Development of the Hard X-ray Monitor onboard WF-MAXI

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Abstract

Wide-Field MAXI (WF-MAXI) is a mission to detect and localize X-ray transients with short-term variability including EM counterparts of gravitational-wave events such as gamma-ray bursts and supernovae etc. WF-MAXI consists of two main instruments, Soft X-ray Large Solid Angle Camera (SLC) for localization of the events with few arc-minutes error in soft X-ray band and Hard X-ray Monitor (HXM) to measure the spectrum and the lightcurves in hard X-ray band. The field of view of WF-MAXI is 20% of all sky at any given time and the energy band is covered from 0.7 keV to 1 MeV. We have developed the HXM components which consists of 24 channel arrays of Ce:GAGG scintillators coupled with APDs covering the hard X-ray band with effective area of above 120 cm^2. To read out signals from the censor arrays, we designed a new LSI dedicated with the readout of 32 APDs' signals using 0.35 μm CMOS technology. We will report the integration and the end-to-end test of the components of HXM BBM.

Key words: Instrumentation: X-ray detectors – APD – VLSI – WF-MAXI

1. Hard X-ray Monitor (HXM)

Hard X-ray Monitor (HXM) is a transient monitor for electromagnetic counterparts of Gravitational-Wave (GW) events. It was designed for *WF-MAXI* which was a mission for detection of X-ray emission from gravitational-wave sources with short-term variability and localization of the sources to be enable for follow-up observation in early time. HXM is designed for wide-band spectroscopy with high-time resolution for identification of the EM counterparts such as short GRB.
HXM consists 1-D multi arrays of Ce:GAGG scintillator coupled with avalanche photo-diodes (APDs) with wide FoV: $\sim$25% of the whole sky (Fig.1). From a requirement of the mission, the detector is small size of $\sim 15\times15\times10$ cm^3 and total power consumption of $<$10 W. The energy band is 20 keV – 1 MeV with an effective area of 120 cm^2 at 30 keV. HXM also has localization capability to utilizes a shaded pattern created by passive shields with accuracy of a few degrees.

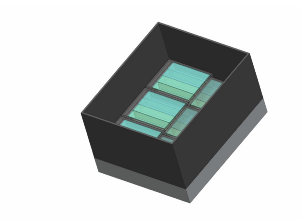

Fig. 1. Schematic view of HXM

2. Development and Performance of VLSI

We have developed new VLSI dedicated for amplification and readout of signals from APDs, which has Wilkinson-type analog-digital converters (e.g., mixed signal LSI).

We utilized a well-studied 0.35 μs CMOS technology; Open IP project initiated by Prof. Ikeda and accumulated knowledge based on developments of CdTe sensors (Sato et al. 2011).

To clear the requirement of the lower limit of energy band of 20 keV, amplifiers of the VLSI must be low noise. However, as a detector capacitor of APDs is very large ($\sim$100 pF), the amplifier noise is very crucial for detection of the low energy photons. In this case, the noise is composed of Johnson and flicker noises. To reduce these noises, we then designed an input transistor of charge sensitive amplifier (CSA) to make a drain current larger and the parallel number of the input transistor larger. Furthermore by transient and AC analyses using SPICE simulator, we determined finely tuned circuit parameters which fulfilled low noise of $\sim$2100e- (RMS) at 100 pF. Then we fabricated the VLSI with function of 32-ch analog amplifiers and AD converters optimized for APDs. From the measurement of the fabricated VLSI, the waveforms (Fast and Slow) were almost the same as the simulated one (Fig.2) and noise performance achieved 1930 e- +1.9e-/pF (RMS).

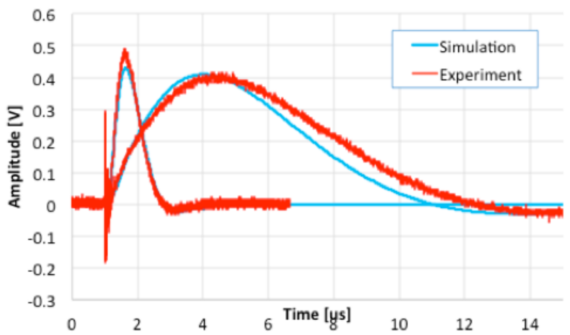

Fig. 2. The experiment and simulated waveforms of Fast and Slow signal by new VLSI for HXM

3. APDs and GAGG crystals

A unit of scintillator arrays consists of scintillator crystal with size of 50×10×10 mm^3 coupled with APD with size of 10×10 mm^2 (Fig.3). 24 units are arranged in 2 rows (12×2) on aparture. We adopted Ce:GAGG (Ce-doped $Gd_3Al_2Ga_3O_{12}$) crystal which had advantages; no hygroscopic, large light yield of 46,000 photons/MeV and fast decay time <100 ns. We also adopted reverse-type APDs of 5×5 mm^2 (S8664-55 provided by Hamamatsu Photonics) which are flight-proven technologies developed by TSUBAME (Yatsu et al. 2014) and ASTRO-H (Kataoka et al. 2012).

We measured the spectrum using the scintillator unit and the new VLSI. Figure 4 shows the spectrum of 137Cs at 25 degrees C. The peak of 32 keV was clearly detected and the noise peak was lower than the lower limit of energy band of 20 keV. The energy resolution was 54.3% at 32 keV and 7.2% at 662 keV.

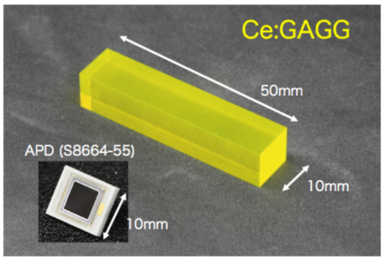

Fig. 3. Size of a unit of crystal and APDs for scintillator-arrays.

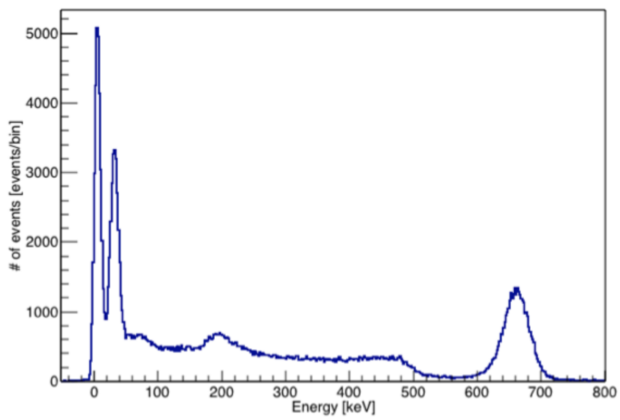

Fig. 4. The spectrum of 137Cs measured by Ce:GAGG+APD and new VLSI. The peak near 0 keV is noise.

4. Data Processing Board

We fabricated data processing FPGA board for telecommunication and control of sensor which made by Meisei Electric Co., Ltd. The FPGA communicate with PC by USB. It make house keeping data per 1 sec and multichannel photon (event by event) data per signal, and control LSI, SRAM, clock, SRAM, ADC and HV with Registered buffer.

We performed operation check of the FPGA and took a spectrum using the FPGA from single Ce:GAGG+APD and the VLSI unit. We will take multi channel data from multi unit arrays.

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