Capacitive Level Sensors for Use in Liquid Xenon Detectors

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Abstract

The LUX dark matter experiment liquid xenon detector uses an electric field created by grids to increase the drift velocity of electrons into xenon gas causing them to produce additional scintillation photons. These photons combined with the data from the original event photons are used to help determine the location and type of the original event. Electrons accelerate differently in liquid and gas phase xenon. Because of this we need to be sure the grids are level with the liquid-gas boundary. To measure the liquid level capacitive level sensors are used. To remove parasitic capacitance from cables a charge amp is used. The charge amp is capable of removing the capacitance from the cable, but does not remove noise from cabling. To reduce the problem of noise in the cable as much as possible, the charge amp will be connected as closely as possible to the capacitors. The liquid xenon is constantly on the verge boiling, so the liquid-gas boundary is not smooth and needs to be monitored. A system for measuring ripples on the surface of the liquid xenon based on low-noise capacitance measurements will be designed and tested in a chamber similar to the chamber used in the LUX dark matter experiment. The capacitive level meters are used to level the LUX system, but we would like to be able to use the information gained from the level sensors to make sure that the liquid xenon is in a smooth state. If we know that the liquid xenon is in a smooth state then we know that our signal will be properly calibrated.
Intro

Scientists have long theorized that there is additional mass in our galaxy that cannot be observed through an interaction with light. The outer edge of galaxies have been observed moving at much higher velocities than would be physically possible without additional hidden mass involved. We also can observe this hidden mass through gravitational lensing, a phenomena where light is bent by a huge mass and its gravitational effects. Other experiments have been done that hint at a hidden mass in the universe. A huge goal in the world of physics is to predict and find the particle making up this hidden mass.

One prospective group of particles is weakly interacting massive particles, or WIMPS for short. As the name states these are extremely massive particles that don’t interact strongly with light. These particles interact with other matter through gravitational interactions and the weak nuclear force. The mass of the particles ranges from approximately $10^1$ GeV to $10^3$ GeV [1].

The LUX dark matter (figure 1) detector works by detecting when a WIMP collides with liquid xenon and produces light. The LUX detector has a large mass of liquid xenon. Light is released when a WIMP collides with a xenon particle. There are arrays of photo multiplier tubes located at the top and bottom of the detector. The arrays in conjunction can be used to locate the location of the collision in the x-y plane of the detector. Near the liquid gas barrier there is a set of grids with a high electric field
between them. This takes electrons from the initial collision and accelerates them causing more photons to be released. From this we are able to calculate the z location of the interaction. This data is used to eliminate noise and to make sure that the signal is actually from a WIMP and not unwanted radiation from the surroundings.

Figure 1: LUX Dark Matter Detector Internals
The detector is located underground at the Davis Cavern at the Sanford Underground Research Facility in Lead, South Dakota [2]. The detector is located underground to block cosmic radiation to increase sensitivity.

The detector needs to be leveled to work properly. Currently we use capacitive level sensors to detect the level of the liquid inside the detector. These sensors work by using the fact that liquid and gaseous xenon have different dielectric constants and the fact that the capacitance of a capacitor changes with respect to the dielectric constant of the material inside it. A simple diagram of our capacitive level sensors can be seen in Figure 2.
Currently our level sensors do a good job of leveling the sensor, but do not have much precision beyond that.
Methods

The measurements of the capacitance need to have as much noise as possible eliminated from them. Noise has been dealt with in three ways. The first is by using a charge amp circuit described in figure 3.

![Charge Amp Diagram]

**Figure 4: Charge Amp**


The circuit works to eliminate parasitic capacitance in the cabling by forcing a voltage drop of zero across the cable eliminating the capacitance of it. The capacitance of the parallel plates to make the level measurement is around 0.1 to 1.0 pico-Farads. The output of this circuit is proportional
Figure 3: Simple Diagram and Image of circuit prototype.
to $C_i/C_r$. For our purposes we want this ratio to be approximately 1. Next a frequency
needed to be chosen. To get the best results from the circuit $\omega \gg \frac{1}{RC}$ where $R$ and $C$ are
the values used in the feedback loop of the op amp in the charge amp circuit. The
 capacitor used was a 10 pF capacitor and the resistor was 1 mega-Ohm. Using these
values a frequency of around 10-100 MHz is needed to make $\omega \gg \frac{1}{RC}$. I was able to get
the charge amp working properly and producing an output voltage approximately the
same as the input with a small phase shift.

The output of the charge amp was then fed into an AD630 Balanced
Modulator/Demodulator chip. This chip in conjunction with a low pass filter operated as
a lock-in amplifier. The chip takes in the signal of charge amp output and a reference
wave of the same frequency. The output is a rectified signal of double frequency. This
signal is fed through a low pass filter and that output gives a signal that can be measured
as the output voltage and from this the capacitance of the sensor can be measured.

The low pass filter was designed to get rid of the 10-100 MHz portion of the
output that is output by the AD630. With the high frequency portion eliminated we are
left with a slowly oscillating wave that is proportional to the capacitance measured.

With the completed circuit the capacitor being measured is replaced by a parallel
plate capacitor made of copper plates with approximately 5mm of separation between
the plates. The level of the liquid would fluctuate between the top and bottom of the
capacitor and with this fluctuation a change in voltage, proportional to the change in the capacitance would be seen.

Problems arose with the AD630 chip and its limitations on frequency input. The AD630 has a bandwidth of 2 MHz and a slew rate of 45 V/microsecond. This caused issues with the signal being output from the AD630. As the frequency increased the 10-100 MHz desired frequency the signal became more and more distorted. Either the input signal needs to be worked out to work at a lower frequency or a new chip allowing higher frequencies should be used.

A simple test apparatus can be constructed to characterize the sensors. The testing apparatus would consist of a chamber of liquid that can be raised and lowered. Measuring the change in the liquid level and comparing it to the capacitance measured I would be able to characterize the sensor and circuit.

Future Aims

From this research I expect one to be able to build a better, more sensitive level sensor. This level sensor should be reliable and work at liquid xenon temperatures with little to no maintenance after the initial installation. The sensors should have a high signal to noise ratio as well.
With the improved sensors we hope to be able to develop an ability to map the surface of the liquid xenon. We have seen evidence of boiling that produces a periodic rise and fall in the liquid level and we would like to better understand this. The data showing the rise and fall in the liquid level can be seen in Figure 4. These fluctuations of up to 8 percent change can have significant effects on data collected. The electrons released by the initial collision move at a different drift velocity in the liquid and gaseous phases of xenon. If we do not know the exact level of the liquid then it can cause errors in the timing of the secondary pulses, which will propagate errors into the measurement of the z position of the initial event collision. A figure showing the secondary pulse or S2 photon can be seen in Figure 5. When the data from Figure 4 was applied to trial data of a peak the peak was sharpened greatly and more centered on the expected energy for the incoming photons. If we have a more accurate measurement of the surface level this data could be improved significantly.
Figure 4: Level sensor data from liquid xenon prototype detector

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Beyond this work we would also like to make a real time mapping of the surface of the liquid in Fourier space using data from the array of level sensors and their data showing the oscillations of the liquid level. With this data the detector could produce much better results.

Conclusions

There needs to be much work done to get the circuit to a working point.
There is a possibility that this circuit would improve the results of the experiment
and offer a more reliable measurement of the leveling of the overall detector system. Much work still needs to be done in finding the proper components that will allow the circuit to work optimally. Once the circuit and the capacitors for detection have been made there needs to be a set up made for data acquisition. An integrated voltage source would also be useful. Finally the circuit needs to be built onto a printed circuit board of some sort and attached directly to the measurement capacitors. This will eliminate as much of the wiring as possible to reduce most of the noise problems we are currently dealing with.

Once the building and characterization is done there need to be work done on building analysis software. This would theoretically take in data from three points of level measurement and from that be able to map the surface of the liquid xenon. This work is far off though.

Acknowledgements

Thanks to Tom Shutt and Dan Akerib for help with the project. Thanks to Ritchie and Dajan for moral support.
Works Cited
