Development of the front-end board of a Xenon gas Time Projection Chamber at the AXEL neutrinoless double beta decay search experiment

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Abstract. AXEL is a project to search for 0νββ using a High pressure Xe non gas TPC. AXEL uses SiPM’s to measure the energies and the tracks of 0νββ events. About 50,000 SiPM’s are required for final 0νββ searching version, so developing Front-End Boards (FEB) are necessary. We develop FEB that has high energy resolution and wide dynamic range.

1. Introduction
AXEL (A Xe ElectroLuminescence detector) is a project to search for neutrinoless double beta decay (0νββ) of 136Xe, using a High pressure Xenon gas Time Projection Chamber (TPC). Figure 1 is the schematics of the final ton-scale version of AXEL detector. AXEL has following 3 features: High energy resolution (aim at 0.5% FWHM @2.4MeV, Q-value of 0νββ of 136Xe), Tracking for background rejection, and Extendable to large size.

These features are based on ELCC (Electroluminescence Light Collection Cell) plane, that we are developing own (Figure 2). Ionized electrons drift along the electric field and they are collected into cells of ELCC plane. These electrons are accelerated and emit photons by the EL (ElectroLuminescence) process. EL process is the intermittent excitation-deexcitation of atoms (Figure 3). There is good linearity between the number of the emitted photons and the collected electrons, so energy of event can be measured correctly. Event topology is able to be reconstructed from the position of cells and the timing of the signals. Additionally ELCC contain solid PTFE plate, so it can be easily extended.

ELCC has many SiPM’s to detect EL photons. The number of SiPM’s is 50,000 in the final ton-scale version, and in the next kg-scale prototype detector what starts measurement by the next year at the earliest, even contains 1,000 SiPM’s. We start developing the Front-End Board (FEB).

2. Basic structure of FEB
The requirements to FEB are following : High channel density for low cost, Recording waveform for tracking, Adjustable system of high voltage for each SiPM, High resolution for charge of event, and Large dynamic range for pulse width (5 - 300 us) and number of photons (1 p.e. - 10^5 p.e.).
To satisfy these requirements, we designed the FEB as Figure 4. There are DAC on the FEB to adjust the high voltage for each SiPM’s. Common HV source apply same voltage to all SiPM’s and then DAC adjust the ground level depending on each SiPM. Thus the gain of each SiPM is able to be equal. Additionally to get wide dynamic range, we use 2 kinds of ADCs. One is the 50 MSPS for taking dark (1pe.) signal, and the other is 1MSPS for measuring the energy of event. The signals of SiPM’s are divided to 3 ways, one of them is summed up with other signals and used for trigger, and other 2 signals are digitized and measured by these ADCs.

Figure 5 is the analog process part to divide signal. Calibration branch is high gain (×15), smoothed by 100ns filter and sampled by 50MSPS. On the other hand, Measurement branch is low gain (×3), smoothed by 2us filter and sampled by 1MSPS.

### 3. Evaluation of the analog process part

The Analog part is evaluated by 2 ways, simulation and the prototype circuit.

#### 3.1. Simulation

There are 2 kinds of important signals for this experiment. One is the $0
\nu\beta\beta$ signal, the energy is 2458keV and ELCC plane collect about $10^5$ electrons in 10us - 300us. The other is a characteristic X-ray from Xenon that is used for energy calibration. The energy of X-ray is 30keV and about 1200 electrons are collected in 4 - 8us.

To simulate these signals, we use some software’s. Geant4 generate 30keV X-ray or 2 electrons from $0
\nu\beta\beta$ and calculate the number and the position of electrons ionized by them. On the other hand, Garfield++ accelerate an electron and calculate the number of the EL photons emitted in ELCC plane. Combine these simulations, we get the number and the timing of photons entered into SiPM’s. Then, SPICE simulate the response of the circuit against the input signal from SiPM’s. Output signals are digitized and sampled by 1 or 50 MSPS. We evaluated the fluctuation of the sum of output signals.
The results are listed on Table 1. The response of the 30 keV signal reach good resolution, compared with the aim (0.5% FWHM @2.4 MeV). Although the response against 2458 keV signal what digitized by 12 bit doesn’t have enough resolution, the resolution reaches 0.46% FWHM at the 14 bit digitizing one. The contribution of circuit of the value is only 0.21%.

3.2. Prototype circuit
We also make prototype circuit. Function Generator input the rectangle signals into the circuit, and digitize both the input and the output signals by digitizer (CAEN V1724: 100MSPS, 14 bit). These data are down sampled to 1MSPS and integrated. Then we evaluated the fluctuation of the ratio of them.

The results are listed on Table 2. We inputted same charge signals (pulse height × pulse width = const. and the charge is the same value of 0νββ signal). The pulse height is scanned between 0.20 V - 1.00 V and the pulse width is changed between 50 - 250 us depending on the pulse height. First, we measure the fluctuation against 1,000 same shape pulses. Though the fluctuation is changed by the shape of pulse, the fluctuation value is between 0.03 - 0.1% FWHM. Second, we measure the fluctuation among different pulses. The value of fluctuation is 0.039% (r.m.s.) and the convert value is 0.092% (FWHM). They are also good value comparing the aim value.

| Table 1: Simulation results |
|-----------------------------|
| fluctuation of | Number of photons | Integral of Calibration | Integral of Measurement | Contribution of Calibration branch | Contribution of Measurement branch |
| 30keV_12bit [% (FWHM)] | 2.74 | 2.73 | 2.85 | ~0 | 0.78 |
| 2458keV_12bit [% (FWHM)] | 0.67 | — | 0.67 | — | 0.53 |
| 2458keV_14bit [% (FWHM)] | 0.41 | — | 0.46 | — | 0.21 |

| Table 2: Results of prototype circuit |
|-----------------------------|
| Fluctuation of Input/Output | Same shape [% (FWHM)] | Same charge |
| Fluctuation of Input/Output | 0.03 ~ 0.1 (depends on the pulse shape) | 0.092 (converted by std.dev × 2.35) |

4. Summary
AXEL is the project to search 0νββ using 136Xe. We are developing the FEB for AXEL that has high channel density, wide dynamic range, and high resolution for charge of event.

We evaluated the analog process part of the FEB. Simulation shows the resolution of the circuit against the 0νββ signal is 0.46% FWHM. Additionally, the prototype circuit shows the fluctuation against the same rectangle pulses is less than 0.1% FWHM, and that against the same charge pulse is 0.092% FWHM (converted).

Towards the start of the measurement using the 1,000 sh next prototype detector, we will have completed this FEB and evaluates them soon.

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