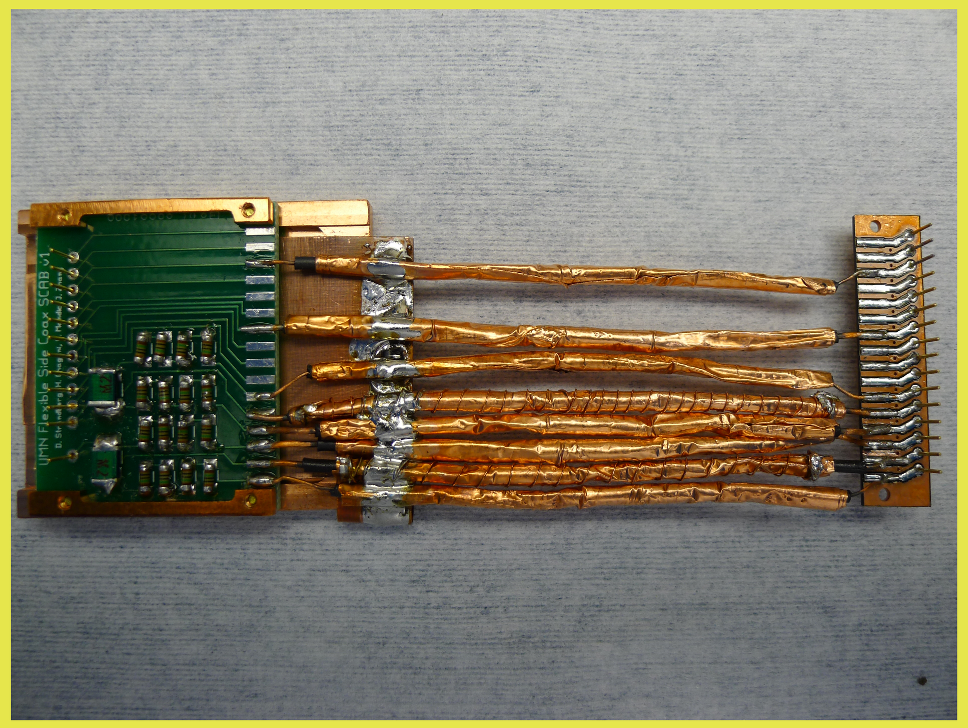
Physical

The tower is quite difficult to install in the fridge, mainly due to its bulk. Eliminating the tower would cut out hours of work in installation and de-installation in between runs on the fridge. Furthermore, removing the tower would decrease the risk of heat leaks, which is fatal for a run

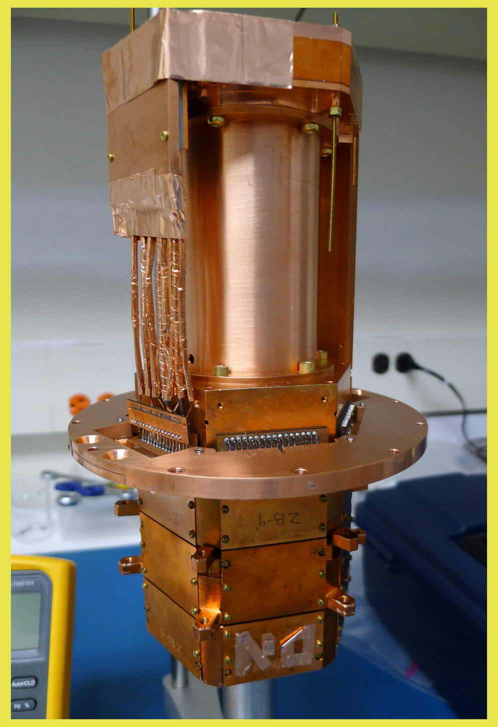
Construction

The coaxial cables used a 20AWG copper wire as the conductor with copper foil as the shield. The insulator was 1/32 inch polyolefin heat shrink tubing, and the shield was copper tape wrapped around the insulated wire. Before the heat shrink tubing was fitted to the conductor, 3 coats of M.E. Taylor Engineering Aquadag E, Conductive Carbon Paint were applied to the conductor and left to dry over night. The polyolefin tubing and copper foil were then applied to this painted conductor to complete the coaxial cable.

Procedure for measuring power spectrum density

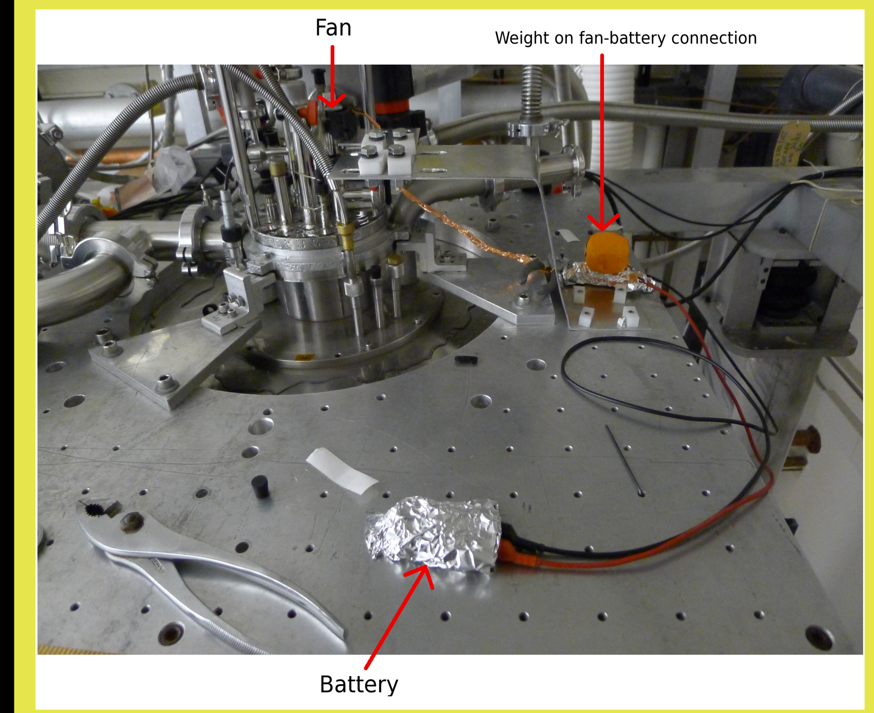


First, the cables had to be soldered to the proper interface boards and the coaxial shields needed to be grounded



Then the flexible coax was installed with a vacuum coax on the tower

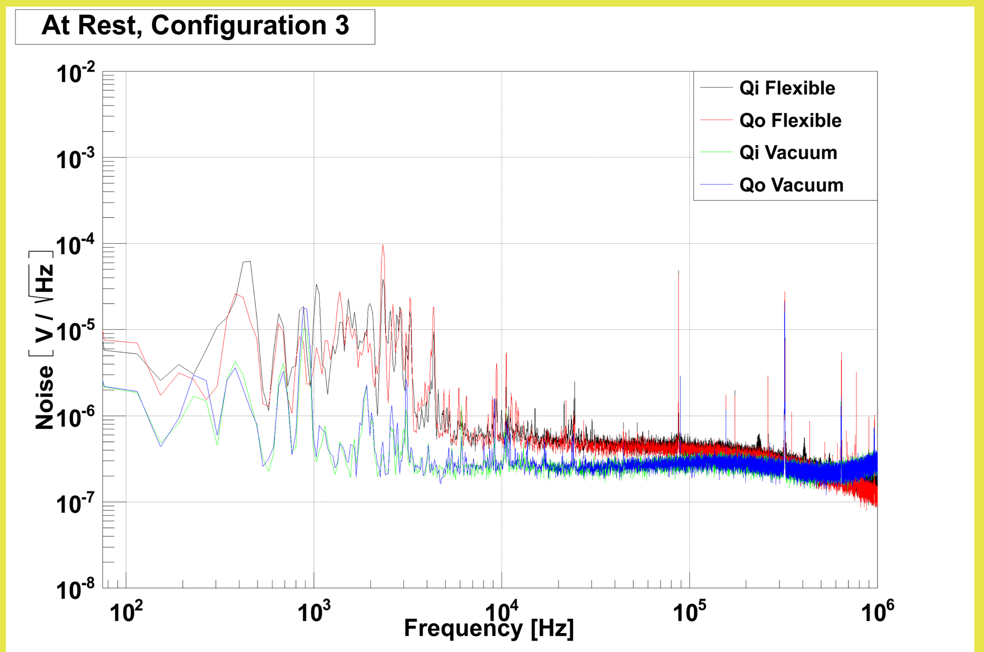
The tower was then installed in the dilution refrigerator



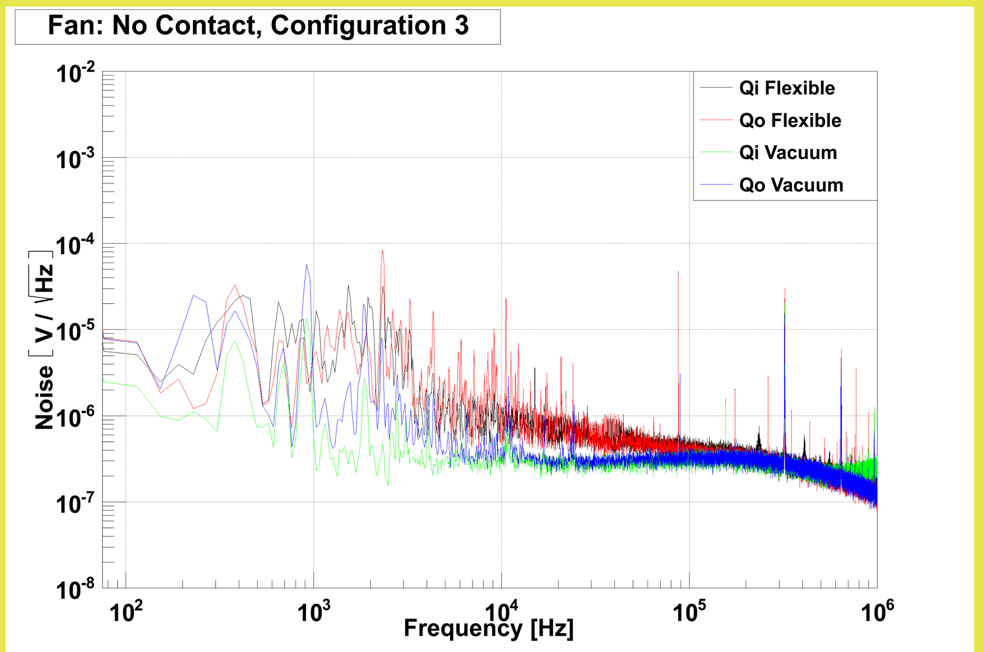
And a LABView DAQ took PSDs of the signal with the fan off, the fan on but making no contact with the fridge, and the fan on making contact with the fridge (procedure modified from [2].)

Measurement of susceptibility to microphonic noise

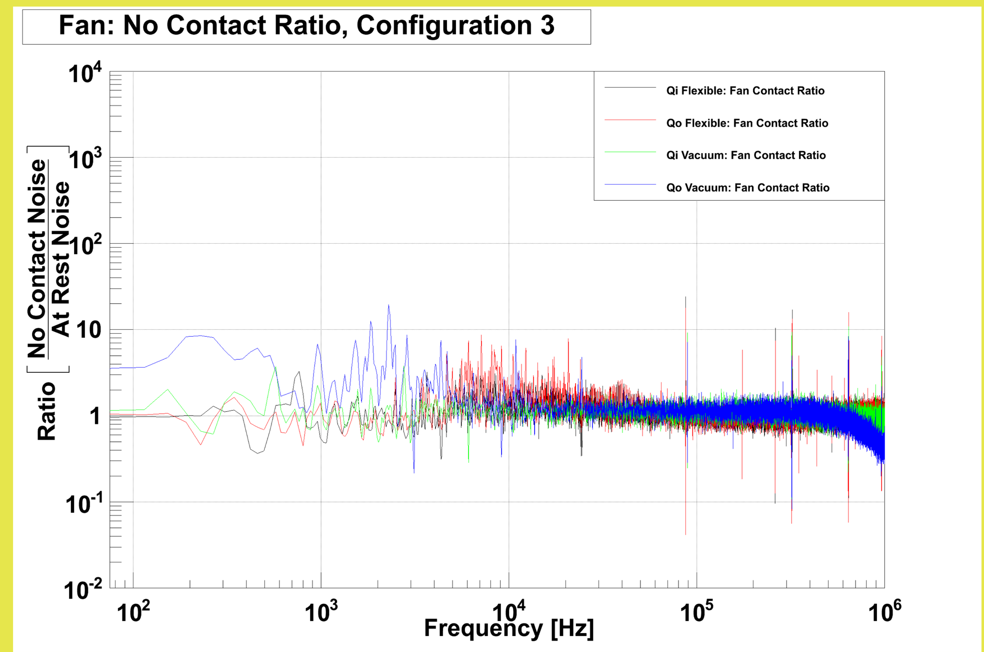
The cables' susceptibility to microphonic noise can be shown by witnessing the effect of subjugating the fridge to mechanical vibrations. This is done by using a fan to strike the fridge structure, thus inducing vibrations on the cable. The susceptibility is quantified by the ratio of a cable's noise with induced microphonics ("Fan Contact") divided by the noise without induced microphonics ("Fan No Contact"). Note the Qi and Qo are two cables of the same design.



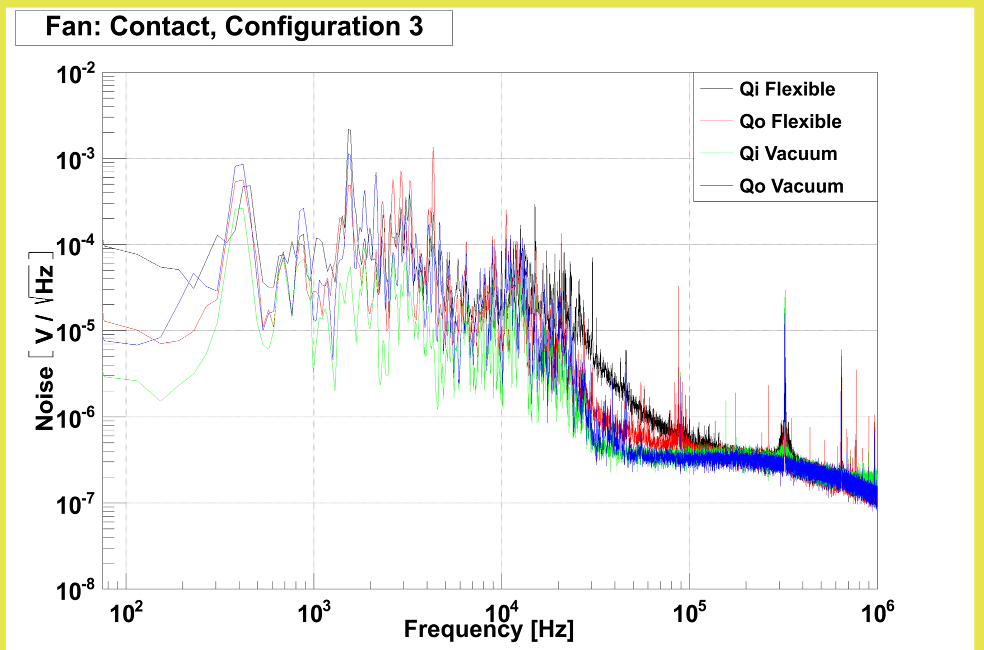
Based on those PSDs, it appears the flexible cables send a noisier signal, especially in the 1 to 10 kHz region. Unfortunately, this is the range of frequencies that the signal is sent in the standard CDMS experiment [3].



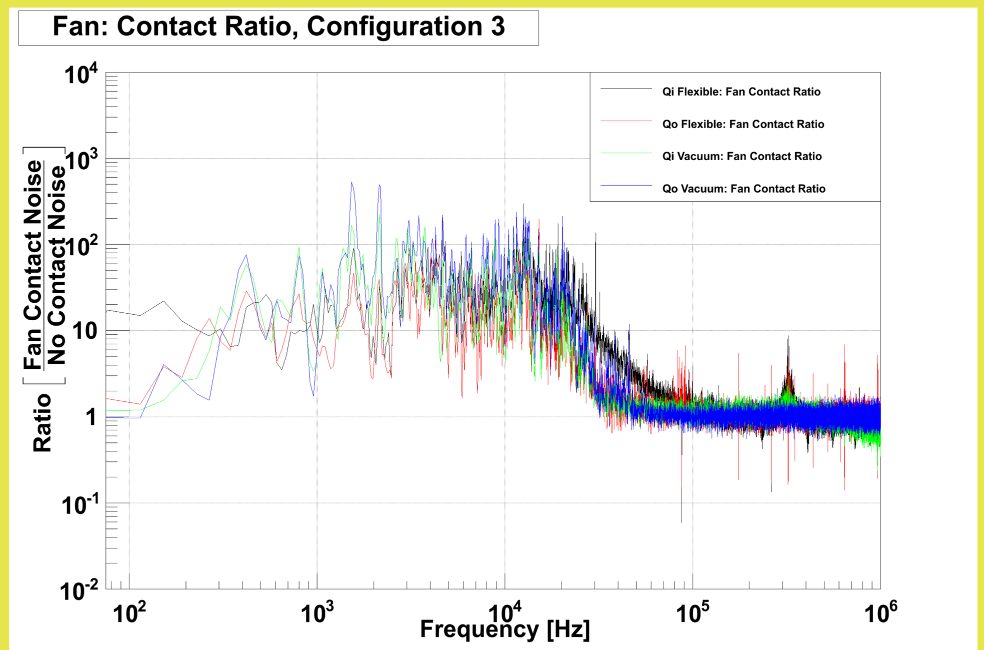
"No Contact" noise is the noise with the fan running but not making contact with anything. This is the background noise and takes into account noise from both background vibrations and electrical signals.



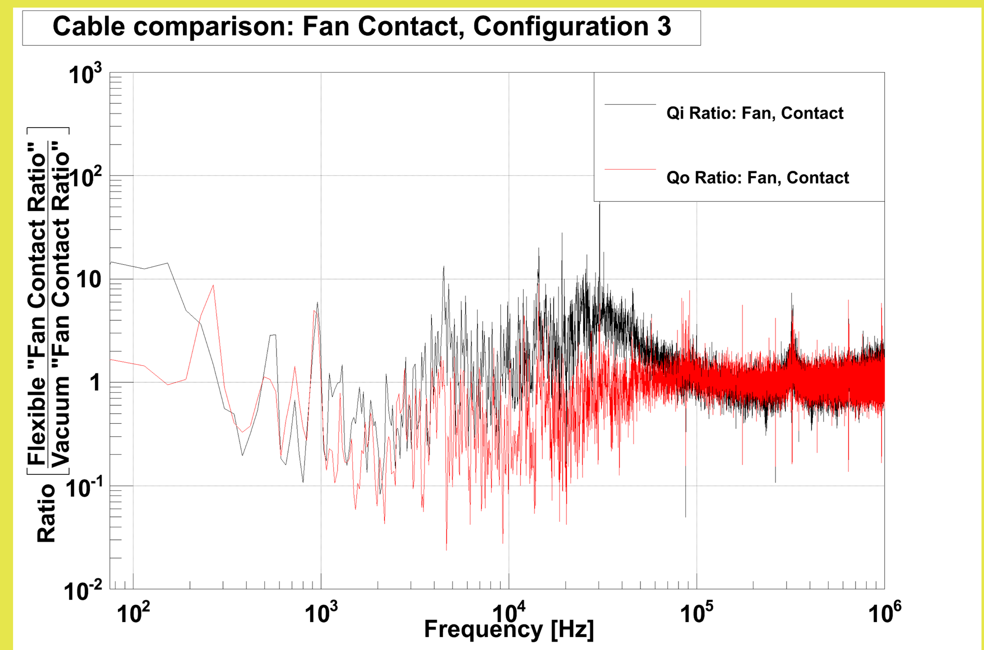
The "No Contact Ratio" is a sanity check to make sure that all cables are functioning correctly and an indication that the fan running without making contact with the fridge is comparable to "At Rest" conditions



"Fan Contact" shows the noise on each cable with induced vibrations. This data alone is not very useful until it is compared with the noise on the cable without induced vibrations



The "Fan Contact Ratio" is a measure of the susceptibility of each cable to microphonic noise. It is greater than 1 at frequencies where the cable is susceptible to microphonic noise



This PSD is a measure of the relative susceptibility of each design to microphonics. Note in the 1 to 10 kHz region, the flexible design is less susceptible to noise, even though it has higher total noise

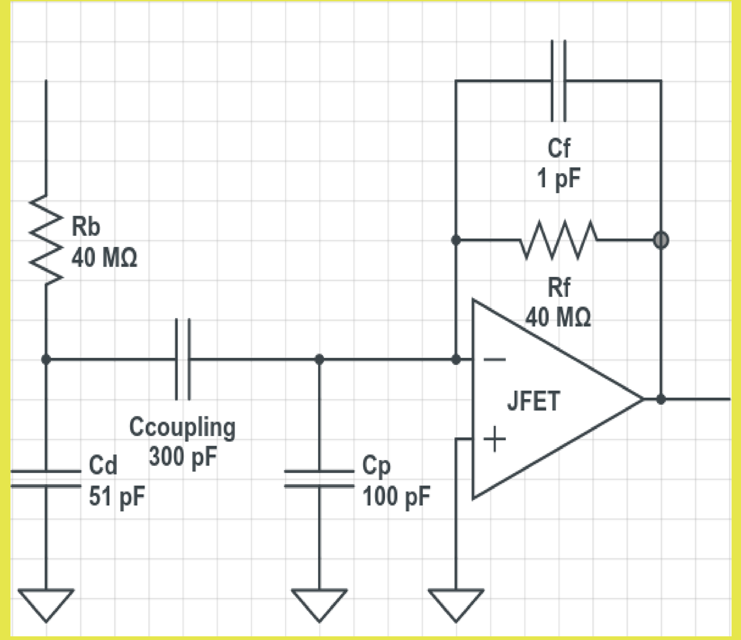
Capacitance

The readout circuit is shown in the circuit diagram below. The noise of this circuit is predicted [4] by the equation

$$e_0^2=|A(f)|^2\left\{e_{FET}^2\left[(C_D+C_p+C_f)^2(2\pi f)^2+\left(\frac{1}{R_f}+\frac{1}{R_b}\right)^2\right]+4kT\left(\frac{1}{R_f}+\frac{1}{R_b}\right)\right\}$$

Where A(f) is the signal shape defined by $A(f)=\frac{R}{1+2\pi iR_fC_f}$

Note that the capacitance of the cable is part of the parasitic capacitance, Cp. While this is not the main source of the noise in this run, it will be a main issue when replacing the tower.



This cable has capacitance 30±5pF/ft. This needs to be closer to the capacitance of the tower, 20pF/foot, in order to keep the parasitic capacitance close to its current value [5].

Conclusion

Analysis of these PSDs showed that, in terms of susceptibility, this design is at least comparable to the standard vacuum cables. However, the flexible cable has more net noise in 1kHz to 10kHz region, which is alarming because the frequencies used for the signals fall in this range.

One suggested cause of this noise is the graphite paint chipping and falling off the conductor. Then, any natural vibrations in the fridge would be seen on the flexible cable but not on the vacuum cable. To combat this, the next design will have the graphite paint sealed with GE varnish. The above consideration of capacitance suggests a stronger dielectric should be used. Therefore, the next design of the cable will use a vacuum dielectric with plastic spacers to allow for flexibility

References

[1] V. Mandic, First Results from the Cryogenic Dark Matter Search Experiment at the Deep Site, Ph.D. Thesis, Department of Physics, U. C. Berkeley (2004).

[2] D. Strandberg, Analysis of Microphonic Susceptibility of a Flexible Side Coax for the Cryogenic Dark Matter Search Experiment, Senior Thesis, Department of Physics and Astronomy, University of Minnesota Twin Cities (2012).

[3] D. S. Akerib, et al. Nuclear Instruments and Methods in Physics Research Section A. 591, (2008).

[4] T. A. Shutt, A Dark Matter Detector Based on the Simultaneous Measurement of Phonons and Ionization at 20 mK, PhD thesis, U.C. Berkeley (1993).

[5] Phipps, The CDMS Ionization Readout Capacitance Budget, Senior Thesis, Department of Physics, U. C. Berkeley (2008).

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