The Performance test of pnCCD with FPGA-based operating system for a CubeSat mission

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Abstract

On 17 August 2017, the LIGO/Virgo collaboration detected a signal of gravitational waves, named GW170817, associated with the merger of two neutron stars. This event was the first detection of the electromagnetic counterpart of gravitational wave events. In general, the error image region of the gravitational wave detectors ranges from a few square degrees to several hundred square degrees. To search for the origin of the gravitational waves or the energetic explosions such as the gamma-ray burst, X-ray observation covering a wide field of view with a good sensitivity is essential to achieve the goal. One of the good candidate instruments to achieve our goal is the combination of an X-ray optics called Lobster-eye optics (LEO) and a large area Si pixel imaging sensor. Furthermore, thanks to the light weight of LEO, it is possible to install on a small platform such as a CubeSat.

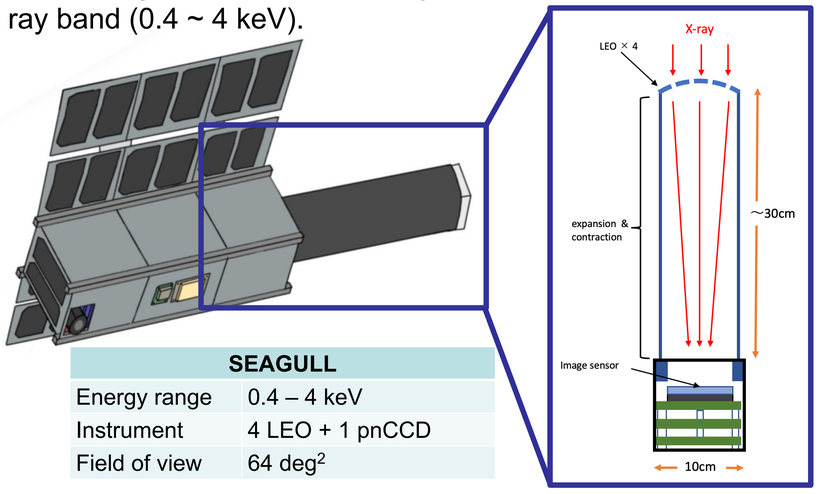
Here, we introduce a future 3U CubeSat mission for searching the electromagnetic counterpart of gravitational waves in the soft X-ray band (0.4 ~ 10 keV) with ~arcmin localization accuracy. The pnCCD detector fabricated by PNSensor Inc. can achieve our mission requirements as an X-ray detector. To operate the pnCCD detector, we developed an FPGA-based fast readout system which is a very compact design to install on the CubeSat mission.Also, we investigate the readout noise of CAMEX, which is the readout ASIC of pnCCD. As a result, the readout noise was ~ 7.4 e^-. In this paper, we report the performance of pnCCD applying our compact FPGA-based data processing system.

3U CubeSat

SEAGULL SEArching origin of Gravitational wave by 3U SateLLrite

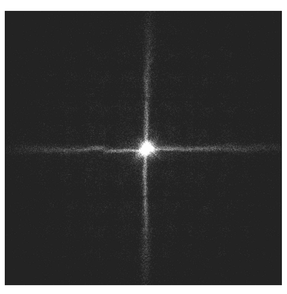
The error region of the gravitational waves detectors ranges from a few square degrees to several hundred square degrees. To search for an origin of gravitational-waves or the energetic explosions such as gamma-ray burst (GRB) , X-ray imaging observation covering a wide field of view with a good sensitivity is essential to achieve the goal.

SEAGULL is a future 3U CubeSat mission for searching the electromagnetic counterpart of gravitational waves in the soft X-ray band (0.4 ~ 4 keV).



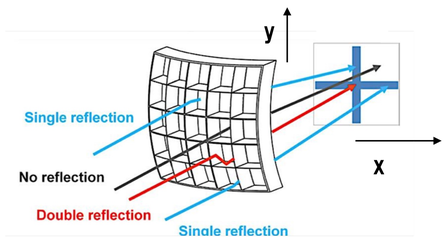
SEAGULL	
Energy range	0.4 – 4 keV
Instrument	4 LEO + 1 pnCCD
Field of view	64 deg^2

Lobster Eye Optics



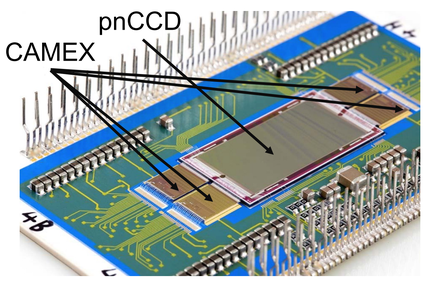
The best-focused X-ray images obtained by LEO (NNVT inc.)

Lobster eye optics (LEO) is an optics composed of many small square-sided tubes aligned along a sphere. LEO can cover a wide field of view in soft X-rays.



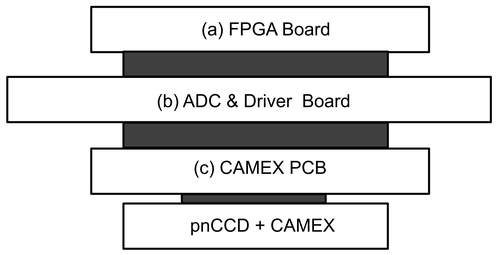
pnCCD & CAMEX

pnCCD is the high resolution spectroscopic X-ray imaging detector developed by PNDetectors. CAMEX is the front-end readout ASIC for pnCCD. There are 4 CAMEX for 1 pnCCD, each CAMEX has 132 channels. pnCCD and CAMEX are mounted on the same ceramic board.



pnCCD	
Active image size	25.3 x 12.7 mm^2
Energy range	0.2 ~ 30 keV
Pixel size	132 μm x 132 μm
Number of pixels	96 (H) x 192 (V)
Frame Rate	~ 1000 fps(max)

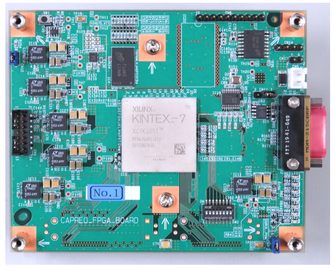
FPGA-Based Operating System



We developed a pnCCD operation system based on field-programmable gate array (FPGA). This system include a (a) FPGA board, an (b) ADC & Driver board, and a CAMEX PCB.

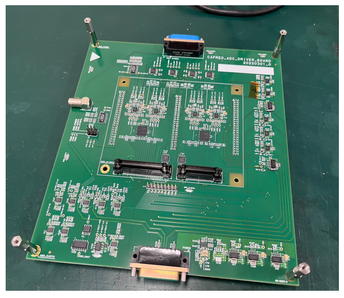
(a) FPGA Board

- Kintex-7 XC7K325T-1FFG676I
- The FPGA controls the pnCCD and processes the image data



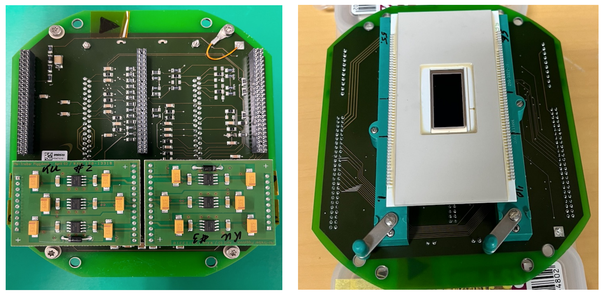
(b)ADC & Driver Board

- Supply voltage setting
- ADC : ADC3441, TI

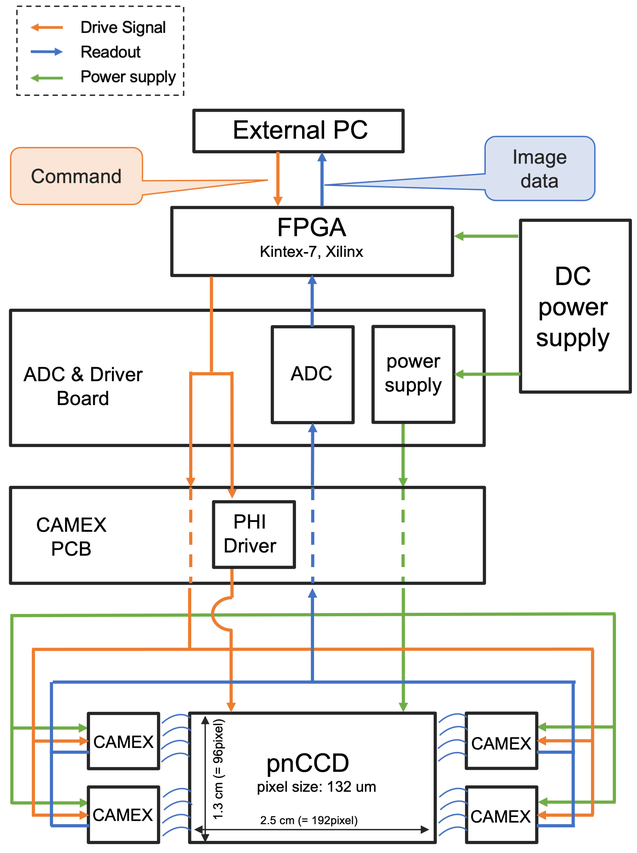


(c) CAMEX PCB

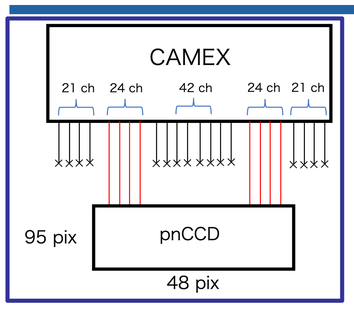
- pnCCD & CAMEX are locked on the zero-force socket

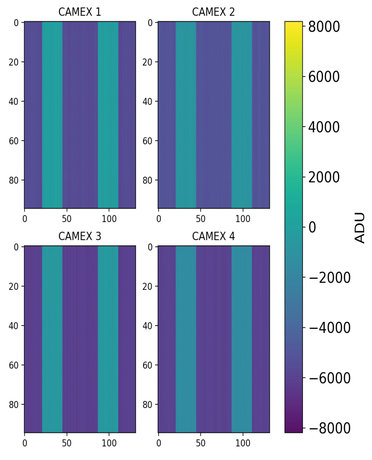


System configuration



Performance Verification





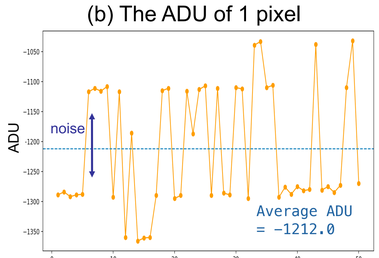
(a) pnCCD image data

Readout Noise

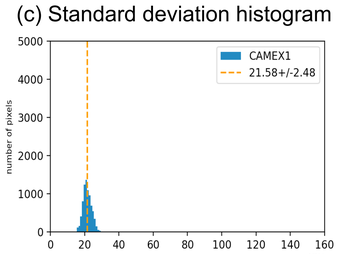
Figure (a) shows the image taken by the pnCCD. The green regions are the data from CAMEX channels which connect to the pnCCD. And the blue regions are the data from non-connected CAMEX channels.

We measured the readout noise by using the data of the blue regions. First, we took 50 frames. Then we calculated the average ADU & standard deviation of each pixel. Figure (b) shows the ADU of 1 pixel for 50 frames, and figure (c) shows the standard deviation histogram of all pixel in CAMEX1. The standard deviation was ~ 22 ADU, which corresponds to ~ 7.4 e^- in CAMEX1.

(b) The ADU of 1 pixel



(c) Standard deviation histogram



Future Work

We will investigate the spectroscopic performance of pnCCD by using the Fe-55 X-ray source. And we will determine the energy resolution and the lower detectable energy threshold by X-ray irradiation test.

As the future plan of the operating system, we will separate the power supply circuits from the ADC & Driver board.