SuperCDMS 150-mm Silicon Crystal Detector Housing Flexible Side Coax Assembly Board Component and Fixture Adaptation

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Abstract

This report characterizes the design and purpose of components that will be used with the scaled 150-mm Silicon crystal detectors that the Super Cryogenic Dark Matter Search (SuperCDMS) experiment may utilize following detector testing that takes place at the University of Minnesota. The parts required are several fabricated PCB boards along with the fixtures that secure the boards to the detector housings. These components will be used while testing the performance of experimental flexible side coaxial cables.

Introduction

The SuperCDMS collaboration aims to detect dark matter particle candidates called Weakly Interacting Massive Particles (WIMPs) using Germanium and Silicon crystal detectors cooled to cryogenic temperatures. Dark matter is believed to be a type of non-luminous matter that comprises roughly twenty five percent of the energy density composition of the entire universe, and its existence is expected based on the observed rotational velocities of spiral galaxies, as well as on other astrophysical observations [5].

Theory

Assuming a spiral galaxy, for instance, is comprised only of visible baryonic matter, it is possible to calculate, using its mass distribution of stars computed from observations of the total luminosity of the galaxy, the behavior of the rotational velocities of its stars as a function of the distance from the galaxy's center of mass, R. The rotational velocities of stars should increase proportionally to R, assuming the density of the galaxy is constant, and then drop off as the square root of R at some distance greater than the scale distance R_s, where the scale distance is a parameter of a spiral galaxy characterized by the behavior of the surface brightness of its disk as a function of R. This is called Keplerian rotation, since this behavior is analogous to what Kepler had discovered for the behavior of planetary orbits in the solar system. This is not what is observed, however. What is observed is that the rotational velocities increase proportionally to R and then remain constant with $R > R_s$. This is only possible if there exists "extra" mass contained within the galaxy [4].

This excess mass does not appear to emit or absorb electromagnetic radiation and therefore interact with light in any way, aside from diverting its path through space-time due to gravitational effects in the presence of its mass. The appropriate term coined for this excess mass is dark matter.

It has been supposed that this missing mass may consist of entities called MAssive Compact Halo Objects (MACHOs) that are difficult to observe using telescopes. MACHOs may be massive objects such as black holes or brown dwarfs scattered throughout the galaxy. These objects are difficult to detect in large quantities, due to their mostly non-reflective nature. Additionally, this missing mass has been hypothesized to be of the form of neutrinos. However, the mass density of these objects has not been observed to be nearly enough to compose all of the missing mass. Thus, dark matter must exist as some alternative form of matter.

Due to its non-luminous nature, it is possible to characterize this matter by its interactions with ordinary baryonic matter, if we assume that dark matter behaves consistently with the accepted standard model of particle physics. Since dark matter does not emit or absorb light, it does not interact via the electromagnetic force, and therefore has no electric charge and must be neutral. Additionally, it is generally assumed that it does not interact via the strong force, since we would observe obvious events involving visible baryonic matter all the time. This leaves only the weak and gravitational force as possible interaction mechanisms between dark matter and visible matter.

We observe cosmological gravitational effects of dark matter via mechanisms such as gravitational lensing. But individual particle interactions at the gravitational level are difficult to detect, since the relative strength of gravity is very small compared to the relative strengths of the other forces. Therefore, current experiments, like SuperCDMS, consider it viable to observe particle interactions with dark matter via interactions whose relative strength is comparable to that of the weak nuclear force.

Direct detection of dark matter relies on mechanisms postulated by the Minimal Supersymmetric Standard Model (MSSM). The neutrilino, denoted by χ in the Feynman diagrams of Figure 1, is the Lightest Supersymmetric Particle (LSP) and may be a viable WIMP candidate. The neutralino scatters elastically from a nucleus in the crystal lattice of the detector in two ways.

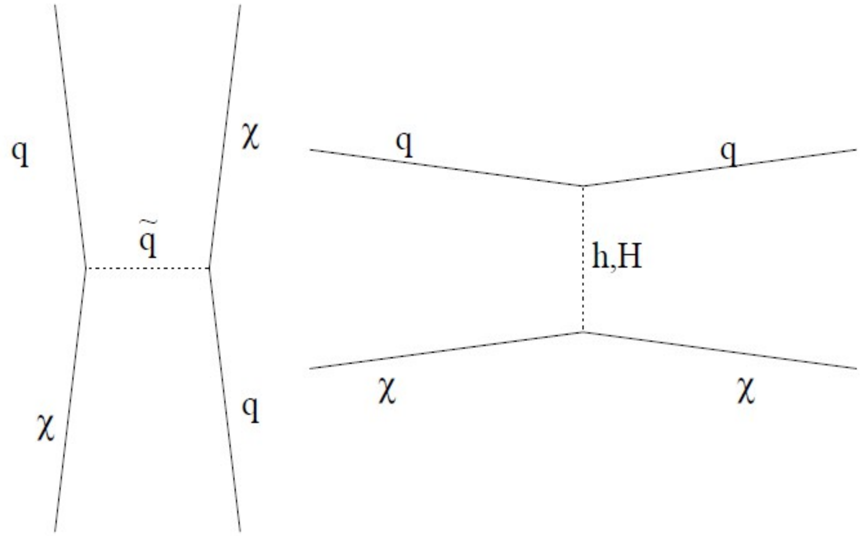

Figure 1. Feynman diagrams representing the hypothetical fundamental interaction with a quark in a nucleus of a detector and a dark matter particle. The two viable scattering processes involve the exchange of a virtual squark (left) or a virtual higgsino or Higgs boson (right) [3].

The first diagram on the left of Figure 1 shows scattering from a quark contained within a nucleus belonging to the crystal, and a neutralino by exchanging what is known as a squark. The other leading process, shown on the right of Figure 1, consists of elastic scattering from the quark with the neutralino by exchanging a higgsino or a Higgs boson particle. These scattering processes produce some nuclear recoil whose energy signal is measured and discriminated against other events such as electron recoils that occur via other background mechanisms [3].

Signal Detection

The SuperCDMS group at the University of Minnesota performs testing of the detectors that will be used to detect WIMP candidates. The detectors, known as interleaved Z-dependent Ionization and Phonon (iZIP) detectors, must be operated at cryogenic temperatures. This is achieved using an Oxford Kelvinox 100 ^{3}He-^{4}He dilution refrigerator. Usually, temperatures of about 50 milliKelvin are required for successful characterization of the detectors [2].

An energetic event that takes place within a detector results in ionization and phonon signals as a consequence of the recoil of an electron or nuclei in the lattice structure of the crystal. Distinguishing ionization signals and phonon signals is achieved by depositing and patterning phonon and ionization sensors on the surface of the detector, and separating the signals using specialized circuit configurations. The iZIP detectors have interleaved channels such that each face of the detector is able to consist of four phonon channels and two ionization channels [5].

An electron recoil results in an ionization signal that is approximately three times greater than a WIMP-induced nuclear recoil of the same deposited energy [5]. It is important to have the sensitivity required to resolve the differences in these energies, so that the different types of events can be distinguished, and it can be determined if a WIMP signal has indeed been observed.

When an ionizing event occurs in the detector, electron-hole pairs are formed. A small bias voltage applied across the circuit configuration shown in Figure 2 separates the pairs. The result is a charge generated at the coupling capacitor (and at the gate of the JFET amplifier). The feedback capacitor is then discharged via the amplifier’s response to bring the voltage at the gate into equilibrium, which discharges through the feedback resistor.

The amplitude of the charge signal can be compared to the phonon signal to distinguish events. The JFET amplifier is used since it has a high input impedance, and therefore, yields a high charge collection efficiency, as well as low levels of noise [1].

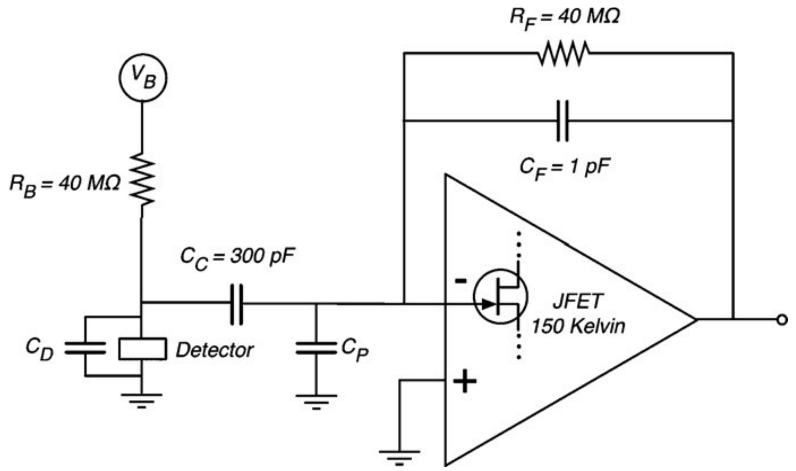

Figure 2. Simplified circuit schematic of ionization signal readout [1].

Ionization signal detection is what is of interest here, since some aspects involving charge detection are being updated. Specifically, it is necessary to adapt some of the hardware used in charge detection to a scaled detector housing containing a 150-mm Silicon crystal that will be tested and characterized at the University of Minnesota.

Project Description

It is of current interest to test specially designed flexible side coaxial cables that bridge two circuit components of the cold hardware configuration. These components are known as the Side Coax Assembly Board (SCAB) and the Side Coax Upper Heatsink Board Assembly (SCUHBA). The interest in these proposed side coaxial cables is that they will be flexible, with low microphonic noise. Using flexible side coaxial cables, as opposed to the rigid design that has been used in previous detector testing runs, will mean that an entire module, known as the tower, may be dispensed of, which has the benefits of using a setup that is less bulky [5].

A 150-mm diameter, 25-mm thick Silicon crystal would weigh 1kg, about 10 times more than the Silicon detectors used in the past. Using such large crystals for direct dark matter searches would simplify scaling up of the detector technology to a large total target mass, leading to corresponding improvements in WIMP sensitivity. To operate such large detectors, it is necessary to adapt the dimensions of the SCAB board, and include a new grounding plane for the purpose of grounding the outer shield of the flexible side coaxial cables. Similarly, the SCUHBA needs to be redesigned to include a grounding plane as well. Redesigning the SCUHBA will be the next step in the process. The PCB layout of the redesigned SCAB component has been completed and is in the process of being fabricated, so that the components may be soldered to the physical PCBs. The layout of the redesigned SCAB is provided in Figure 3.

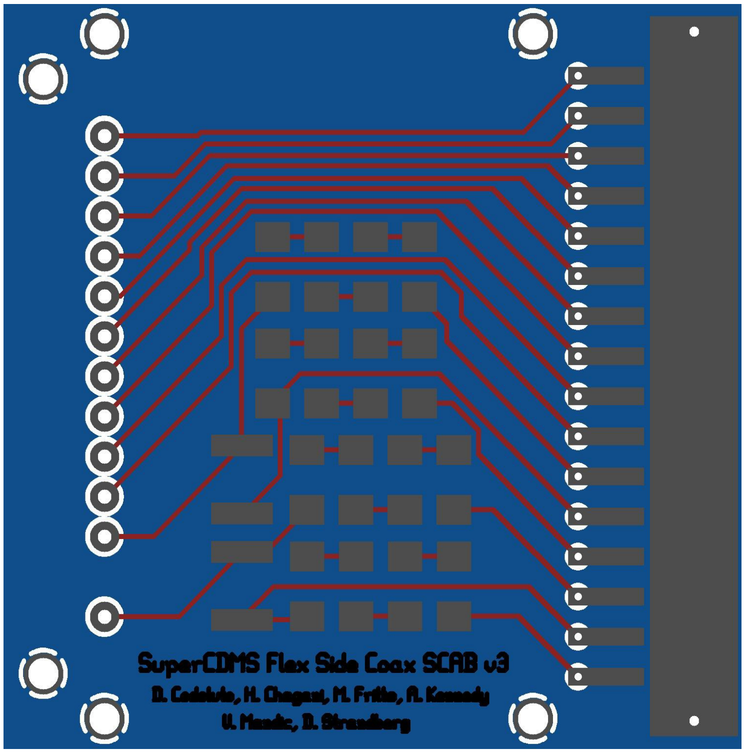

Figure 3. PCB layout for the redesigned SCAB board to be used with the new 150-mm Silicon crystal detectors.

The components of the simplified circuit, as shown in Figure 2, that are located on the SCAB circuit board are the coupling capacitors and the feedback resistors. Since the SCAB is operated at such low temperatures, the resistors required need to have little change in resistance at low temperatures, and hence a low temperature coefficient. This is achieved using metal film resistors. Because it is difficult to find metal film resistors with a high resistance, it is necessary to use four 10 MΩ resistors in series to comprise the needed 40 MΩ of resistance in the circuit. The coupling capacitors also require low temperature operating characteristics. This is achieved using capacitors made with mica as the dielectric material. The capacitance required for the coupling capacitors in our configuration is 300 pF.

The PCB was designed in a program called PCB design. Its dimensions were designed according to specific requirements, since it needs to properly mate with the detector housing and flexible side coaxial cables. After being designed and approved, the layout was exported into Gerber files. Gerber files are the files that are sent to the fabrication facility, where the board layout will be printed. The fabricated PCBs will require manual mounting of the surface mounted devices, i.e., the resistors, capacitors and pins.

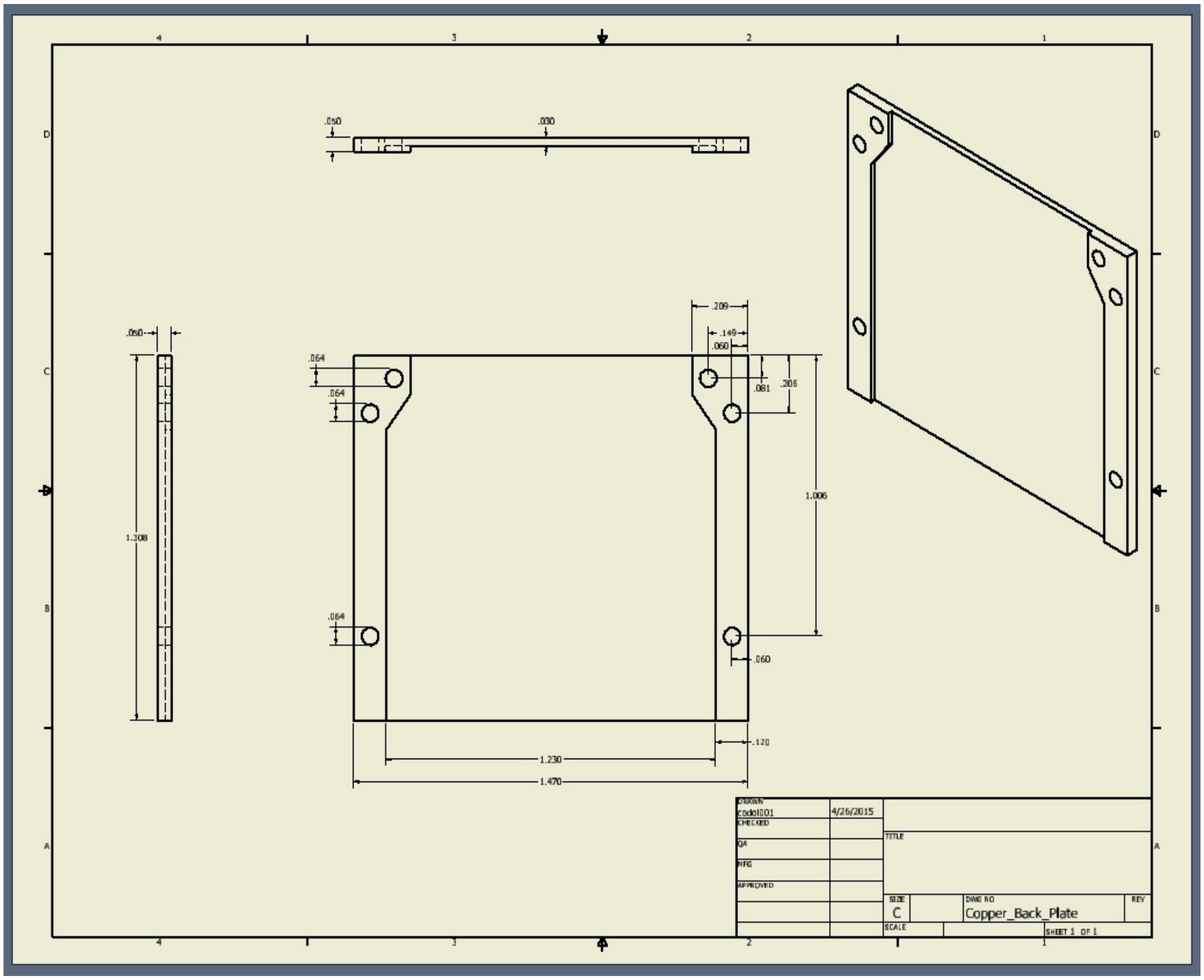

Figure 4. Copper back plate that will be used to secure the PCB to the detector housing. Units shown are in inches.

A copper back plate and spacers, located on the component side of the PCB, will secure the PCB to the housing of the detectors. Additionally, the back plate serves as a heat shield for infrared radiation that may contribute to a heat load during the operation of the dilution refrigerator. The diagrammatic sketches representing these pieces are shown in Figures 4 and 5. The design is relatively simple and consists of a spacer that separates the housing from the component side of the PCB and a back plate that fastens the back side of the PCB to the entire fixture. A model of each fixture was designed in Autodesk Inventor Professional, which was subsequently created into a drawing. The drawings, once approved, will be provided to the machine shop at the University of Minnesota in which the fixtures will be machined.

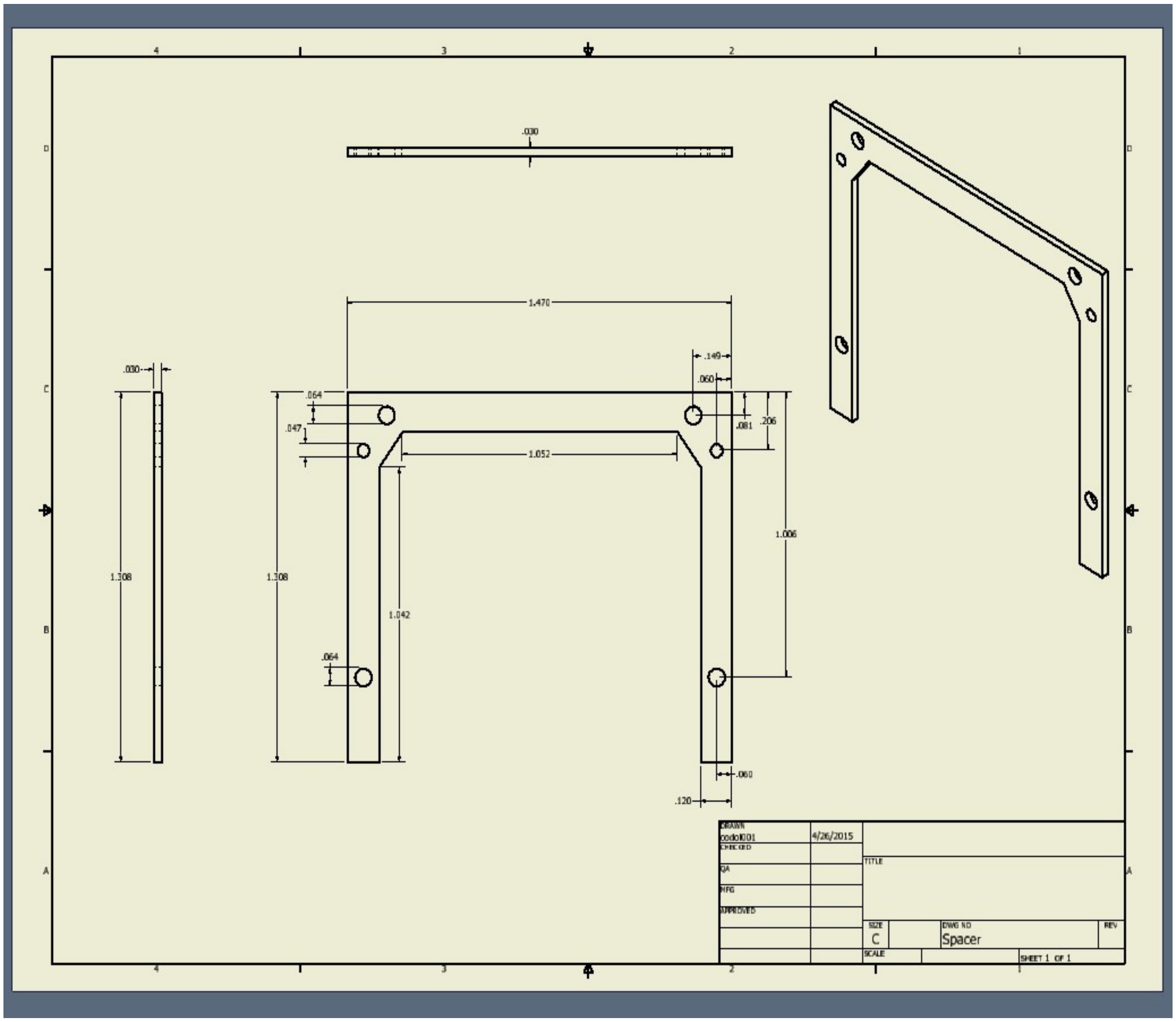

Figure 5. Copper spacer that separates the component side of the PCB board from the detector housing. Units shown are in inches.

Conclusion and Future Prospects

Once all of the aforementioned components have been physically fabricated and assembled, they will be used in a detector testing run to evaluate the performance of the larger 150-mm Silicon detectors, along with the flexible side coaxial cables. The new components, like the SCAB and the SCUHBA, in some sense, are guaranteed to operate as expected, since not much has changed, aside from the introduction of the grounding plane. However, it is hoped that the flexible side coaxial cables are successful candidates as a replacement for the rigid coaxial configuration, assuming that they do not contaminate signals with undesired noise.

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