High-speed X-ray imaging and spectroscopy system with Zynq SoC for solar observations

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Abstract

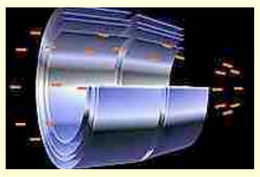
We developed a system combining a back-illuminated CMOS sensor and Xilinx Zynq system-on-chip (SoC) device for high-speed soft X-ray (0.5-10 keV) imaging and spectroscopy observation of the Sun to investigate dynamics of the solar corona. We use the Zynq SoC device to achieve X-ray photon counting measurements with a frame rate of ~1000 frames per second. We are going to use the system for the Focusing Optics Solar X-ray Imager (FOXSI) sounding rocket experiment for the first 2-dimensional X-ray imaging and spectroscopy of the Sun.

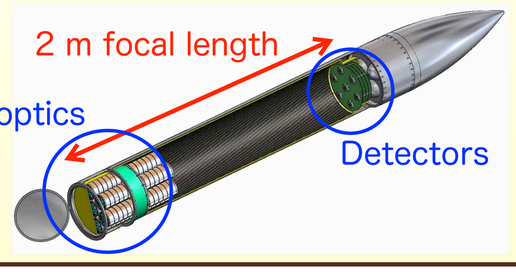
Soft X-ray observation of the Sun with the sounding rocket

Since a typical timescale of phenomena in the solar corona is a few minutes or less, X-ray imaging and spectroscopic observation was not realized with slow readout speed of CCD cameras. We will achieve the first soft X-ray (0.5-10 keV) imaging spectroscopy of the Sun by using a high-speed back-illuminated CMOS sensor with a frame rate of 1000 frames per second for an area larger than 100 x 1000 pixels (See presentation 394 by Narukage et al.).

We will apply this technique for the third flight Focusing Optics Solar X-ray Imager (FOXSI-3), international collaboration sounding rocket experiment by University of Minnesota, University of California, Berkeley, NASA and JAXA.

FOXSI achieved high-sensitivity hard X-ray observations of the Sun, and the combination with the soft X-ray instrument for FOXSI-3 will cover wider detectable temperature range.

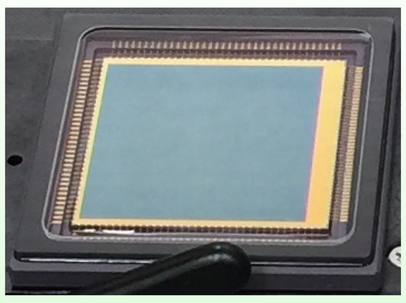




FOXSI soft X-ray observation summary

Energy range	~0.5-10 keV
Energy resolution	240 eV FWHM (@5.9 keV)
Focal length	2 m
Spatial resolution	~5'' FWHM
Field of view	Almost entire solar disk (high-speed readout is for a part of the field of view)
Observational duration	~360 s
Launch site	White Sands Missile Range, New Mexico, USA
Launch date	August 2018

CMOS sensor for the flight



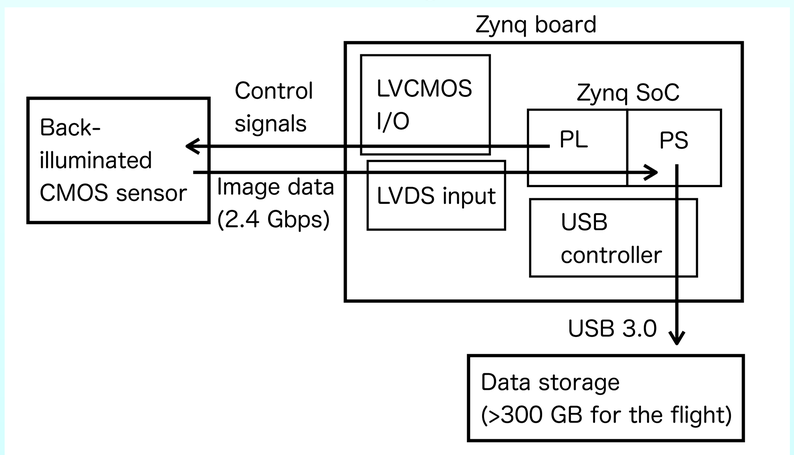
High-speed CMOS sensor for the flight.

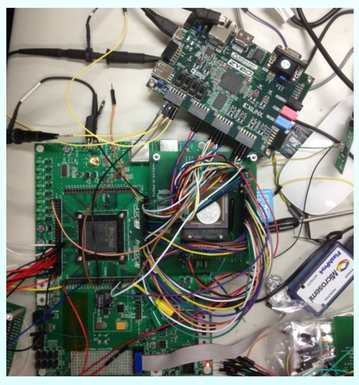
We will use a back-illuminated CMOS imaging sensor with low-noise and high-speed readout capability to realize soft X-ray imaging and spectroscopy from 0.5 keV (Narukage et al., in prep.). The output data rate of the sensor is 2.4 Gbps, and we need a readout system to drive the sensor, acquire and save high-speed data with a compact size and vacuum capability to launch by the sounding rocket.

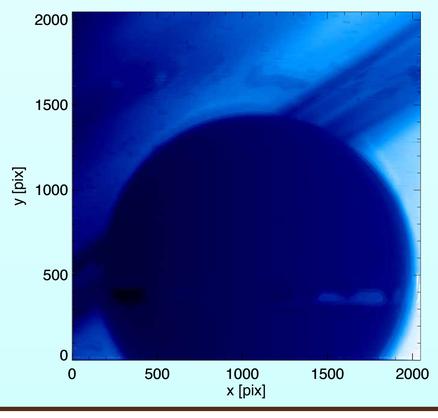
High-speed DAQ system with Zynq SoC

We will use a device in the Xilinx All-Programmable System-on-Chip (AP SoC) Zynq series to realize the high-speed data acquisition during the flight. Zynq has flexibility of software (asynchronous) and high-speed of hardware (synchronous) by combining ARM CPU core (processing system, PS) and programmable logic (PL) part in a single chip. Close connection between PS and PL provides high bandwidth, and we can achieve the high-speed imaging and spectroscopy by using PL to control the sensor and receive data, and PS to record the data with a file structure using an operating system.

To confirm this concept, we developed a prototype system with a commercial Zynq evaluation board ZYBO, and we successfully read and save image data from the CMOS sensor for the flight.



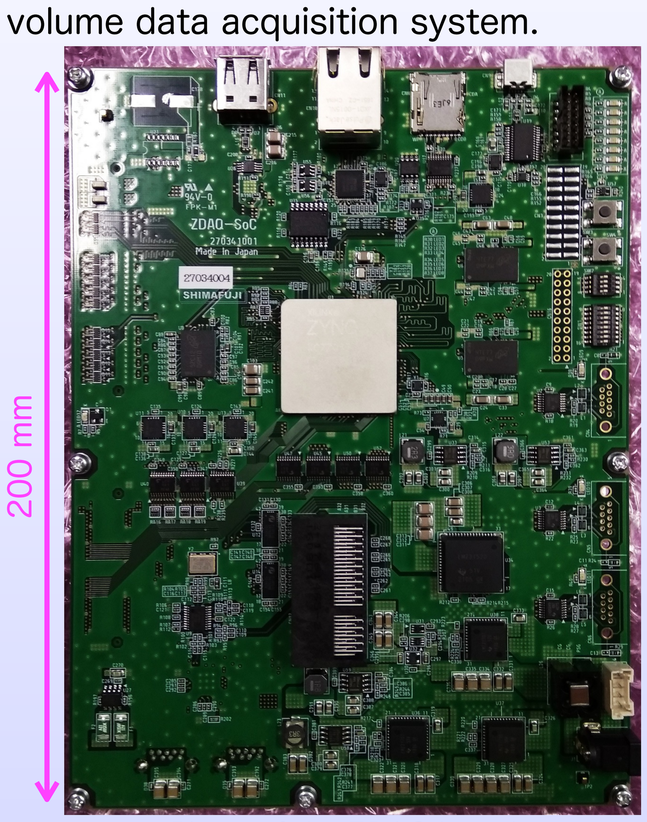




Block diagram of the high-speed CMOS readout system (left), Photo of the prototype system (top right) and obtained image (bottom right)

Readout board "ZDAQ"

For the flight, we developed a new powerful and compact data acquisition board "ZDAQ" with a Zynq chip, enough number of I/O ports to drive the CMOS sensor and several interfaces (USB3.0, PCIexpress, Gigabit Ether and SpaceWire), as a general purpose data acquisition module. Many applications are possible for high-speed and large volume data acquisition system.



⇔ 1 GB DDR3
⇔ SD card slot (for boot)

SoC chip: ZYNQ XC7Z045 with ARM Cortex A9 CPU core (Dual core, 667 MHz)

⇔ USB 3.0
⇔ PCIe x 4
⇔ 1000Base Ether
⇔ SpaceWire x3
⇔ 96 LVCMOS I/O
⇔ 48 LVDS I/O pairs
⇔ 256 MB SDRAM buffer

Photo of the ZDAQ board

We also developed a board "ZDAQ-ANALOG-1" for 200 Msps A/D, D/A conversion and DDS easily connectable to ZDAQ.

Summary

- For the first 2-dimentional soft X-ray imaging and spectroscopy with the FOXSI-3 sounding rocket experiment, we developed a readout board with Zynq SoC.
- The prototype system successfully acquire data from the CMOS sensor for the flight, and we developed the new data acquisition board ZDAQ for the FOXSI-3 flight and other applications.