Development of miniaturized circuit boards for GEM detectors onboard the CubeSat X-ray observatory NinjaSat

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1. Introduction

NinjaSat (Enoto+20)

- 10×20×30 cm^3 size CubeSat X-ray observatory (Fig. 1)
- Scheduled to be launched in Oct. 2023
- Operation altitude: 550 km
- Observe X-ray transient from bright neutron stars or black holes
- Flexible observation in cooperation with ground-based and space station observatories

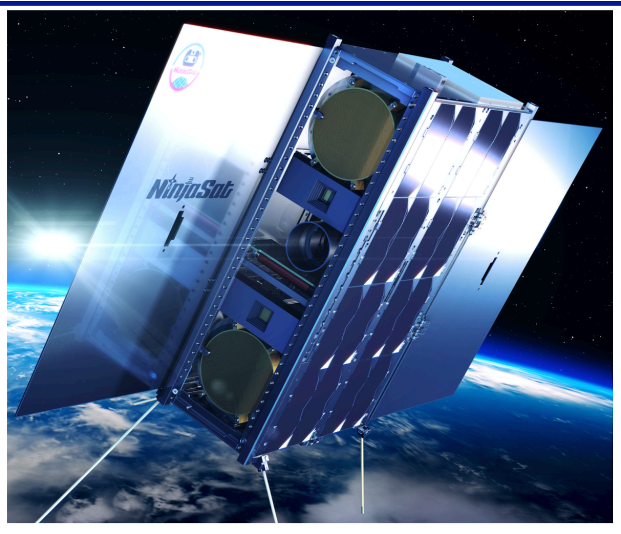

Fig.1 CG Image of NinjaSat

Gas Multiplier Counter (GMC)

- 10 cm cube X-ray detector (Fig. 2) ×2
- Observation band: 2–50 keV
- Achieved energy resolution: 25% (FWHM) @ 6 keV
- Sensor
  - Generate charges by photoelectric effect
  - Filled with Xe/Ar/DME (volume ratio: 75/24/1 @ 0˚C, 1.2 atm)
  - Equipped with **single liquid crystal polymer Gas Electron Multiplier** (Tamagawa+09) (Fig.3)

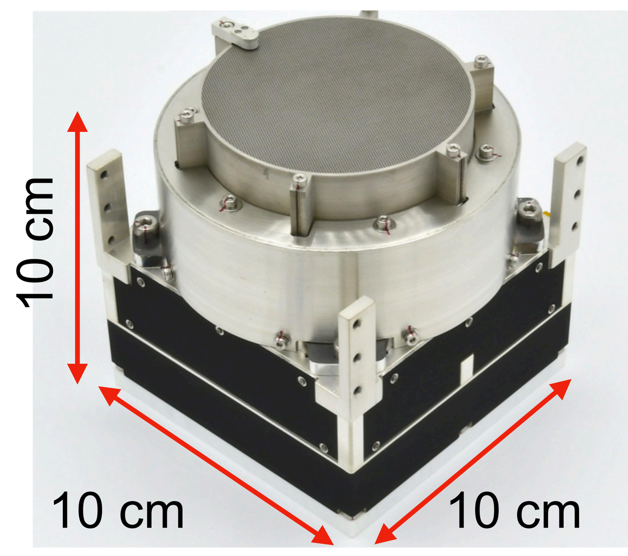

Fig.2 Appearance of GMC

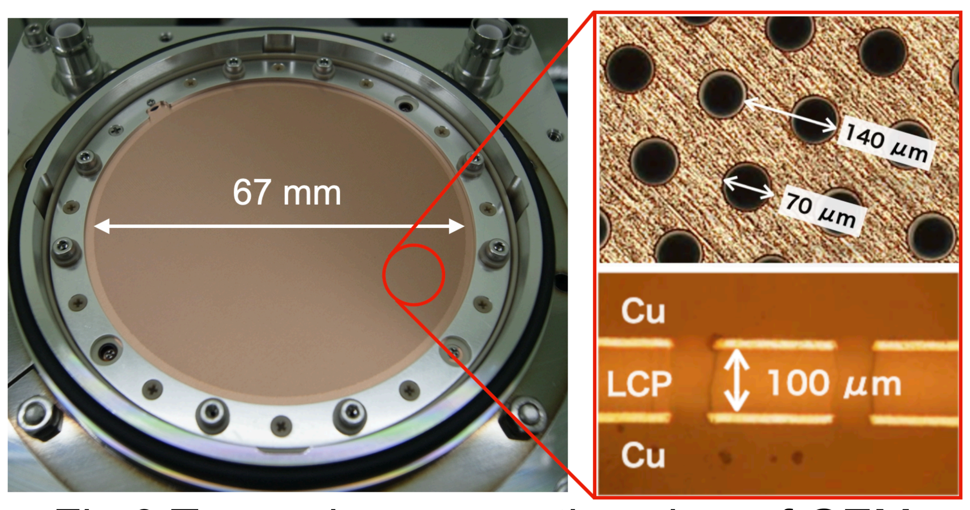

Fig.3 Top and cross-section view of GEM

Front End Card (FEC)

- Apply High Voltage (HV) to the Sensor (Fig.4,5)
  - Applied Voltage to GEM: 590 V
- Analog signal processing (Fig.4,5)
  - 2 V dynamic range
  - Conversion gain: 20 mV/keV
  - Input-output linearity <2% @ 2–50 keV
- Low power consumption of 130 mW

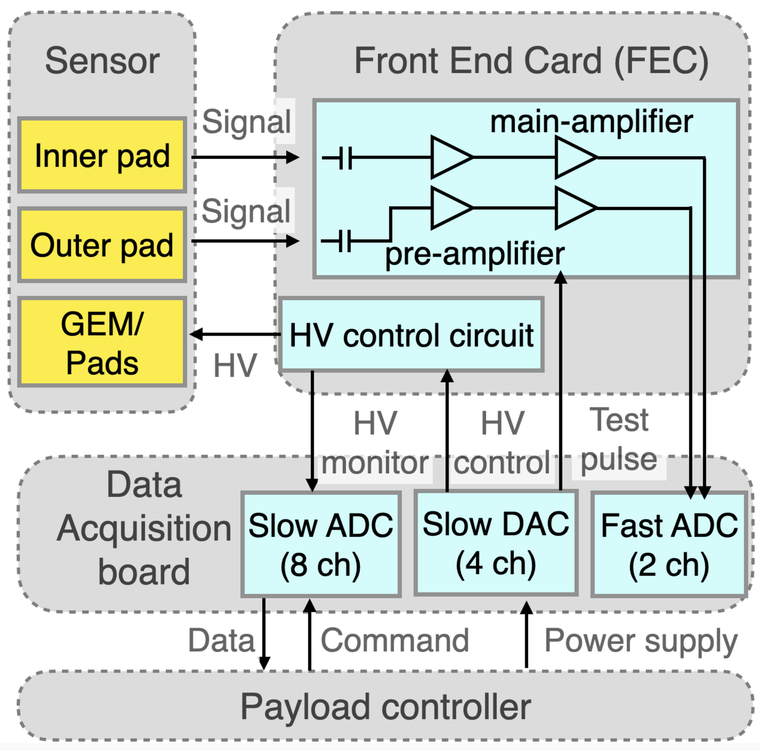

Fig.4 Function diagram of GMC

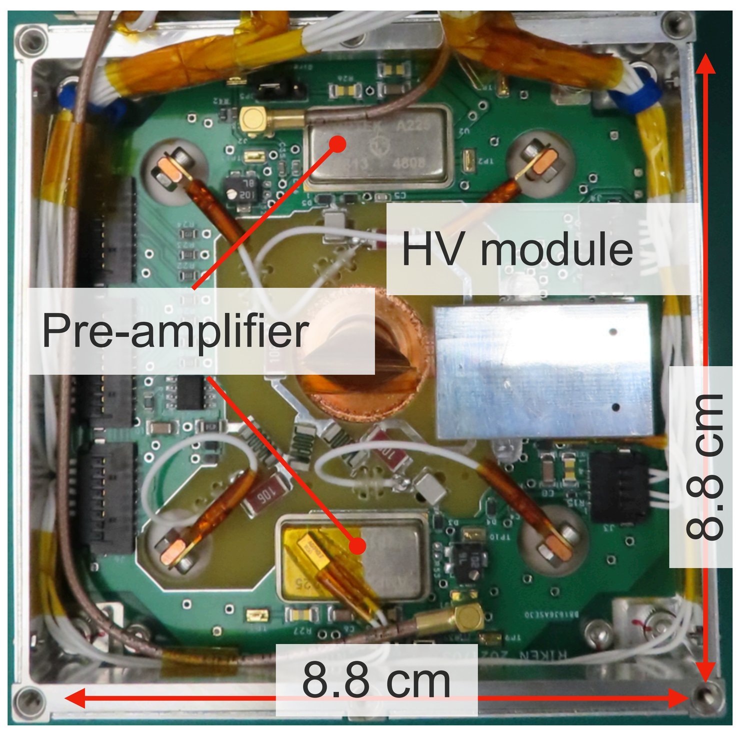

Fig.5 Appearance of FEC

Purpose of this study

Design and performance evaluation of FEC

- Noise suppression from a HV module
- Evaluation of discharge risk by heavy ions in space

2. Noise suppression

HV module

We selected the small size module UMHV0520 (HVM Technology, Inc.) (Fig.6)

- Output up to 2 kV
- Oscillation frequency: 40 kHz

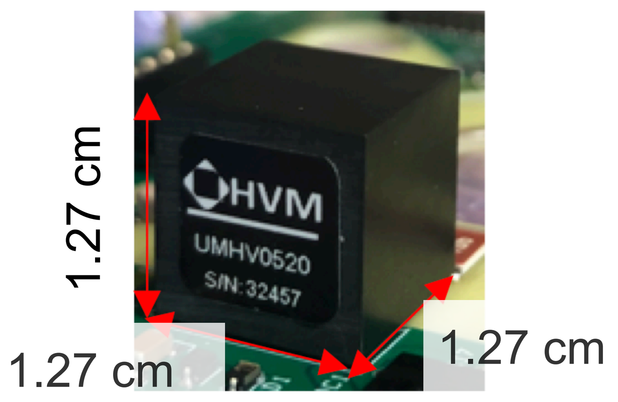

Fig.6 HV module UMHV 0520 (HVM Technology, Inc.)

The HV module is mounted near pre-amplifiers

Noise amplitude ~1 V on the preamplifier output of the prototype FEC

Suppression method

- Analog filter circuit (Fig.7, 8)
- Aluminum shields (Fig.9)

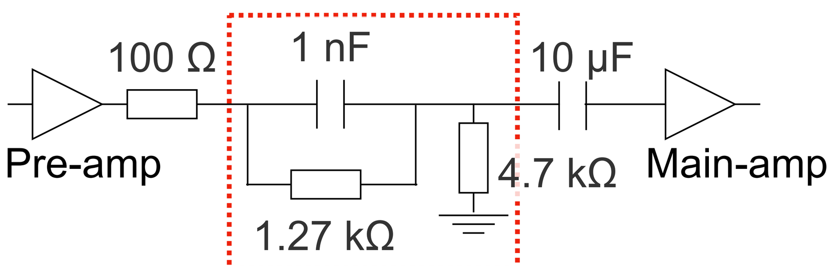

Fig.7 High-pass filter circuit diagram

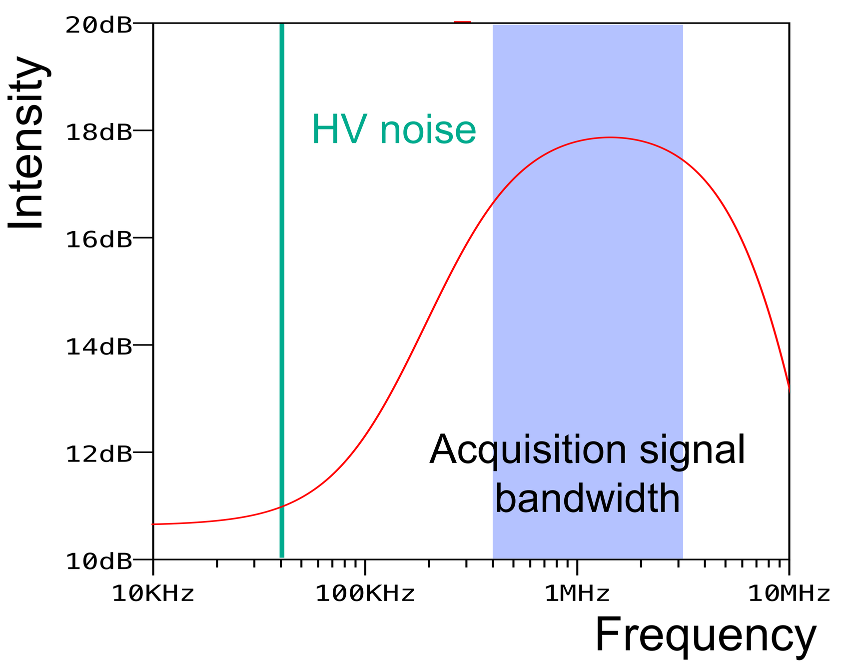

Fig.8 FEC frequency response simulation

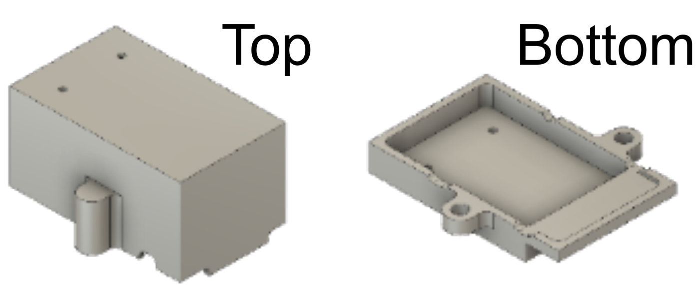

Fig.9 Aluminum shield designed to surround HV module

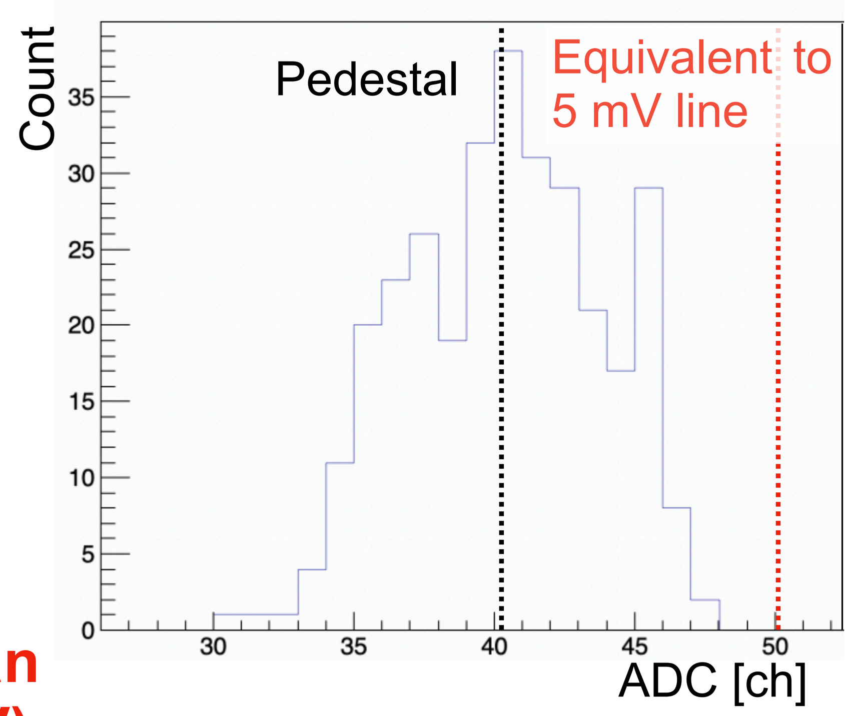

Fig.10 Noise level histogram of FEC

Noise level

Noise level < 5 mV (Fig.10)

trigger threshold (1 keV) ~20 mV (@ GEM gain=400)

➡ **Noise is surpassed less than GMC trigger threshold (1 keV)**

3. Evaluation of discharge risk

Discharge by heavy ions and protection design

FEC must withstand discharges in GEM caused by heavy ions in space (Fig.11).

We designed clamping diodes at the inputs of preamplifiers to prevent over-voltages

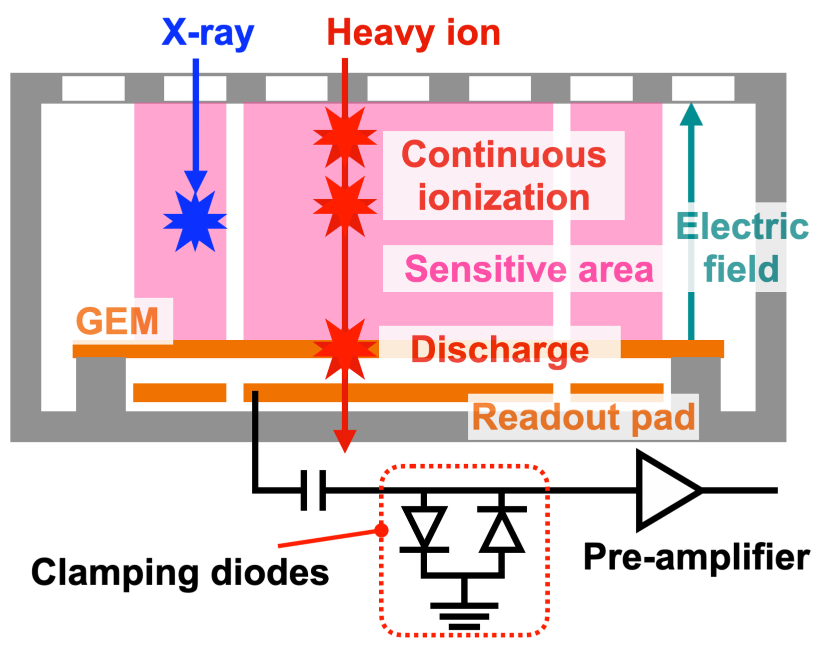

Fig.11 Overview of GMC and protection against discharge using clamping diodes

Heavy ion irradiation test

Verify tolerance of the circuit against discharges at Heavy Ion Medical Accelerator in Chiba (Fig.12).

- Irradiated Ion: 500 MeV/u Fe
  - Typically deposits ~10 MeV
  - Generate ~10^5–10^6 electrons in sensitive area
- Total Irradiation rate ~20 cps (total amount: 10^4 counts)
  >> Fe ion (>500 MeV/n) rate to GMC in the orbit ~10^{-3}–10^{-2} cps
- Monitor ^{55}Fe 5.9 keV X-rays as a normal operating reference during irradiation

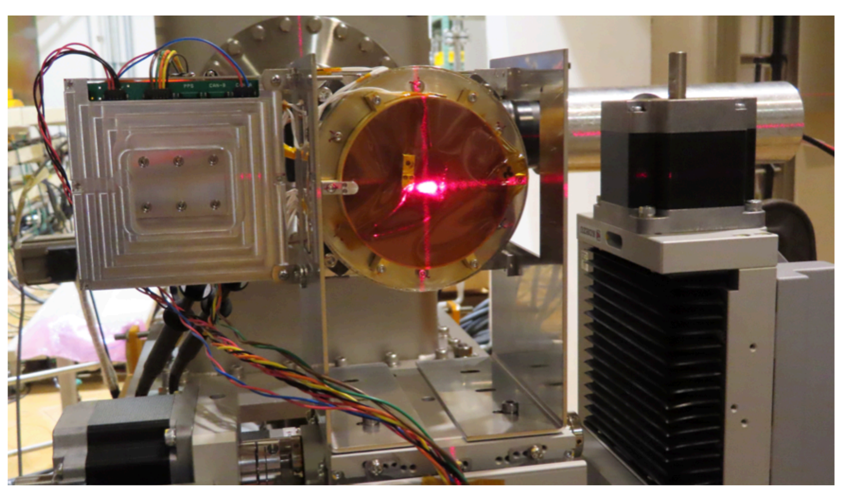

Fig.12 Set up of heavy ion irradiation test

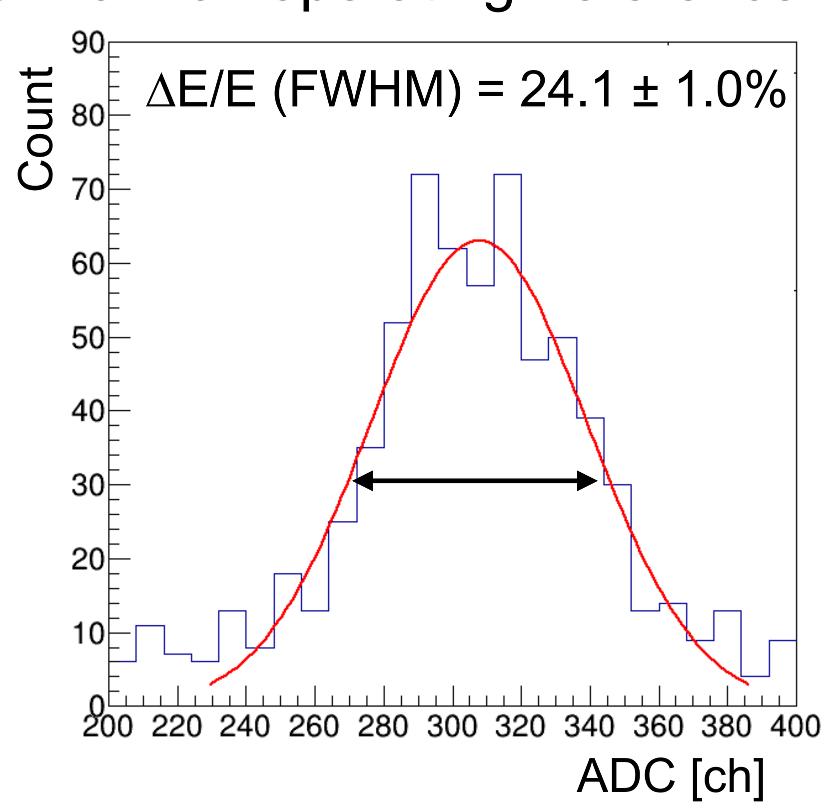

Fig.13 ^{55}Fe 5.9 keV X-ray spectrum during beam irradiation

GMC detected X-rays with a required energy resolution during irradiation (Fig.13)

➡ **Withstand discharges and operated normally.**

4. Conclusion

- The noise level of FEC was suppressed to less than the required specification of 1 keV trigger threshold.
- It was confirmed that FEC withstands discharges caused by heavy ions.

Reference

- Enoto et al, 2020, Proc. SPIE 11444, 114441V
- Tamagawa et al, 2009, NIMA, 608, 390