Calibration for the SAMPA ASIC in HERD transition radiation detector front-end electronics

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Abstract—The High Energy Cosmic Radiation Detection (HERD) facility is a part of the Chinese Cosmic Lighthouse Program in China's Space Station, which will be launched in 2027. HERD is expected to work for 10 years in orbit and will indirectly detect dark matter, measure cosmic rays, and observe high-energy gamma rays. As a sub-detector of HERD, the transition radiation detector's (TRD) main scientific goal is to calibrate the electromagnetic Calorimeter (CALO) at the TeV energy range, improve the measurement accuracy of the CALO, and detect astronomical phenomena of high-energy gamma rays. The front-end electronics (FEE) of the prototype of TRD uses four SAMPA ASICs for 128 signals of anode, realizing a high-speed, low-power, and high-reliability data acquisition system. In this work, we completed the calibrations of the gain and shaping time in the unsupported modes of SAMPA to achieve an adjustable dynamic range on orbit. The effect of the different fitting algorithms on the test results is also discussed under different modes of operation.

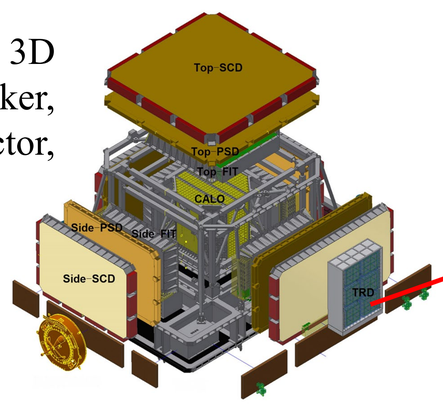
HERD and the prototype of TRD

High Energy Cosmic Radiation Detection (HERD) facility is a part of the Chinese Cosmic Lighthouse Program in China's Space Station, which will be launched in 2027. the TRD is mounted on the side of the HERD, and the 2×3 detection array composed of 6 detector units can be extended through the mechanical turntable.

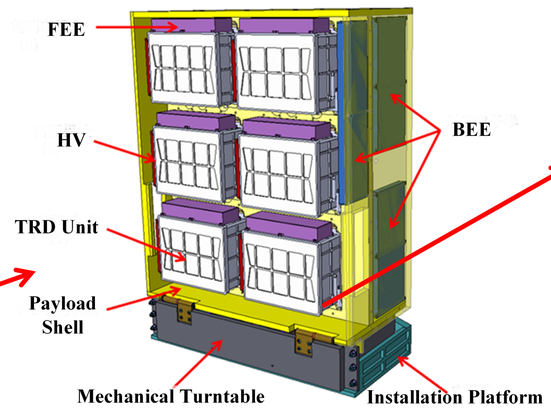
HERD consists of five detectors: a 3D Imaging calorimeter (CALO), fiber tracker, plastic scintillator, silicon charge detector, and transition radiation detector (TRD).

Scientific goals:

- Indirectly detect dark matter.
- Measure cosmic rays.
- Observe high-energy gamma rays



Architecture of HERD



Architecture of TRD detection system

TRD unit

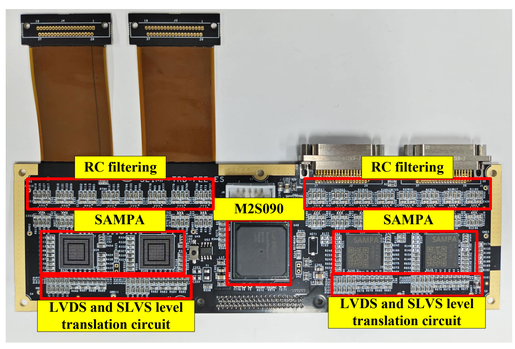
The sealed gas detector will first large-scale used in space exploration.

Calibration mode: The calibration of the TeV energy range of the CALO to improve the accuracy of cosmic ray detection.

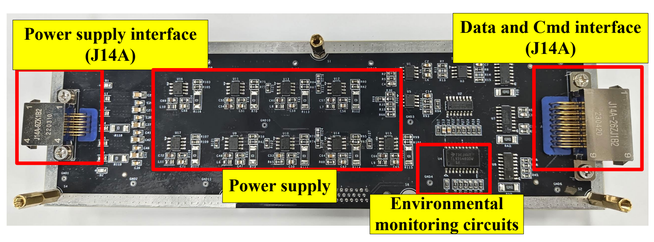
GRB mode: The detection of high-energy gamma rays.

The design of the FEE

A. Hardware design of the FEE



The picture of the FEE



The FEE design is divided into two layers of PCBs, one for power supply and communication and one for reading the detector signals. The FEE uses an irradiation-resistant FPGA (Smartfusion2 M2S090) design to improve the irradiation resistance characteristics of the system. Flexible board interfaces have been added, and new ways to replace cable connections have been sought.

The FEE uses four SAMPA ASICs for 128 detector signal readouts.

B. Firmware design of the FEE

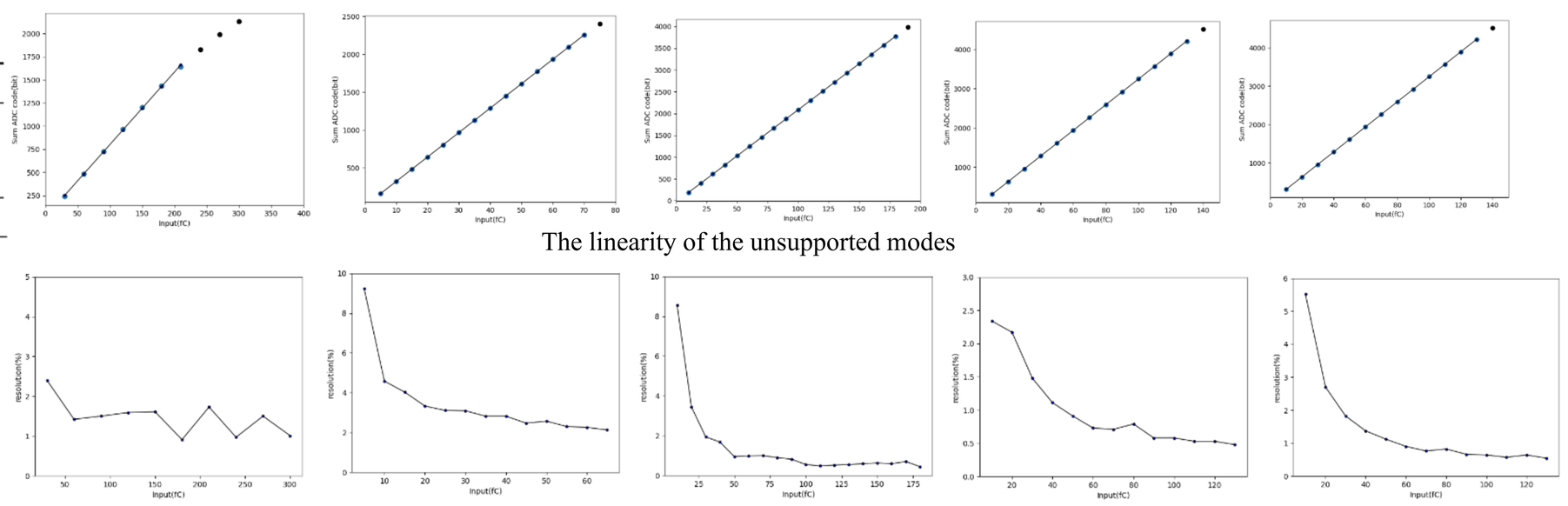
It consists of five modules: a Trigger unit, a CMD unit, a SAMPA configuration unit, a Data processing unit, and a Data transmission unit. A new function has been added to enable on-orbit gain adjustment for readout electronics.

Calibration for the SAMPA ASIC

The SAMPA manual provides three supported operating modes, which are insufficient for practical applications. We performed calibration tests on SAMPA's unsupported modes, analyzed their noise levels, and tested linearity and resolution. The unsupported modes have been tested and found to meet the needs of the detector.

Gain	Shaping time	CTS	CG0	CG1
30 mV/fC	160 ns	low	high	high
20 mV/fC	160 ns	low	low	high
4 mV/fC	300 ns	high	low	low
Unsupported modes				
9 mV/fC	160 ns	low	low	low
33 mV/fC	160 ns	low	high	low
16 mV/fC	300 ns	high	low	high
11 mV/fC	300 ns	high	high	low
17 mV/fC	300 ns	high	high	high

unsupported mode



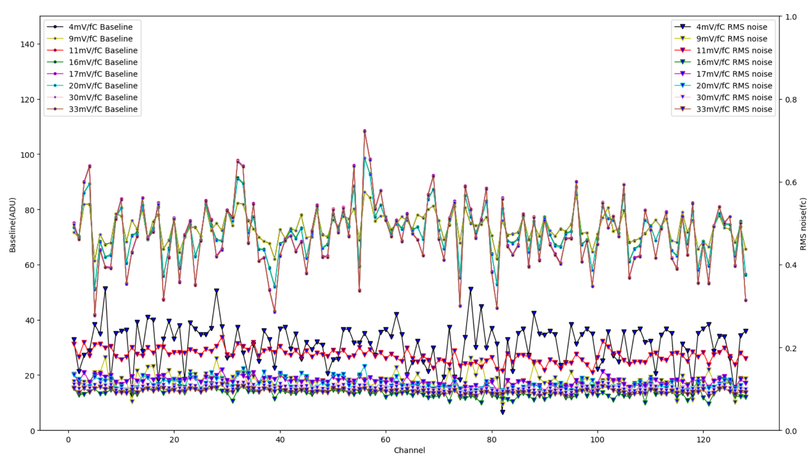
The linearity of the unsupported modes

The resolution of the unsupported modes

Conclusion

The actual dynamic range and linearity of SAMPA's unsupported modes are given in the table below.

Gain	33mV/fC	17mV/fC	16mV/fC	11mV/fC	9mV/fC
Dynamic range	60mV	117mV	125mV	181mV	222mV
Actual dynamic range	80mV	145mV	205mV	145mV	370mV
INL	0.15%	0.23%	0.16%	0.27%	1.26%



The RMS noise of the unsupported modes

References

[1] D. Kyratzis, and HERD Collaboration, "Latest advancements of the HERD space mission," Nucl. Instrum. Methods Phys. Res. A, Vol 1048, Mar. 2023, no. 167970.

[2] A. Velure, "A Digital Signal Processor for Particle Detectors: Design, Verification and Testing," Germany: Springer Cham, 2021.