DIGITAL SIGNAL PROCESSING SYSTEMS OF AN X-RAY MICROCALORIMETER ARRAY FOR GROUND AND SPACE APPLICATIONS

Session : missions and applications

Short Paper

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ABSTRACT

We are developing a high resolution EDS (Energy Dispersive Spectrometer) for a Transmission Electron Microscope (TEM). The EDS utilizes an array of TES (Transition Edge Sensor) micro-calorimeter, which operates at 100 mK and achieves an extremely high energy resolution of FWHM < 10eV in 0.1 to 10keV energy range. The analog signals from the calorimeter array are continuously digitized. Then X-ray events are detected by a digital logic in an FPGA and the blocks of data are buffered in it. Then the data blocks are transferred to a CPU via SpaceWire. The CPU performs optimum digital filtering to determine the pulse height.

We assume a high count-rate condition, such as 200 counts/s/pixel, and data transfer rate between the FPGA and the CPU is estimated to be 25 Mbps, corresponding to a 800 counts/s (4 pixels per FPGA). SpaceWire can accommodate this high-speed transfer rate, and this is why we chose standardized SpaceWire devices for this system.

All components were connected and system performances are being evaluated. At present, data transfer speed via SpaceWire is ~ 1Mbps and energy resolution using ideal waveforms is ~300 (E/ΔE). We have been improving software and logics. We will combine this data acquisition system with a TES micro-calorimeter array this year.

1 INTRODUCTION

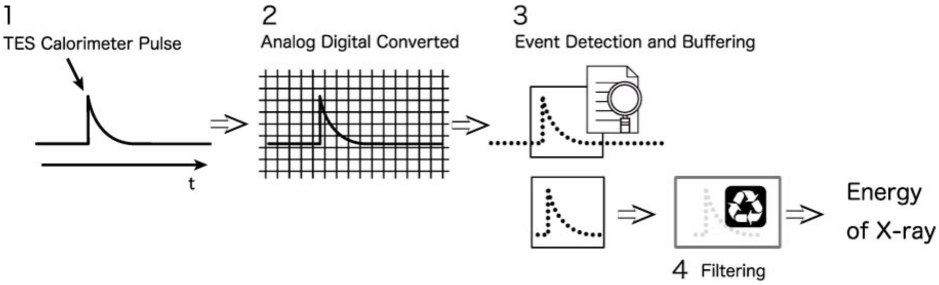
Micro-calorimeter is an X-ray EDS which measures the small temperature increase induced by X-ray with high-sensitive thermometer and achieves very high energy resolution (E /Δ E > 1000). TES micro-calorimeter use TES as a thermometer. To reduce thermal fluctuation, micro-calorimeter is operated at ~100mK. In order to realize such potential energy resolution, a digital waveform processing system in addition to low noise read-out circuits is indispensable. So-called "optimal filtering" to maximize signal-to-noise ratio of a thermal equilibrium calorimeter is realized only by usage of the total wave-form, or wide-band pulse spectrum in the frequency domain[1,3]. It requests a very fast waveform digitizing system with an enough accuracy and multi-input channels (typically ADC vertical resolution >10bit, horizontal resolution >10kHz).

And now, high count-rate adapted calorimeter system is required both in space missions and ground applications. Future X-ray space missions like IXO, which will have collecting area as large as 5 m [2], and X-ray spectroscopic detectors on the ground will request high count rates. As the optimal filtering method assume that each pulse has similar shape to the ideal one, a pulse with a secondary one (pileup events) should be treated with special attention. Discard of pile-up events as dead-time events will reduce the appeals of calorimeters.

In TEM, accelerated electrons (~10keV) interact with target materials and fluorescence X- rays are emitted. Using TES calorimeter as an X-ray detector, surface structure can be scrutinized and perhaps chemical shift (energy shift by chemical bound: ~1eV) can be observed.

2 SYSTEM DESIGN

2.1 EVENT PROCESSING FLOW



Event processing flow can be summarized in following steps;

Step 1: Irradiated energy into a TES calorimeter is converted to the heat and an analog read-out electronics produces a pulse.
Step 2: The output signal is continuously sampled by a fast ADC (analog-to-digital converter).
Step 3: Sampled waveform is scanned to find the pulse in FPGA. When a pulse is detected, a trigger is sent to store the data with enough length to cover the whole waveform.
Step 4: The stored waveform is transmitted one by one via SpaceWire, and a CPU calculated the pulse height by the optimal filtering method.

In step 2, record length, sampling accuracy and speed should match with the requirements from the energy resolution. Clever trigger logic to detect double pulses and buffer handling in step 3 is the key issue to achieve the high count-rate performance. See reference[5] to know more details about these logics.

2.2 SYSTEM REQUIREMENTS

We assumed that 10 pixels of a TES array with a count rate of 200 counts /s/pixel as a spectrometer in a TEM. Energy band is from 0.3keV to 10keV and required energy resolution is 5eV in all range. To achieve required energy resolution, a total waveform (event) becomes 4k Byte (16bit vertical resolution for data handling and length of 2048 samples) and total count rate reaches 2000 counts/s or 8M Byte/s. In order to process such large data in real time, we divided processing flow as shown in 2.1.

2.3 DEVICES

A project to develop common hardware accommodate SpaceWire and data acquisition system has been promoted in Japan for NeXT and other missions by JAXA, Osaka Univ., Univ. of Tokyo and other groups[6]. Digital I/O (DIO) board, one of the outcome of this project, is used in this TES system. It has various data port and a FPGA (Xilinx Spartan-3 XC3S400FTG256) which users can install their logic to handle their data. We programmed the trigger and buffer handling logic, and the control of an ADC board in this FPGA. ADC boards of 4 channels, 14-bit, and 1 MS/s are fabricated for this application. Four channels of waveform data are continuously sent from the ADC board to the DI/O, and the DI/O detects the events and buffered data are sent via SpaceWire to a CPU called “SpaceCube”. SpaceCube is a small TRON-based computer, developed as a platform of SpaceWire verification by ISAS/JAXA and Shimafuji Electronics. Optimal filtering program including the production of the template waveform by FFT, and the calculation of the pulse height by the cross correlation is transported already.

3 EVALUATION OF THE SYSTEM AND FUTURE APPLICATIONS

3.1 SYSTEM ASSEMBLING

The evaluation tests have been started with simulated waveform of TES pulses from a 14-bit function generator. The 14-bit ADC runs in a sampling rate of 1.2 MS/s. The handshaking between ADC and DI/O boards, DI/O and SpaceCube work correctly, and the triggered waveforms are collected by the SpaceCube. We confirmed trigger and buffer handling logic, producing several patterns of waveforms which included pile-up events, and input to the system.

3.2 EVALUATION OF THE PROCESSING SPEED

We evaluated data acquisition speed of event buffering logics in FPGA inputting ideal waveform at various frequencies using function generator. As a result, the event buffering logics in FPGA work well and can collect all input pulses at 1kHz. This is enough for system requirement. We also evaluated event transfer speed between I/O board and SpC via SpaceWire. In this process events were stored in the memory onboard SpC. Event transfer takes 28ms per event (34 events/s, ~1Mbps). If we upgrade the SpaceWire FPGA IP-core this speed will be drastically improved.

3.3 OPTIMAL FILTERING APPLIED TO THE IDEAL PULSES

To assume energy resolution, we input ideal waveform and applied total process to these pulses. In SpC, averaged pulse (figure 3-1) and noise spectrum (figure 3-2) were calculated using collected events and filtering template (figure 3-3) was created using these averaged pulse and noise spectrum. The pha spectrum (figure 3-4) was obtained adapting optimal filtering method to ideal waveforms using this template. We fitted this spectrum with gaussian and get the result that E/ΔE is 300(we assumed gaussian FWHM as ΔE and gaussian center as E). This degradation of the energy resolution will be induced from noise generated in function generator and algorithm used in our optimal filtering method. The cause of the low energy tail seen in figure 1 still be unknown. We have been refining software and logics.

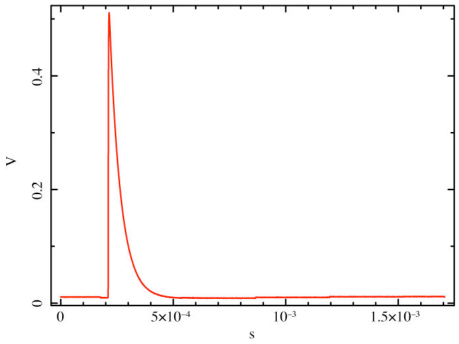


figure 3-1. Averaged pulse.

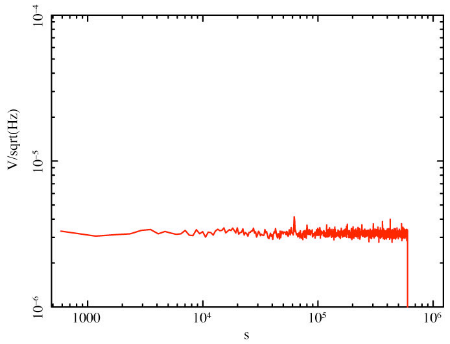


figure 3-2. Noise spectrum.

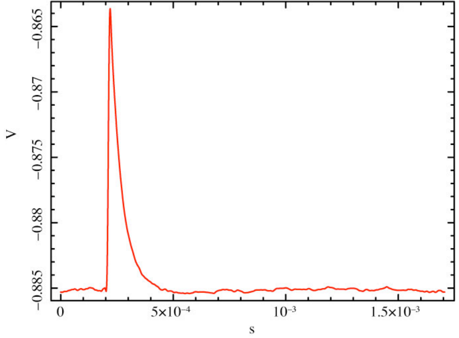


figure 3-3. Filtering template.

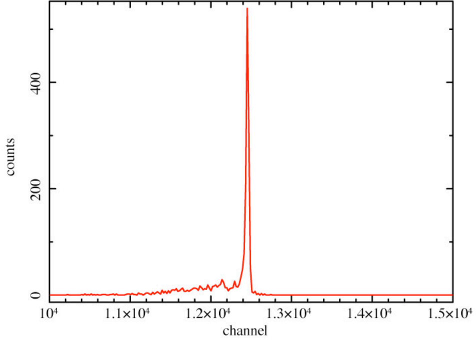


figure 3-4. PHA spectrum.

4 REFERENCE

[1] D. J. Fixen, S. H., Moseley, B. Cabrerra, E. Figueroa-Feliciano, AIPC, PRoc., 605, 339F, (2002).

[2] R. L. Kelly et al., Publ. Astson. Soc. Jap., 59, 77 (2007).

[3] D. MaCammon, Topics in Applies Phys., 99, 1(2005).

[4] K. Mitsuda et al., Journal of Low Temperature Physics, Volume 151 3/4, pp 703(2008)

[5] T. Hagihara et al., Journal of Low Temperature Physics, Volume 151 3/4, pp 997(2008)

[6] T. Yuasa et al., A Portable SpaceWire/RMAP Class Library for Scientific Detector Read Out Systems, International SpaceWire Conference 2008