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Performance and limitations of the pulse shape processor of ASTRO-H SXS for bright X-ray targets

Main author:

ISHISAKI Yoshitaka

Co-authors:

Boyce Kevin R., NASA/GSFC
Chiao Meng P., NASA/GSFC
Eckart Megan, NASA/GSFC
Ishisaki Yoshitaka, Tokyo Metropolitan University
Kazuhisa Mitsuda, ISAS/JAXA
Kelley Richard L., NASA/GSFC
Kilbourne Caroline, NASA/GSFC
Leutenegger Maurice, NASA/GSFC
Porter F. Scott, NASA/GSFC
Seta Hiromi, Tokyo Metropolitan University
Takeda Sawako, Saitama University
Tashiro Makoto S., Saitama University
Tsujimoto Masahiro, ISAS/JAXA
Watanabe Tomomi, NASA/GSFC
Yamada Shinya, Tokyo Metropolitan University

The PSP (Pulse Shape Processor) is a digital signal processing electronics for the microcalorimeter instrument, SXS (Soft X-ray Spectrometer), onboard the X-ray astronomy satellite, ASTRO-H, to be launched in 2016. The SXS has 36 sensor pixels, which are operated at 50 mK to measure heat input of X-ray photons and realize energy resolution of < 7 eV FWHM in the range 0.3-12.0 keV. Receiving digitized wave-form (14 bit, 12.5 kHz sample) from 2x18 channels, two identical units of PSP-A and -B trigger X-ray events, assign an event grade, and perform optimal filtering to measure energy deposit on the microcalorimeter pixels. One unit of PSP is composed of one FPGA board and two CPU boards. The flight hardware of PSP including the FPGA logic is already mounted on the spacecraft, and the flight-candidate onboard software for CPU is written in EEPROM of the flight PSP. It is a challenge to process as much X-ray events as possible within the limited resource of four CPU boards for space use (60 MHz clock of CPU, 4 MB

SRAM + 64 MB SDRAM), without losing any function for pulse detection, event grading, and input energy evaluation. Requirement for SXS is to process more than 150 c/s/array, corresponding to 37.5 c/s/CPU. It is also needed to reconstruct the actual observing time (GTI; Good Time Interval, in word of X-ray astronomy) by the offline process on ground.

We tested performance of PSP for high count rate X-ray irradiation up to ~ 2000 c/s/array using the engineering model (EM) of PSP, which is electrically identical to the flight hardware with the same FPGA code. The same binary image of EEPROM for the onboard software can be used for the PSP EM. The rate of 2000 c/s/array corresponds to very bright celestial target for SXS, e.g., point-like source with X-ray flux of 1 Crab unit. It is demonstrated that PSP can process more than ~200 events/s/array, including X-ray events and electrical crosstalk events. The electrical crosstalk events originate in wiring of the detector signal output, which have fast rise-time and easily screened out by offline processing. Fraction of electrical crosstalk depends on input X-ray energy and the pulse threshold. It becomes more than 100% above a few keV with default threshold of PSP.

PSP begins to discard events when the input rate exceeds the processing limit of ~200 c/s/array, namely ~50 c/s/CPU. Discarding events is usually done by flushing the waiting FIFO for each pixel. PSP reports the time-tags of the first- and last-event discarded, mixing into the normal events. It is also demonstrated that offline software can reconstruct the GTI using the time-tag information even in the brightest irradiation of ~2000 c/s/array. In the implementation of the onboard software, each microcalorimeter pixel is taken care by a separate computer task (or thread), and they are scheduled in the same priority. Therefore, when the count rate is not uniform among the pixels, almost 100% of events are processed for pixels with count rate less than ~5 c/s/pixel, while dead time fraction increases in proportion to the count rate for pixels with higher count rate. Non-uniform irradiation is usually the case for a point-source observation with SXS, because the X-ray from the target is focused by Soft X-ray Telescope (SXT) with half power diameter of ~ 1 arcmin, which is comparable to the SXS field of view of 3.05 arcmin. This automatic adjustment is useful for observation of bright X-ray targets, because central high rate pixels are mostly low-grade events which have degraded energy resolution, while outermost pixels with moderate count rate are expected to have better energy resolution.