High Density and High Cost Performance Data Acquisition System for Multiple Gamma-ray Detection

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***Abstract*-- To measure neutron cross-section data of the minor actinides, we construct a 4-π Ge-spectrometer utilizing multiple gamma-ray detection method. This spectrometer consists of 30 Ge crystals and BGO anti-Compton shields. Generally, a data acquisition system for such a big Ge spectrometer consists of many NIM modules; it requires large space and huge cost. To overcome these problems, we developed a new data acquisition system with digital signal processing techniques. This system is mounted in a 19 inches VME sub-rack, and the cost of this system is greatly reduced.**

I. Introduction

THE aim of our study is the acquisition of neutron cross-section data for the minor actinides (such as ^{237}Np, ^{241}Am and ^{243}Am) that are important for the development of innovative nuclear reactor technology. We developed a new advanced measurement technology for the acquirement of neutron cross-section data of the minor actinides [1]. In this technique, we construct a 4-π Ge-spectrometer utilizing multiple gamma-ray detection (gamma-gamma or higher-fold coincidence) method. Fig. 1 shows the conceptual design of the 4-π Ge-spectrometer. The present 4-π Ge-spectrometer will be for the Time Of Flight (TOF) with pulsed neutron. This spectrometer consists of 30 Ge crystals and BGO anti-Compton shields. Two of these 30 crystals are segmented into 6 channels, thus, this spectrometer has 40 Ge outputs and 128 BGO outputs.

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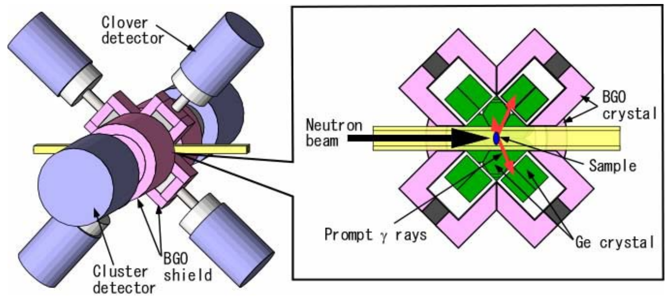

Fig.1. Conceptual design of a 4-π Ge-spectrometer.

In multiple gamma-ray detection method, we deal multiply coincident signals from an array of Ge and BGO detectors. To make a trigger signal, we check the anti-coincidence of the output signals from Ge detectors and BGO detectors first, and we detect a coincidence pattern of the signals from the Ge detectors after that. Generally, a data acquisition system for such a Ge-spectrometer consists of NIM modules. However, because the coincidence pattern is very complicated and changed by the kinds of the experiments, many NIM modules, large space, and costs, which require more than US 20,000 dollars per one Ge detector channel, are required [2].

Recently, digital signal processing techniques and digital-analog conversion technology improves rapidly, and a high density and high cost performance data acquisition system became possible. Because of that, the digitization of the data acquisition system develops rapidly in many fields such as physics experiments and space development [3]-[5].

From these backgrounds, we developed a new data acquisition system for the 4-π Ge-spectrometer with digital signal processing techniques.

II. System Description

A. Conceptual Design

Fig. 2 shows a conceptual design of our data acquisition system. The system consists of three Main ADC modules, five Fast Timing modules and a Coincidence module. A photo of the Main ADC module, the Fast Timing module and the Coincidence module are shown in Fig. 3. The preamplifier outputs of the Ge detectors are directly put into the Main ADC modules and the Fast Timing Modules. The outputs of BGO anti-Compton detectors are only put into the Fast Timing Modules. The Fast Timing Module discriminates detector signals and send them to the Coincidence module. The Coincidence Module checks (anti-)coincidence of these signals and generates a trriger signal to the Main ADC Modules. On the Main ADC modules, when a trigger signal comes, the pulse height is analyzed by fitting or filtering digitized data. All modules are 9U VME boards and can be mounted in a 19 inches VME sub-rack. The cost of this system is reduced one order of magnitude.

B. Triggering

The Fast Timing module consists of a big removable analog daughter board and a 9U digital board. On this analog daughter board, there are 32 input channels from the preamplifier outputs of the Ge detectors and the PMT outputs from BGO anti-Compton detectors. On the analog daughter board, input signals are shaped with a differentiation circuit, a pole-zero cancellation circuit, and amplification circuits. The shaped input signals become LVDS output signals with a Constant-Fraction Discriminator (CFD) for judging the existence of the signals by the gamma rays. The 32 output signals of CFDs are input to the Coincidence Module. The constant of the wave shaping (the time constant of the differentiation circuit and the pole-zero cancellation circuit, and the gain of the amplification circuits) and the threshold values of the CFDs can be changed via a VME-bus or Front Panel switches.

For the Coincidence Module, we choose a Field Programmable Gate Array (FPGA: XC2V2000-6FG676C, 2M-gates 200MHz) because the coincidence condition varied in the experiments and we deal the input logic signals from the Fast Timing. The Coincidence module has the 256 LVDS input channels. It detects a coincidence condition with FPGA and makes and sends a trigger signal to the Main ADC modules.

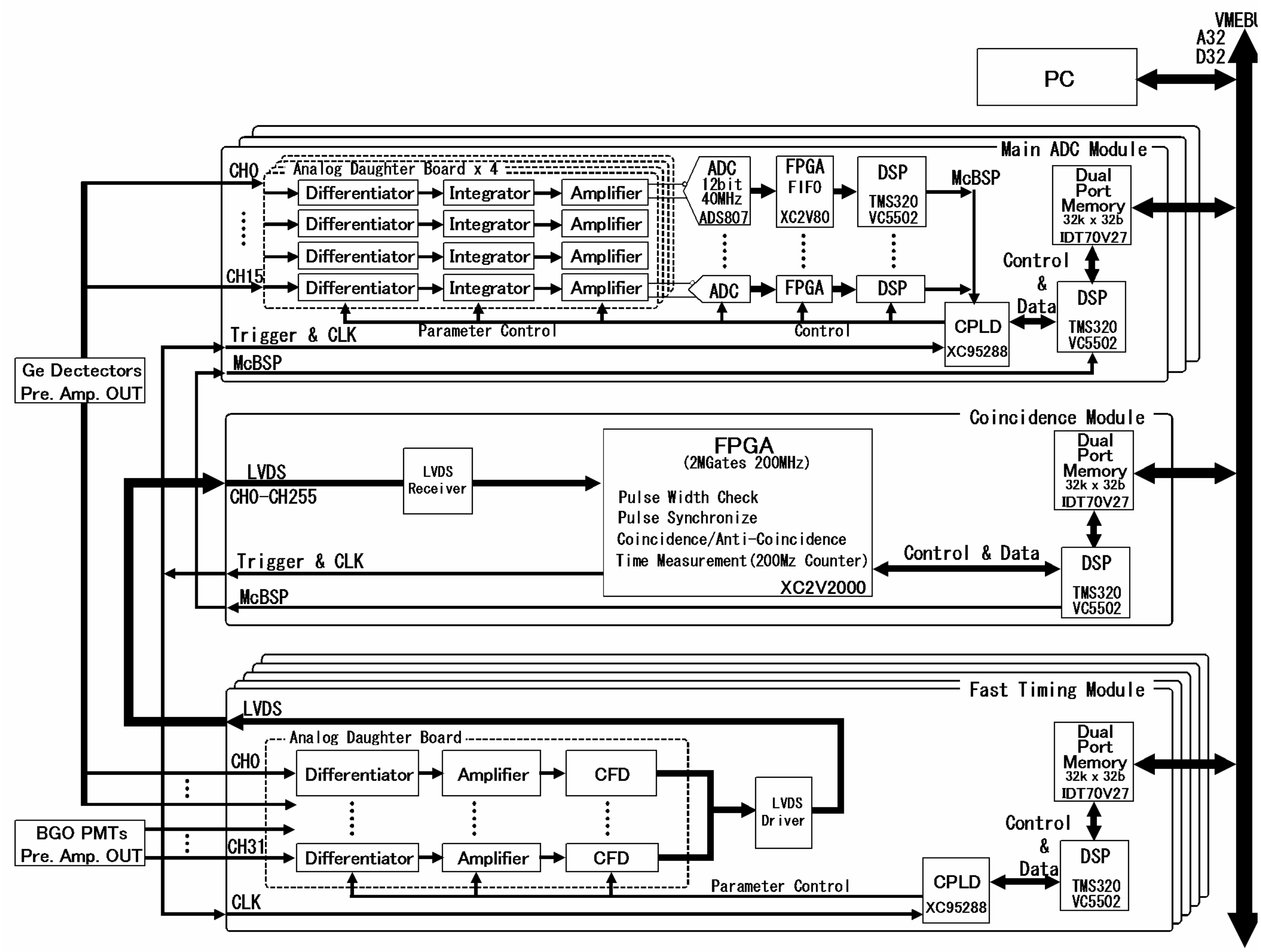

Fig. 2. Conceptual design of the Data Acquisition System for the 4-π Ge-spectrometer.

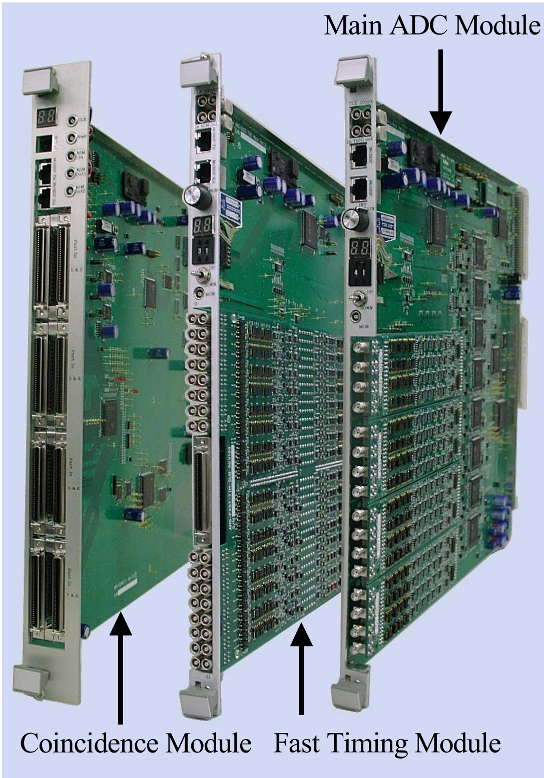

Fig. 3. Photo of the Main ADC module, the Fast Timing module and the Coincidence module.

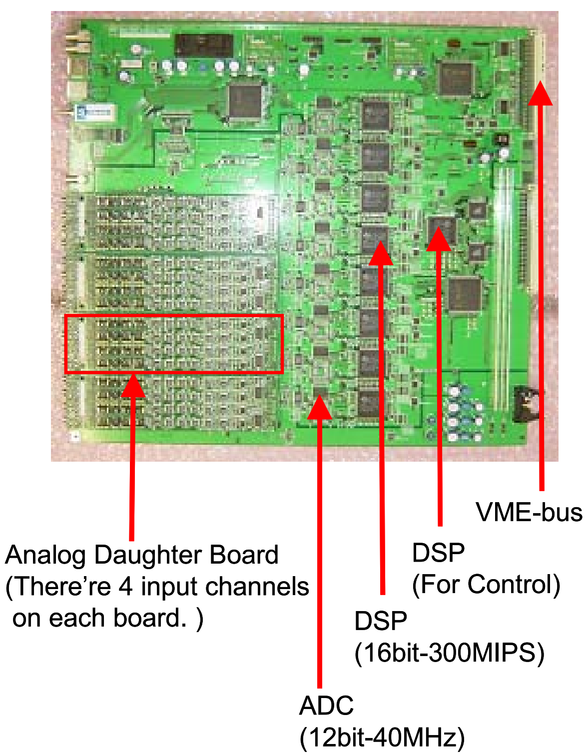

Fig. 4. Photograph of the Main ADC Module.

Because the program of the FPGA can be uploaded via VME-bus, the coincidence condition can be freely changed by the kind of the experiments.

In some of the experiments, we need to measure the time of the signal interval. That time interval is very wide from several ns for judging the coincidence condition to several ms for TOF experiments. Because of that, by using the FPGA, we can measure the time interval of the signals with time resolution of 5ns and maximum range of 84 ms.

On the Coincidence Module and Main ADC Modules, there are connectors for Multichannel Buffered Serial Port (McBSP). McBSP is a TI's proprietary serial line implemented in DSPs and has a speed of 50Mbps. By using McBSP for the communication between the Coincidence Module and Main DSP Modules, it can do a more intelligence triggering, such as to transmit the trigger information to the DSPs on Main ADC modules.

C. *Energy Measurement*

Photograph of the Main ADC Module is shown in Fig. 4.

In the Main ADC Modules, we implement Digital Signal Processor (DSP: TMX320VC5502APGE-300, 16bit 300MHz 600MIPS) for each channel because we want to change a digital filter freely and the cost of the chip is low.

Since detector signal is digitized in a high-speed ADC, it seems possible to do all analog processing such as differentiation and integration or filtering within the DSPs [6, 7]. However, this necessitates longer data size for fitting and consumes data processing power. In addition, because our 4-π spectrometer will be for TOF experiments with pulsed neutron, event rate can be very high and there will be large pile-up. To prepare such large pile-up signal, without pulse shaping, we must reduce amplifier gain and it degrades signal-to-noise ratio. To prepare the pile-up without degrading the signal-to-noise ratio, we implement analog pulse shaping circuits on the Main ADC Modules.

The Main ADC Module consists of 4 removable analog daughter boards and a 9U digital board. Each analog daughter boards has 4 input channels and each channel has analog circuits for differentiation, pole-zero cancellation, integrating, amplification and offset adjustment. All constants of the wave shaping (the differential time, the integral time, the pole-zero cancellation, the voltage gain, and the offset adjustment) also can be changed using a VME-bus or Front Panel switches. The shaped output signals of the analog daughter boards are digitized with 16 ADCs (12bit 40MHz), and the digitized data is stored in FIFO which is implemented in an FPGA. When a trigger signal from the Coincidence Module is comes, the FIFO FPGA sends the digitized data to a DSP with a Trigger ID number. The pulse height is calculated by using the DSP and is sent to another DSP for control via McBSP lines connected through a CPLD. The control DSP bundled 100 sets of the data from the 16 channels, and put into a Dual Port Memory. The bundled data is read out from the Dual Port Memory with a PC.

D. Technical Summary

The following data, shown in Table 1 summarize specifications of our new data acquisition system.

TABLE I
SUMMARIZE SPECIFICATIONS OF THIS DAQ

Main ADC Module		
Analog input	16ch	SMA connector
Input impedance	50 /1k W	Jumper selectable
Input Voltage	0~9/0~-9V	Jumper selectable
Voltage gain	0.1~40	256 steps
Integral time	33ns~3.3us	256 steps
Differential time	220ns~7.9us	256 steps
Time constant of pole-zero cancellation	220ns~220us	256 steps
Offset adjustment	-0.3~0.3V	4096 steps
Fast Timing Module		
Analog input	32ch	LEMO connector
Delay Time of CFD	300ns	Fix (Replaceable)
Threshold Voltage	0~2.5V	256 steps
Input impedance	50 /1k W	Jumper selectable
Input Voltage	0~9/0~-9V	Jumper selectable
Voltage gain	0.1~20	256 steps
Differential time	12ns~3us	256 steps
Time constant of pole-zero cancellation	100ns~200us	256 steps
LVDS Output	32ch	
Coincidence Module		
LVDS input	256ch	32x8ch
Time Resolution	5ns	Max 84ms

III. PERFORMANCE OF THE MAIN ADC MODULES

A complete performance evaluation has not yet been made, because the 4-π Ge-spectrometer hasn't been completed yet. The performance of the Main ADC module has been tested with a pulse generator (ORTEC 419) and Eurisys clover detector, which is one component of the 4-π Ge-spectrometer.

A. Noise And Cross Talk

Fig. 5 shows output signals of ADC #1~4 when test pulse from a pulse generator is injected on input #1. Though periodic noise originated from the VME clock frequency (8MHz) was seen, there is no detectable cross talk and the noise is below acceptable level (1.5~3.3 of least significant bit: LSB).

Fig. 6. shows a time dependency of the peak height on ch1 and 2. Test pulses are generated with a pulse generator, and it was the temperature change of 10K in this measurement. Temperature dependency of the peak height is substantially small, when the peak height is about 1200 LSB, the temperature dependence is less than 0.15 LSB/K at room temperature.

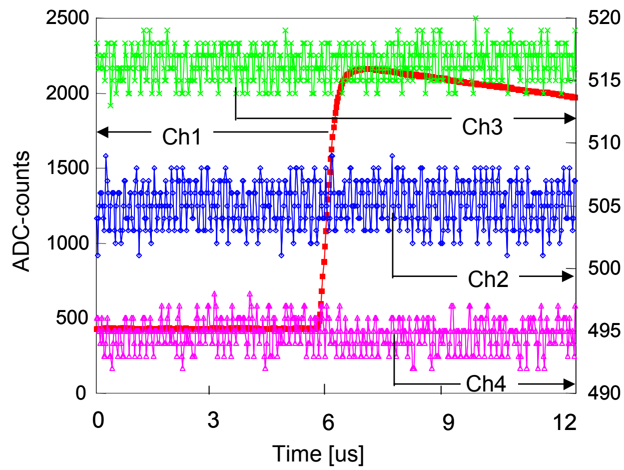

Fig. 5. Output signals of ADC #1~4 when test pulse from a pulse generator (ORTEC 419) is injected on input #1.

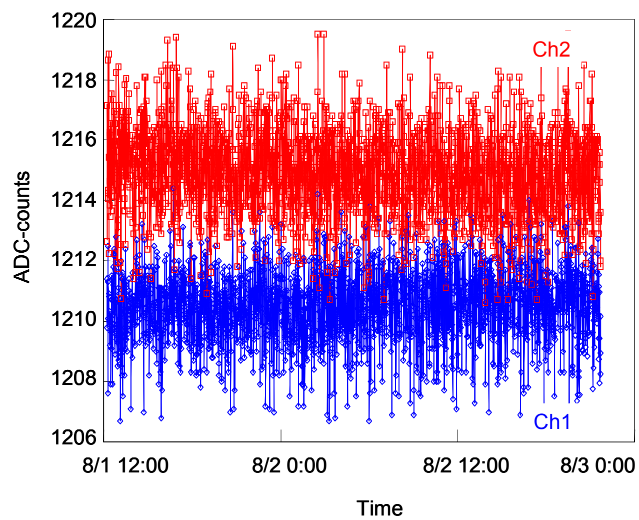

Fig. 6. Time dependence of the peak height on ch1 and 2. Test pulses are generated with a pulse generator.

B. Test With a Clover Detector

To test the performance of the Main ADC module, the energy resolution was measured with the clover detector.

Fig. 7. shows acquired traces for fully absorbed 1.33MeV gamma-rays (^{60}Co). The trace shaped with analog circuits (Differential time: 500ns Integral time: 120ns) is shown in trace (a), and the trace with largest differential time (33us) and smallest integral time (120ns), which is almost the same as preamplifier output, is shown in trace (b). To compare these

traces, the trace shaped with Moving Window Deconvolution (MWD) filtering[8] (filter length: 2us), which is widely used in digital signal processing, is also shown in trace (c).

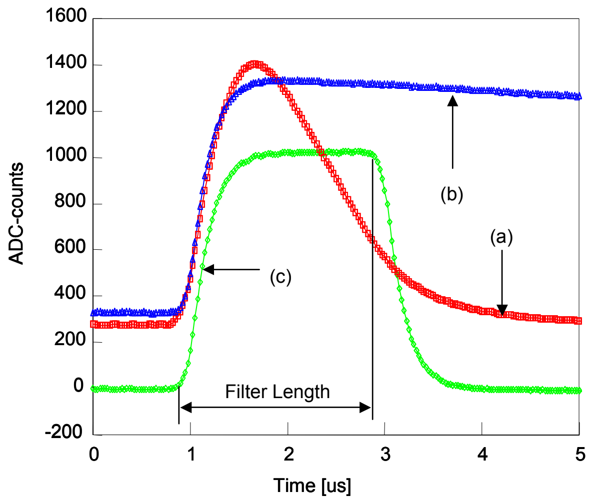

Fig. 7. Acquired traces for fully absorbed 1.33MeV gamma-rays (^{60}Co). (a) with analog filtering, (b) preamplifier output, and (c) with MWD filtering. Note that the gain of (a) is different from the others.

In Table 2, the FWHM of the full energy peak at 1.33MeV is shown. To evaluate FWHM of this system, we measured the gamma-ray spectrum with Labo: 2100C MCA and main ORTEC: 572A amplifier (shaping time 2us). The FWHMs show almost the same value for MCA and the new system, and good energy resolution could be achieved with short shaping time.

TABLE 2
ENERGY RESOLUTION

Filtering	FWHM	
	input #1	input #2
Analog Filtering	2.57	2.48
MWD Filtering	2.52	2.42
MCA and main Amp.	2.30	

IV. CONCLUSION

We have described the design and the performance of a new data acquisition system for the 4-π Ge-spectrometer with digital signal processing techniques. In the tests with the clover detectors, good energy resolution can be achieved with short shaping time. This system can be mounted in a 19 inches VME sub-sub-rack, we can reduce the cost of the readout system by one order of magnitude.

V. REFERENCES

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