Caliste-256, 580 μm pixel pitch CdTe imaging spectrometer for space science


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Outline

- Introduction
- Caliste 256 technology
- Caliste 256 performance
- Caliste 256 technological maturity
Recent developments for CdTe detectors

- Activity supported by CEA and CNES since 2003

- Goals
  - Bounce on Integral/ISGRI return
  - Demonstrate entirely new sensors based on CdTe pixel detectors in the hard X-ray domain
  - Develop new devices for space applications
    - High reliability and modular concept
  - Demonstrate high performance
    - Spectroscopy, imaging, timing

- Means
  - Microelectronics development in house for analog front-end ASICs
    - Low noise, low power, radiation hard
  - Industrial means for device production
    - Hybrid stacking technology
  - Development according on space rules
    - Technological evaluation for high technological readiness level
  - Performance evaluation
Needs for future hard X-ray astronomy missions

- Simbol-X, Astro-H, NuStar, NHXM...
- Energy band: 4-80 keV
- ~10 arcsec angular resolution
  - Typ. 1-2 mm HEW PSF
- Large effective area
  - ~10 arcmin field of view
- High spectral resolution
  - Typ. 1.2 keV FWHM @ 60 keV
- Background rejection by anticoincidence
  - Timing resolution < 100 ns rms
  - Integration in the shielding

Detector
- CdTe, 1-2 mm thick
- Fine pitch pixels
- Mosaic of 1 cm² crystals
- Low leakage current

Front-end electronics
- Low noise ASIC
- Time-walk correction

Hybridization
- Low input capacitance
- 4-side buttable device

IDeF-X

Caliste
IDeF-X v2 front-end ASIC for Caliste-256

- CMOS 3.3V AMS 0.35 µm
- 32 analog channels
- 1 output buffer and 1 trigger output
- Slow control interface, 6 configuration registers
- Gain: 200 mV/fC
- Dynamic range: 50 ke-
- Shaper peaking time: 0.9-9 µs
- Individual low-level threshold set by 6-bit DAC
- 3 readout modes: all channels, hit channels or on demand
Caliste-256 design and technology

IDeF-X v2 ASIC
32 analog channels

Cd(Zn)Te 256-pixel detector
(0.58 mm pitch, 1 or 2 mm thick)

Mounting on PCB

8 ASIC stacking
perpendicular to the detection surface

Electrical body
with a 7 x 7 pin grid array

Caliste-256 camera
Caliste-256 fabrication and tests

- Mean features
  - 16 × 16 pixels of 580 µm + guard ring
  - Volume: 10 × 10 × 21 mm³; Mass: 4 g
  - Power: 816 mW (3.2 mW/channel)
  - 220 keV energy range
  - Programmable individual low-level threshold (step ~0.28 keV)
  - 8 differential outputs

- Operation in the lab
  - Vacuum chamber + cold finger
  - 14-bit ADCs
  - 20 MHz sequencing clock
  - 1 FPGA for ASIC and ADC control and data frame packaging
Noise performance

- Characterization with test injection signal over the 256 channels
  - 65 electrons rms without detector

- Uniformity
  - $\sigma_{256} = 5$ el. rms (8%)

- Expected energy resolution (70 el. rms)
  - 0.76 keV FWHM @ 14 keV
  - 0.86 keV FWHM @ 60 keV

Noise map with test injection pattern
Spectroscopic characterization with $^{241}$Am source

- **2 mm-thick CZT**
  - 800V, −15°C, 6.0 µs peaking time
  - 0.91 keV FWHM @14 keV
  - **1.09 keV FWHM @60 keV**
    - $\sigma_{256} = 0.13$ keV fwhm (12%)
  - Low threshold ~2 keV
  - Extracted current 30 pA/pixel

- **1 mm-thick Schottky CdTe**
  - 300V, 0°C, 9.6 µs peaking time
  - 0.73 keV FWHM @14 keV
  - **0.85 keV FWHM @60 keV**
    - $\sigma_{256} = 0.09$ keV fwhm (11%)
  - Low threshold ~1.5 keV
  - Extracted current 10 pA/pixel
Energy resolution: analysis

- 1.38 keV FWHM @122.06 keV
  - $\sigma_{256} = 0.09$ keV fwhm (11%)
  - $\sim 1.0$ keV expected

- Interpretation: CSA architecture
  - Output voltage of the CSA opens the feedback reset transistor → causes additional noise source on the signal itself, → called non-stationary noise

- Fixed in the new IDeF-X version
  - See poster ID62 / session IV (A. Michalowska)
Technological evaluation

- **Total ionizing dose**: OK up to 1 Mrad
- **Latch-up**: LET threshold > 65 MeV.cm².mg⁻¹
- **Single-event upset**: LET threshold > 9 MeV.cm².mg⁻¹ (on-chip detection)
- **Life-test**: OK up to 2000 h at 125°C
- **Sine vibrations**: 20 g, 20-2000 Hz, 3 axis → passed
- **Shocks**: 1500 g → passed
- **Thermal cycling**: 50 cycles −55°/55°C + 50 cycles −55°/100°C → passed
- **THB (temperature, humidity, bias)**: 240 h at 85°C/ 85% RH → passed

Conclusions

Tests performed according to ESA standards.
All tests required for space qualification have been passed.
Conclusions

- Caliste 256 performs in hard X-rays high resolution imaging spectroscopy.

- Technology mature to be used as a space-qualified component

- Ways of improvement
  - Power consumption (3 mW/channel) → thermal issue
  - Electrical interface (49 pins) → integration and PCB routing issue

- Next steps
  - New Caliste generation: 8 IDeF-X HD ASIC, 0.8 mW/channel, 16 pins
  - Modular assembly of Caliste Spectroscopic Imagers (MACSI)
For the next NDIP conference…

- MACSI: 8 cm² CdTe camera, 2048 channels

Integration test with Caliste mock-ups

Thank you!