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Development of high-speed multi-channel data acquisition system for large-area Compton camera (LACC)

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1. Introduction

The large-area Compton camera (LACC)[1] achieves both high imaging sensitivity and high imaging resolution by using large monolithic scintillation detectors. In each detector of the LACC, the interaction energies and positions of the gamma radiation for image reconstruction are estimated using the 36 channel signals from 6×6 photo-multiplier tubes (PMTs) array[2]. In order to process the signals, the current signal processing system utilizes time-division multiplexing, reducing 36 channels to 5 channels. This approach, however, not only increases system dead time, but also makes the system response unstable at high event rate situation mainly due to pulse pile-ups. In the present study, a new high-speed multi-channel data acquisition system, which directly digitize the signal from the preamplifier was developed to address the aforementioned issues. The developed system was then implemented in the LACC to compare the performance with that of the current system.

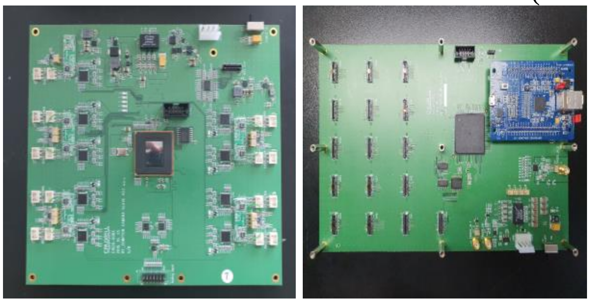
2. Methods and Materials

2.1 Detectors of the LACC

The LACC comprises two large monolithic scintillation detectors. Each detector is composed of a large monolithic NaI(Tl) scintillation crystal, which was custom-built by Scintitech (MA, USA), coupled with 6×6 array of 2-inch square-shaped XP3290 PMTs manufactured by Photonis (France). The signals from 36 PMTs are used to estimate energy and position of photon interaction in the detector.

2.2 Current data acquisition system

In the current data acquisition system[1], a set of signals from the 36 PMTs of a detector module is first duplicated. Then, one set of signals is shaped with a 250 ns fast shaping time and summed to generate a trigger pulse, and the other set of signals is shaped with a 1000 ns slow shaping time for measuring signal amplitude. When the fast-shaped signal exceeds a trigger threshold, the sample-and-hold part samples and maintains the peak voltage of the slow-shaped signal. Then, the sampled voltages of 8 channels are sent to the multiplexer to generate 8-to-1 multiplexed signal by switching input channel sequentially with 1.5 μsec transition time intervals. Finally, the multiplexed signals are transferred to the analog-to-digital converter (ADC) controlled by a field programmable gate array (FPGA). The total signal processing time for one trigger pulse is about 15 μsec.



(a) (b)

Fig. 1. The slave FPGA board (a) and master FPGA board (b) of developed multi-channel data acquisition system

2.3 New data acquisition system

A new multi-channel data acquisition system was developed (Fig. 1). The system is composed of several slave FPGA boards to digitize and process the signals and a master FPGA board to control the slave boards and transfer data to a personal computer. The PMT signal is digitized with 14-bit 100 MSPS ADC and processed with Altera Cyclone 5 FPGA operating at 100 MHz clock rate. Each slave board handles 9 channels of detector signals, and up to 16 slave boards (i.e., total 144 channels) can be connected to one master board. In the present study, 4 slave boards were used to measure 36 channel signals of one detector.

The signal processing and data acquisition flow of the developed signal processing system is shown in Fig. 2(a). It includes smoothing, triggering, measurement of the baseline and the maximum voltage of a pulse, and calculation of a pulse height. The trigger is generated based on the sum of the digitized signals of one detector. If the change of the sum signal within the preset time interval exceeds the trigger threshold, the detector trigger is generated. If the detector triggers occur from both the scatter and absorber within the coincidence window, the coincidence trigger is generated, which means that a candidate for an effective event for the LACC has occurred. When the trigger is generated, pulse heights of corresponding channel is measured and transferred to the PC.

In Fig. 2(b), the parameters for signal processing are displayed with an example signal. The average of the signal during the baseline measurement interval (A) is taken as a baseline, and the pulse height is determined

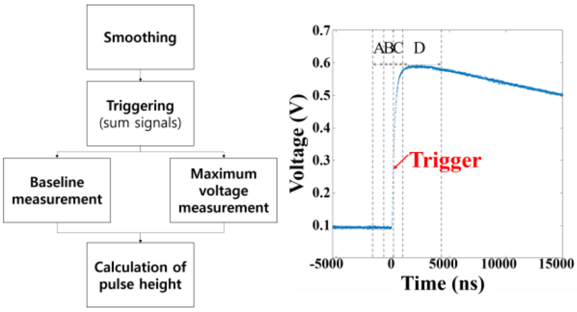


Fig. 2. The signal processing and data acquisition flow of the developed multi-channel signal processing system (a) and parameters for calculating pulse height (b)

as a difference between the baseline and the maximum voltage during the maximum measurement interval (D). The baseline offset (B) and maximum offset (C) are set to control the timing of A and D. The parameters for measurement including A-D have been determined considering the characteristics of signals and noise as follows: 8 clocks for the moving average smoothing to prevent triggering by noise, 20 mV for the trigger threshold that corresponds to 20 keV of lower limit of energy measurement, 80 ns for the baseline measurement interval (A), 100 ns for the baseline offset (B), 700 ns for maximum offset (C), and 1000 ns for maximum measurement interval (D).

3. Performance evaluation

To evaluate performance of the new data acquisition system was tested at different event rates, and the performance of the new system was compared with that of the current system.

A ^{137}Cs point check source (7.2 µCi) located at 44 cm distance, which generate the event rate of 9.14×10^3 cps (counts per second), was measured using the current and the new data acquisition system. The measured energy spectrum is shown in Fig. 3. The energy resolution of each system is 7.92% and 7.74% for the current system and the new system (Fig. 3), respectively.

In the next experiment, the event rate is set to 5.03×10^4 by locating the ^{137}Cs point source at (0, 0, 14) cm. Figure 3 shows the energy spectrum at the increased event rate. The energy resolution of the current system is deteriorated to 19.9%. In addition, the 662 keV peak of source was shifted downward to 578 keV. One of the reasons of this peak shifting is the baseline shift from pulse pile-up. Such instability in pulse measurement affects the calculation of Compton cone to reconstruct source image and results in deteriorated imaging performance at high event rate.

On the other hand, the new system not only maintains the same energy resolution even at increased

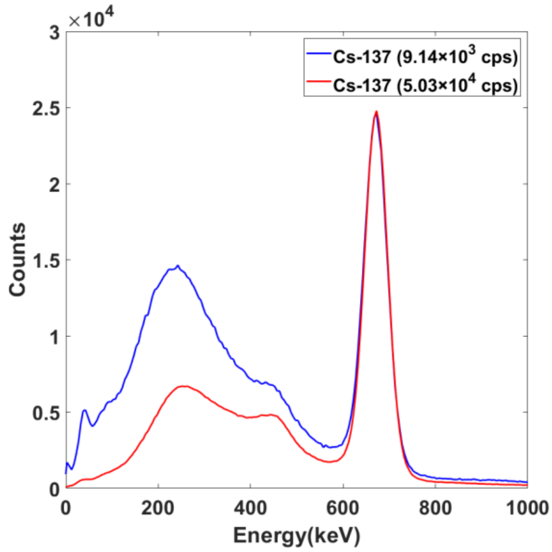


Fig. 3. The energy spectra of ^{137}Cs point source measured by high-speed multi-channel data acquisition system.

event rates, but also peak shifting was not observed. When the event rate was increased up to 6.01×10^5 cps, by locating 251 µCi of a ^{137}Cs point source at (0, 0, 14) cm, the peak shift was not observed and the system showed the energy resolution of 8.22%.

4. Conclusions

In the present study, a high-speed multi-channel data acquisition, directly digiting preamplifier signals, for the LACC was developed and tested. The new system showed stable performance even at the high event rates considered in the present study. The developed system performed energy resolution of 7.74% at 9.14×10^3 cps and 8.22% at 6.01×10^5 cps event rate, without significant peak shifting.

REFERENCES

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[2] Y.S. Kim, J. H. Kim, H. S. Lee, and C. H. Kim, Position-sensitive NaI(Tl) detector module for large-area Compton camera, J. Korean Phys. Soc., vol. 72, no. 1, 2018.