Low Power & Low Noise Multi-Channel ASIC for X-Ray and Gamma-Ray Spectroscopy

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Abstract

The XA is an application specific integrated circuit (ASIC) for gamma and x-ray energy spectroscopy and imaging. The circuit was designed to read signals semiconductor radiation sensors such as cadmium zinc telluride (CZT) or cadmium telluride (CdTe). The assembly of CZT sensors with XA ASICs allows one to measure energies of gamma and X-rays in the range from 20 keV to 360 keV. The XA ASIC contains 128 preamplifiers each followed by pulse shaping circuits and level comparators for triggering and address encoding. Upon interaction of radiation in the sensor the XA delivers an analog signal proportional to the energy of the gamma ray as well as a digital address corresponding to the pixel position.

A total of 128 ASICs (16384 channels) of XAs will be used in the Atmosphere Space Interaction Monitor (ASIM). ASIM is an experiment proposed for the International Space Station (ISS) external facilities on the Columbus module, from where it will study radiation phenomena over terrestrial thunderstorm regions.

Results from tests with CZT-based radiation detectors for ASIM will be presented.

Introduction

Multi-Channel Radiation Detector Readout with XA-ASICs

- Radiation Energy Spectroscopy
- Radiation Imaging

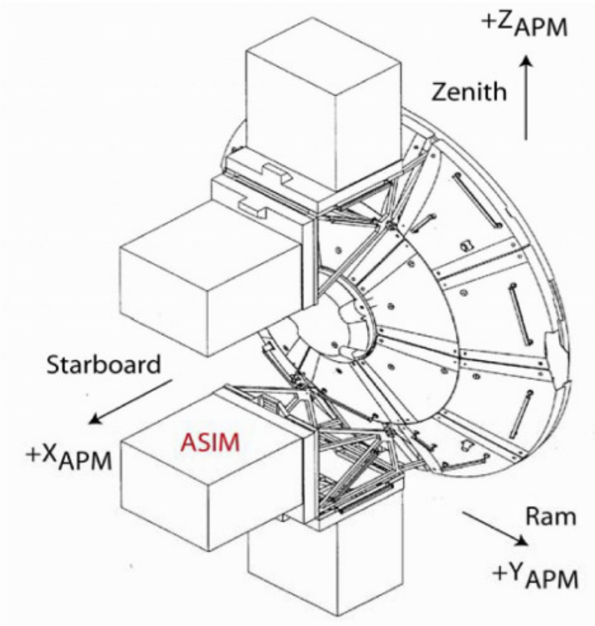
Fields of Applications

- Space and Balloon applications, i.e. ASIM on Columbus
- Nuclear Medical Imaging (Small Animal SPECT, Gamma Mamography)

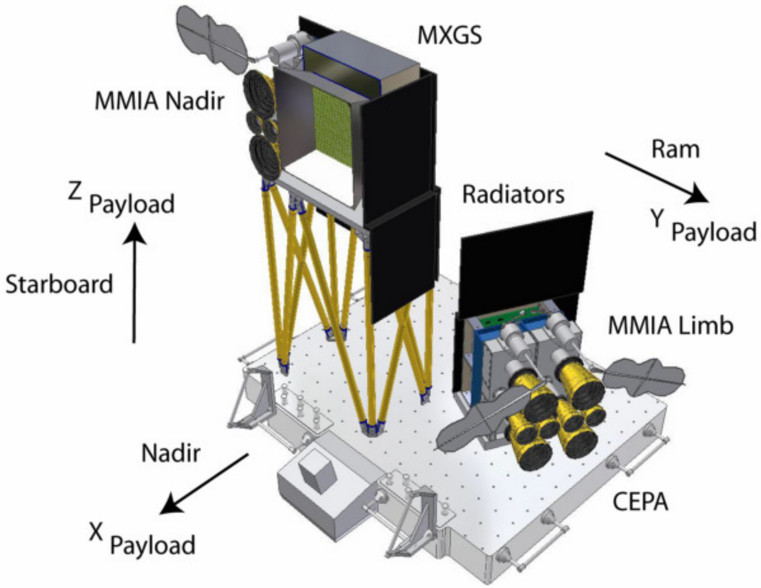
Rationale for Detector Readout with ASICs

- Size and weight - very large scale integration (VLSI) of electronic readout
- Low power dissipation
- Low electronic noise
- Low cost per channel

Space Application (1)



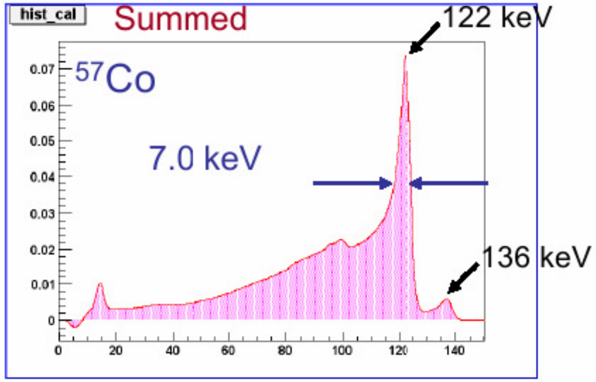
ASIM on Columbus



ASIM on CEPA

GAMMA MEDICA-IDEAS
INNOVATION FOR LIFE

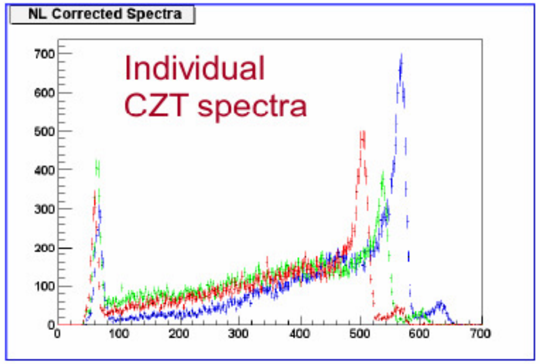
Large Scale CdTe/CZT Experiment in Space (2)

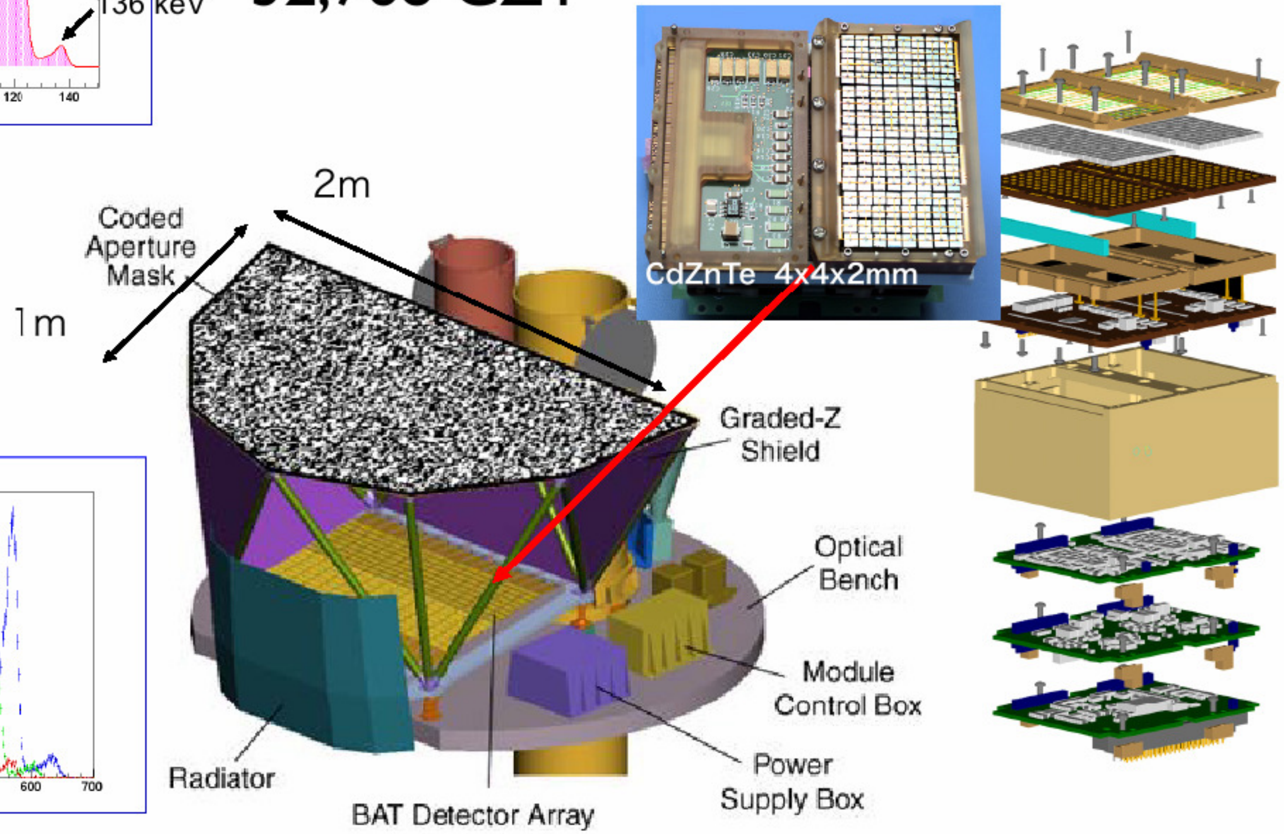


Burst Alert Telescope (BAT) on Swift
(Launched in 2004)

XA Chip (IDEAS)

32,768 CZT





Takahashi, SNIC 2006

Examples of ASICs in Space (1)

- **SuperAGILE (launched April 2007):** Luigi Pacciani, Ennio Morelli, Alda Rubini, Marcello Mastropietro, Geiland Porrovecchio, Enrico Costa, Ettore Del Monte, Immacolata Donnarumma, Yuri Evangelista, Marco Feroci, Francesco Lazzarotto, Massimo Rapisarda, Paolo Soffitta, “SuperAGILE Onboard Electronics and Ground Test Instruments”, Nucl. Instr. Meth. A 574, 2, 2007, 330-341.
- **STEREO/PLASTIC (launched Oct. 2006, http://stereo.sr.unh.edu/):** A.B. Galvin et al., “The Plasma and Suprathermal Ion Compositioin (PLASTIC) Investigation on the STEREO Observatories”, Space Science Reviews, 136, 1-4, April 2008.
- **SWIFT/Burst Alert Telescope (launched Nov. 2004):** L.M. Barbier, F. Birsa, J. Odom, S.D. Barthelmy, N. Gehrels, J.F. Krizmanic, D. Palmer, A.M. Parsons C.M. Stahle, J. Tueller, “XA Readout Chip Characterization and CdZnTe Spectral Measurements”, IEEE, Trans. Nucl. Sci. 46(1), 7, 1999.
- **AMS (AMS-01 launch 1998, AMS-02 launch t.b.d.):** B. Alpat, ”Alpha Magnetic Spectrometer (AMS02) Experiment on the International Space Station ISS”, Nucl. Sci. Tech. 14, 3, 2003.

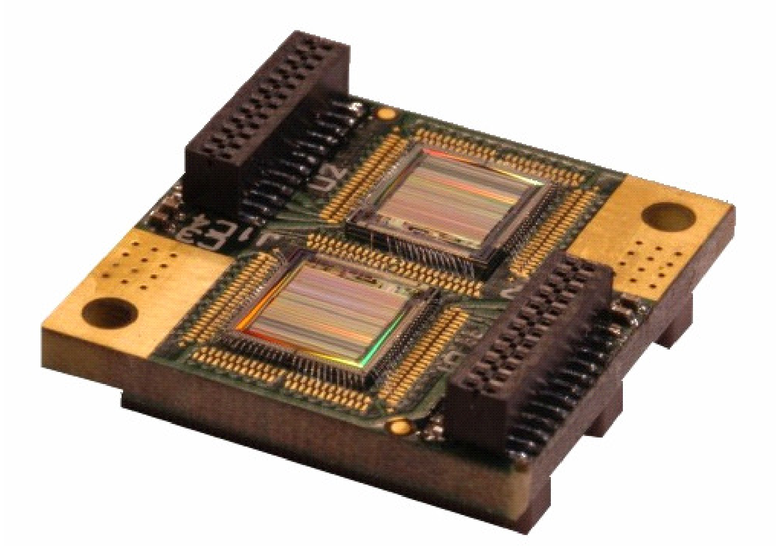
Examples of ASICs in Space (2)

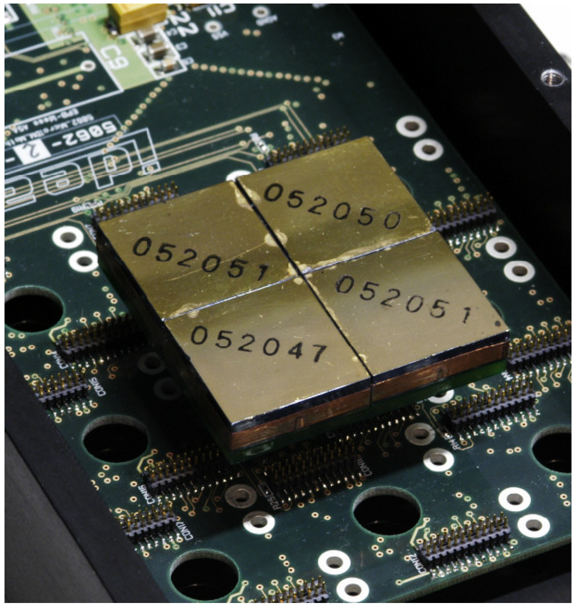
- **BepiColombo, launch Aug. 2013** to Merkur: Takashima/Takahashi
- **NeXT Soft Gamma Ray Detector:** H. Tajima, T. Kamae, G. Madejski, T. Mitani, K. Nakazawa, T. Tanaka, T. Takahashi, S. Watanabe, Y. Fukazawa, T. Ikagawa, J. Kataoka, M. Kokubun, K. Makishima, Y. Terada, M. Nomachi, and M. Tashiro, “Design and Performance of the Soft Gamma-Ray Detector for the NeXT Mission”, IEEE Trans. Nucl. Sci. 52, 6, (2005), 2749.
- **CREAM (balloon experiment):** M.G. Bagliesi, C. Avanzini, G. Bigongiari, A. Caldarone, R. Cecchi, M.Y. Kim, P. Maestro, P.S. Marrocchesi, F.Morsani, R. Zei, “Front-end electronics with large dynamic range for space-borne cosmic ray experiments”, Nucl. Phys. Proc. Suppl. 172:156-158, 2007.
- **ESA Science Payload and Advanced Concepts Office, studies for future space missions based on compound semiconductors:** F. Quarati, R.A. Hijmering, G. Maehlum, A. Owens, E. Welter, “Evaluation of a CdZnTe Pixel Array for X- and G-ray Spectroscopy Imaging”, Nucl. Instr. Meth. A 568 (2006) 446-450.

Application

Front-end Readout for Radiation Detector Modules

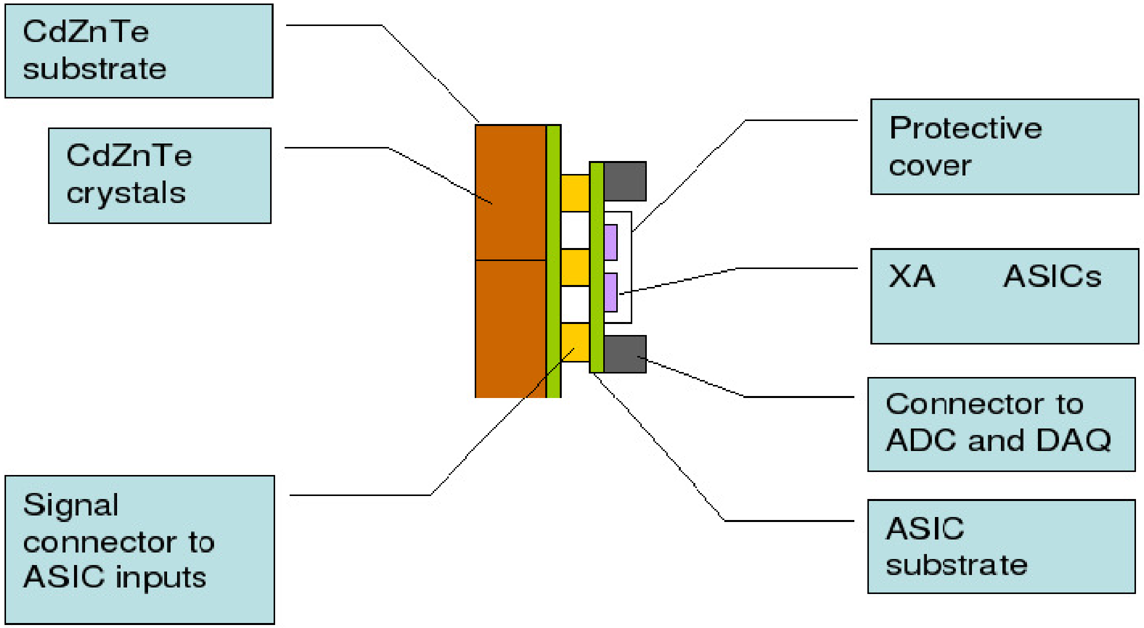
- Radiation sensor Cadmium Zinc Telluride (CZT), pixelated
- Integrated Readout - Application Specific Integrated Circuits (ASIC)
- Each CZT pixel measures energy from 20 keV – 360 keV



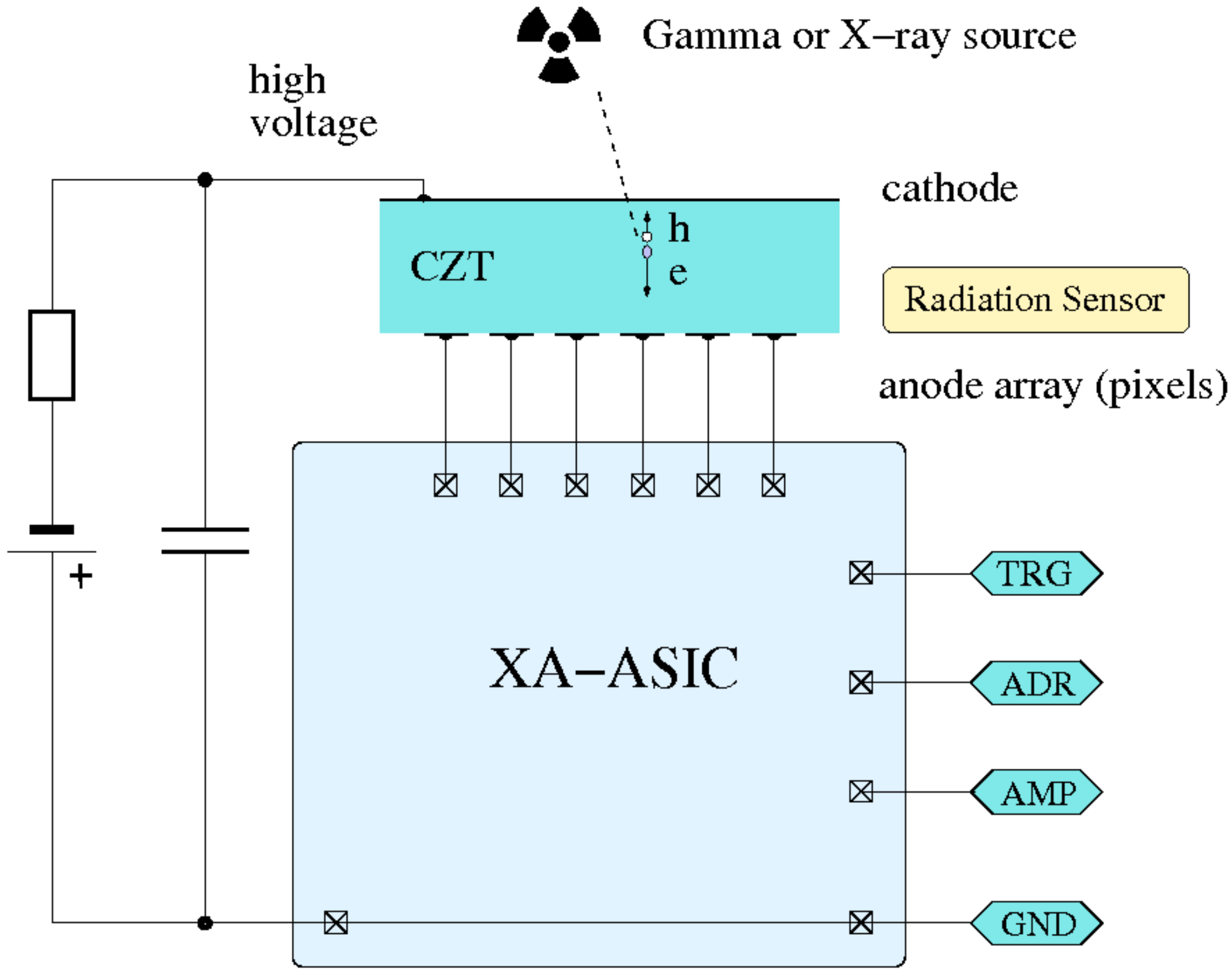


Radiation Detector Principle (1)

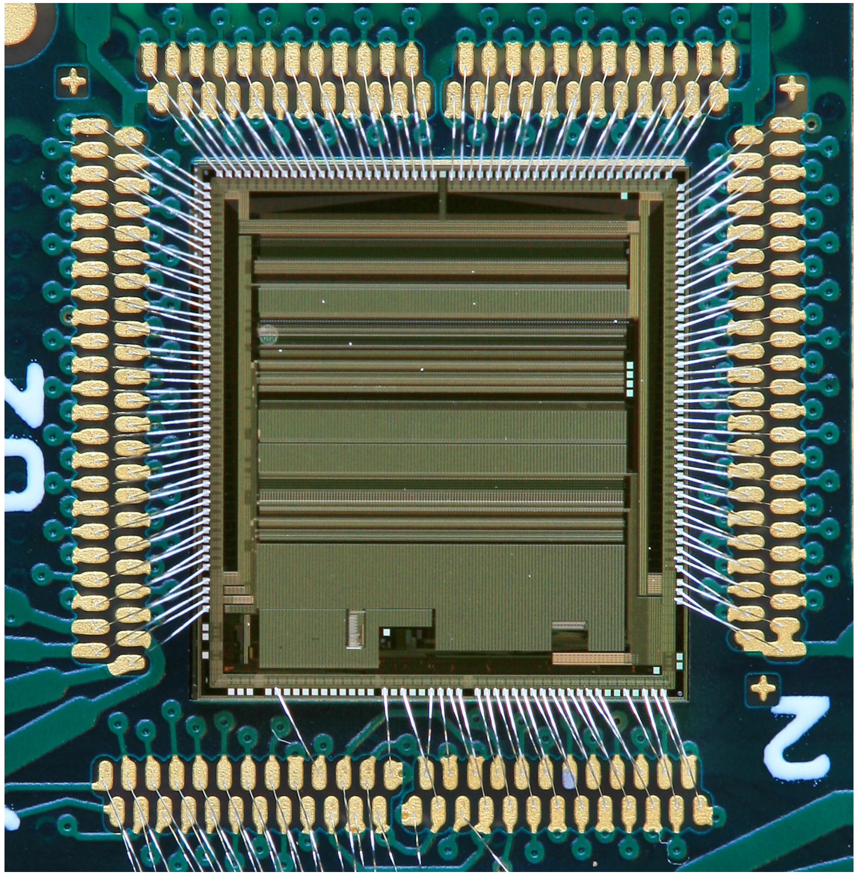
Schematic drawing of the module

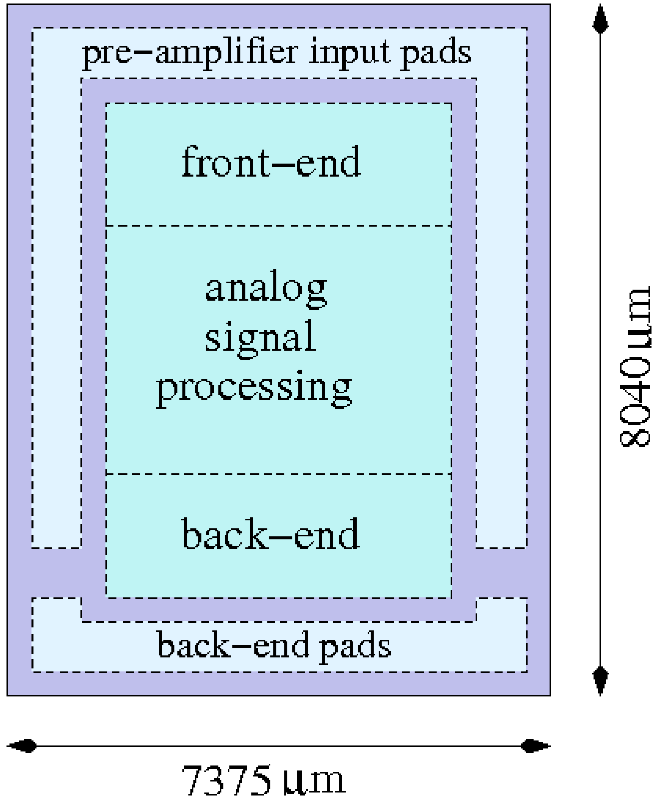


Radiation Detector Principle (2)



ASIC Layout





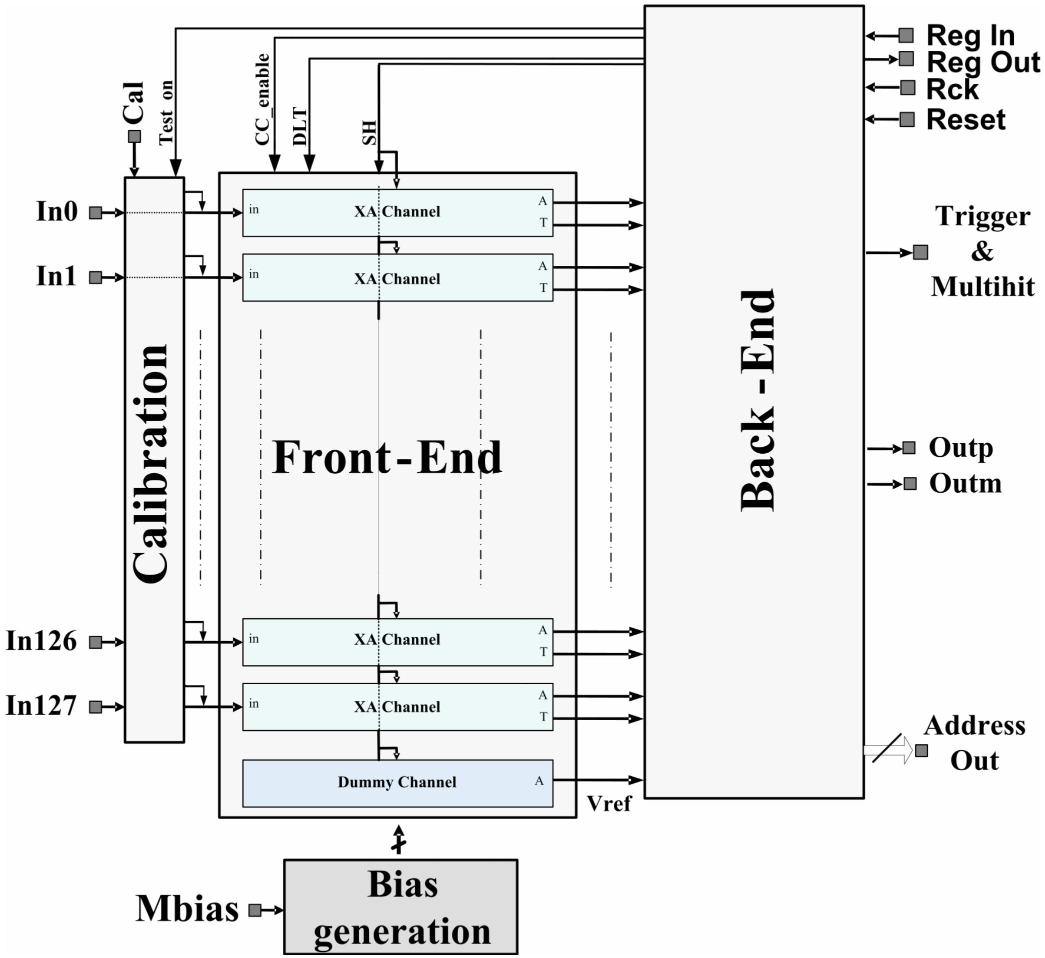
Size	8040 um x 7375 um x 725 um

XA-ASIC Basic Functionality

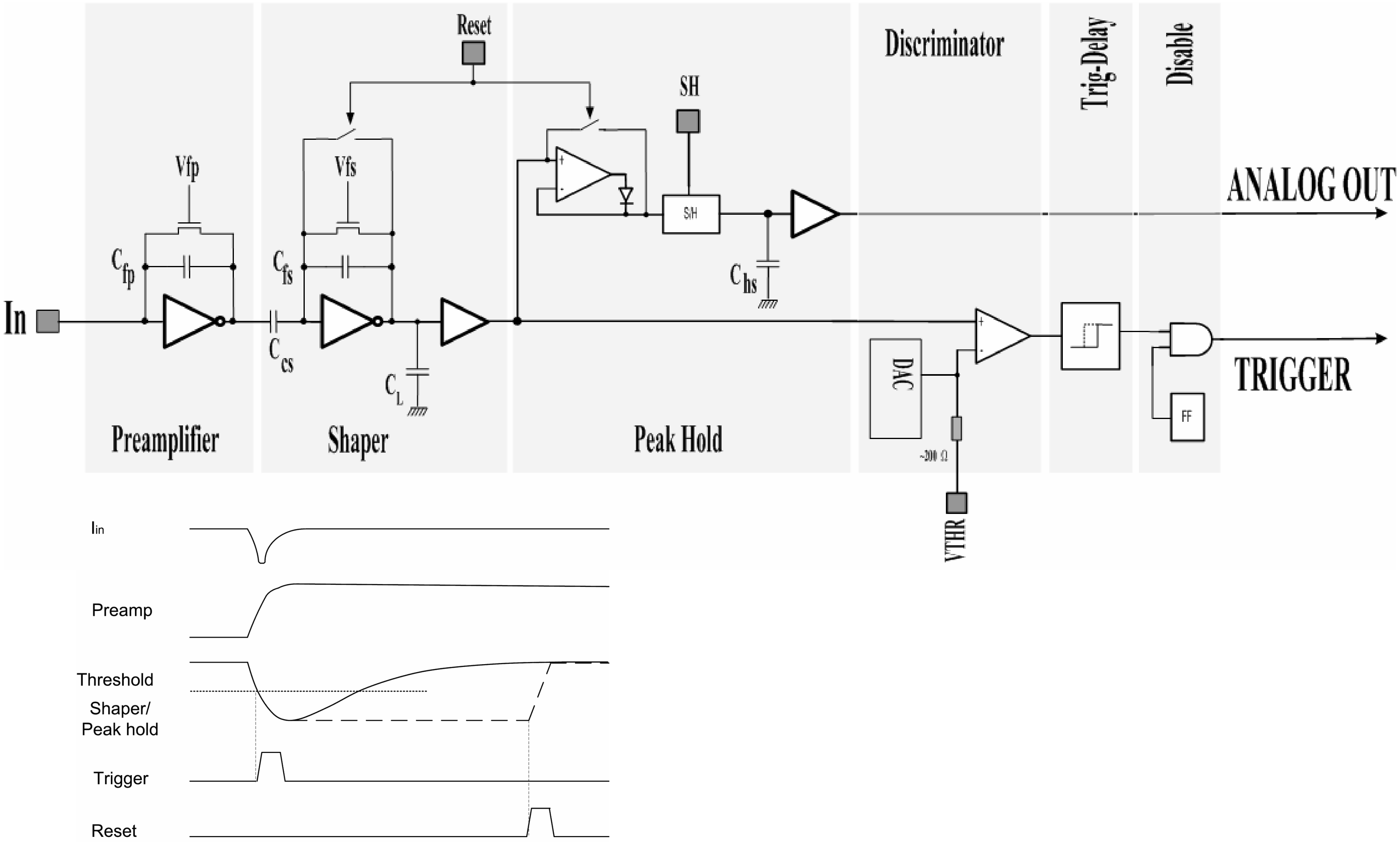
Functionality	Concept
Input: Readout of 128 radiation sensors/electrodes/strips/pixels	128 parallel & independent inputs channels, current input
Signal processing • 128 x amplitude spectroscopy • simultaneously and independent	128 x analog signal processing: • charge sensitive amplifiers CSAs, • Semi-Gaussian shapers, • peak-hold device (stretcher)
Data sparsification	Amplitude discriminators and multiplexer
Output: Delivers • analog amplitude and • digital address	Delivery right after radiation event without external hand-shake, "radiation driven"

Basic Functionality: Input, Processing, Ouput.

ASIC Architecture



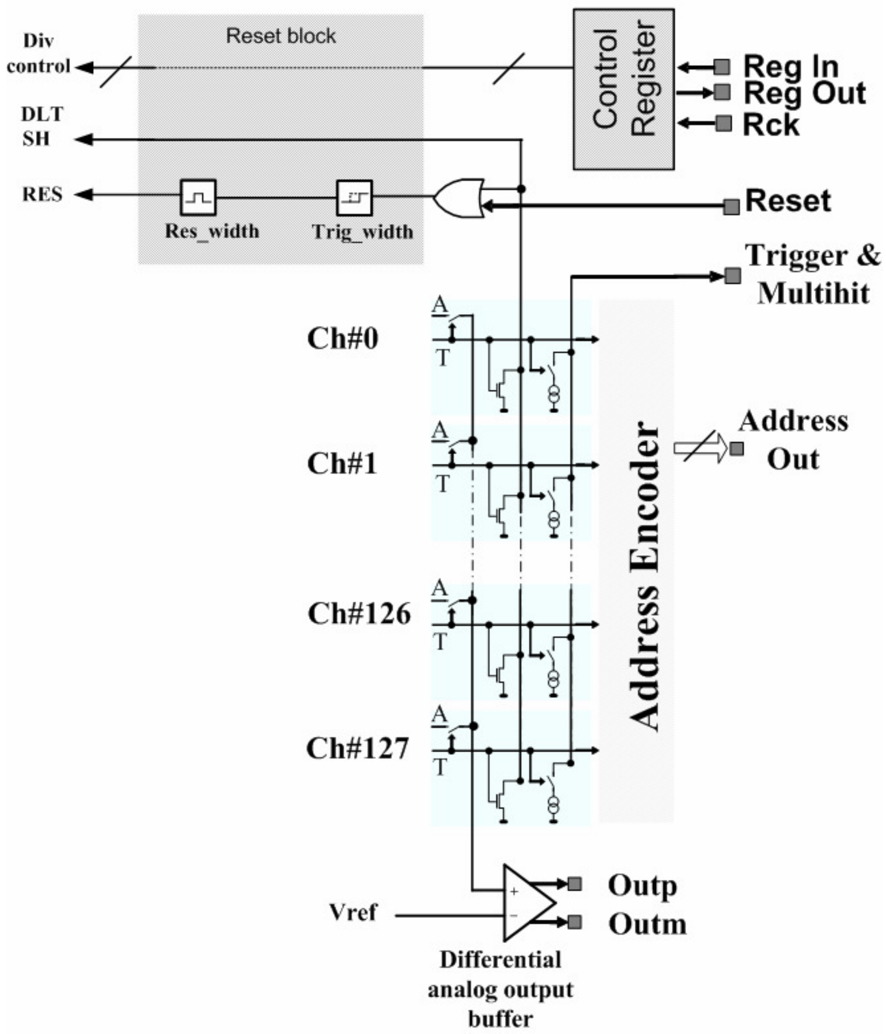
ASIC Channel Architecture



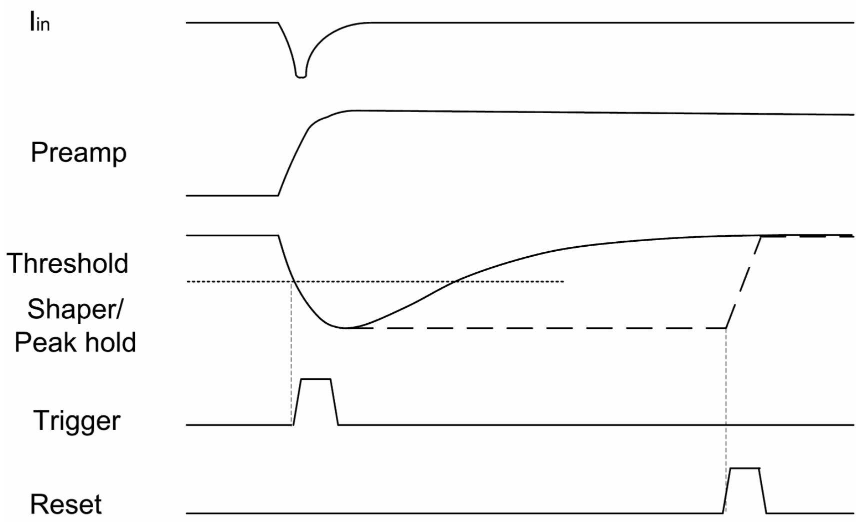
Electrical Performance Specifications

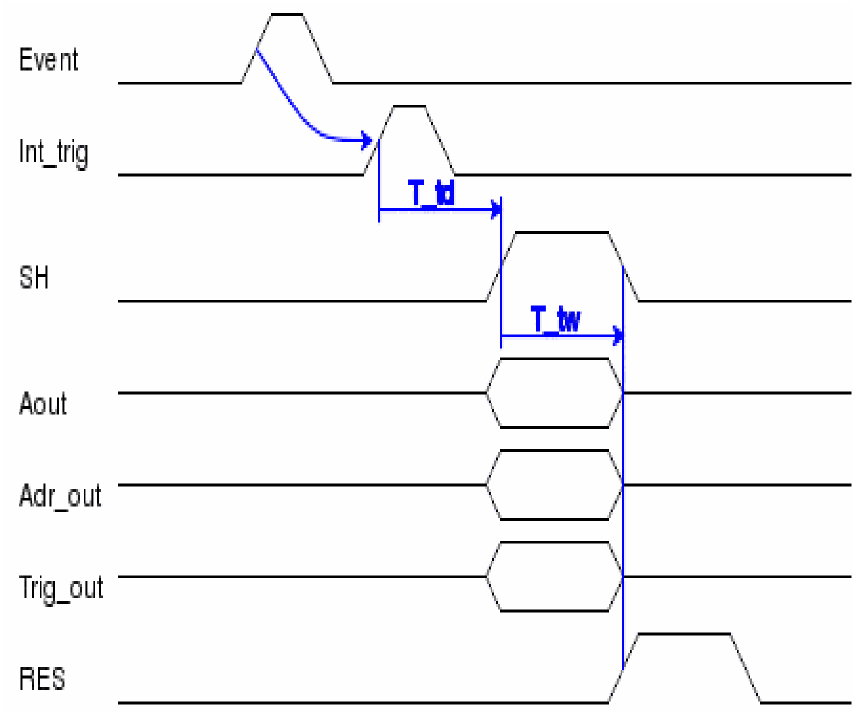
Parameter	Value	Comment
Number of Input Channels	128	Readout for 128 pixels
Input charge dynamic range	0 .. -12.5 fC	Negative charge, readout of anodes
Power consumption	0.5 mW/channel	64 mW total (nominal setting)
Electronic noise of CSA	130 e + 20 e/pF	At 0.5-µs shaping time. Measured energy resolution is 5.4 keV FWHM at 122 keV in CZT pixels
Threshold	0.3 fC, negative charge	10 keV in CZT
Rate capability, maximum	20 kHz .. 100 kHz per ASIC	Highest rate tested with this ASIC is 20 kHz. Depending on system configuration, >100 kHz is expected to be possible
Detector Capacitance	0 pF .. 10 pF	Optimized for 4pF
Detector Leakage Current	0 nA .. – 100 nA	Positive current out of the preamplifiers

Back-End Architecture



Timing Diagrams

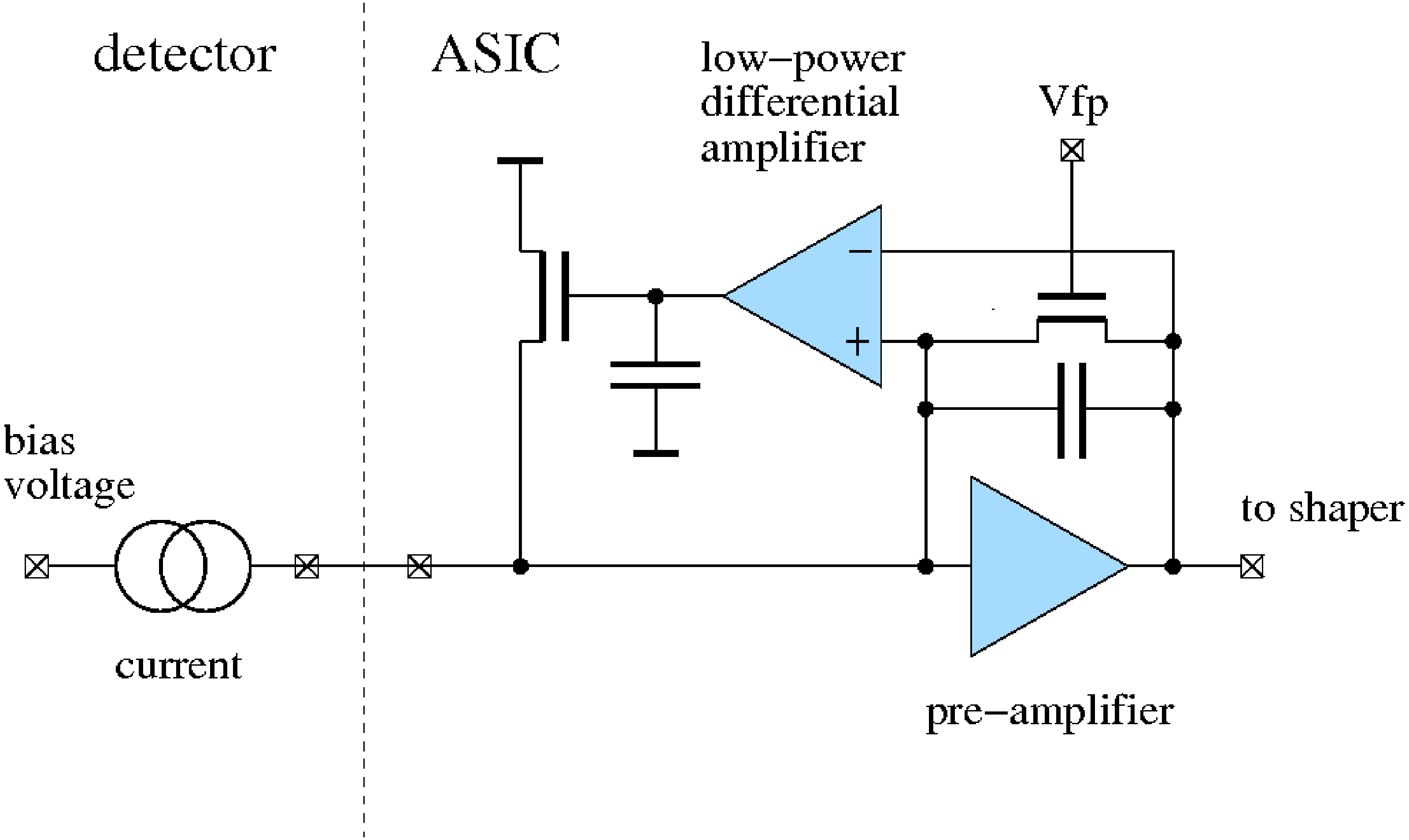




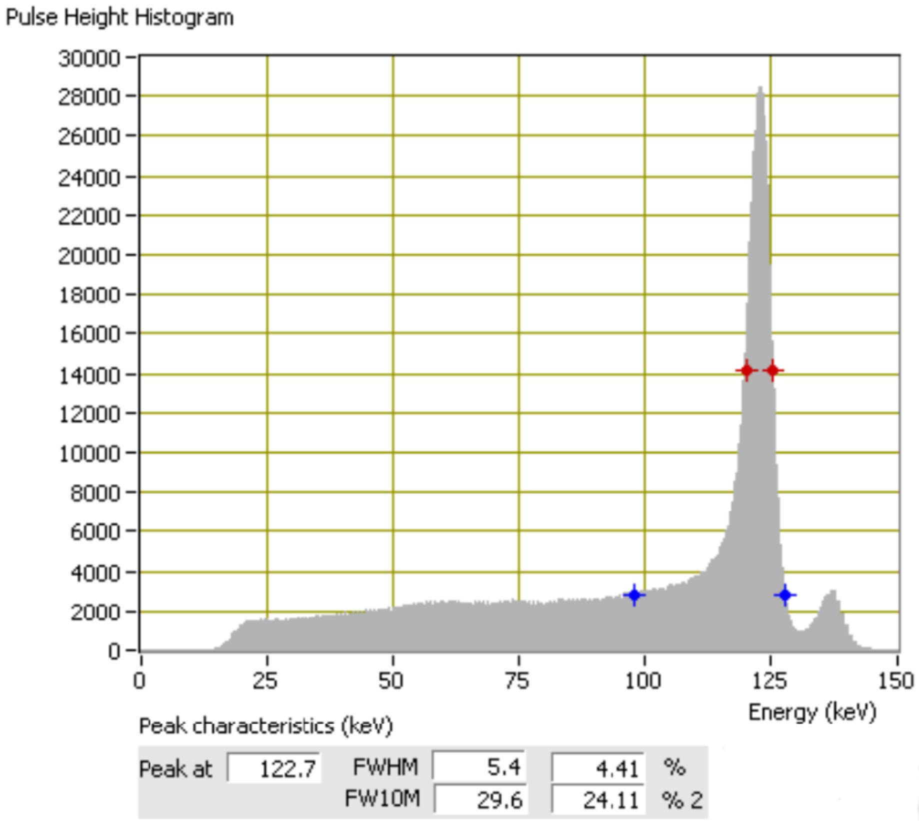
XA-ASIC Extended Functionality

Function	Implementation
User can adjust internal bias values	programmable DACs
User can adjust all thresholds individually	programmable DACs
User can enable or disable channels	progammable configuration register
Amplitude calibration and test of functionality	Internal capacitor, charge injection for all channels
Combine several ASICs	Common address bus and common analog line
Compensate change of external temperature	Differential signals
Compensate large detector leakage current	current compensation network
Electrostatic Discharge (ESD) protection	Diodes at the inputs, optimized for low noise
Radiation tolerance, prevent Single Event Upset (SEU)	Implemented in predecessors

Current Compensation



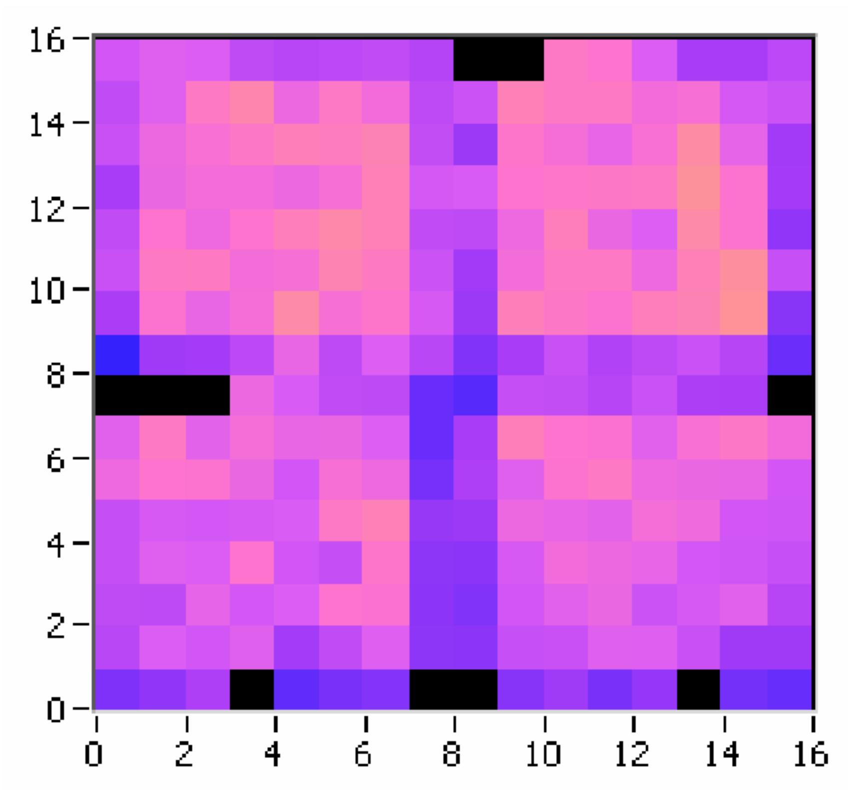
Tests – Energy Spectroscopy

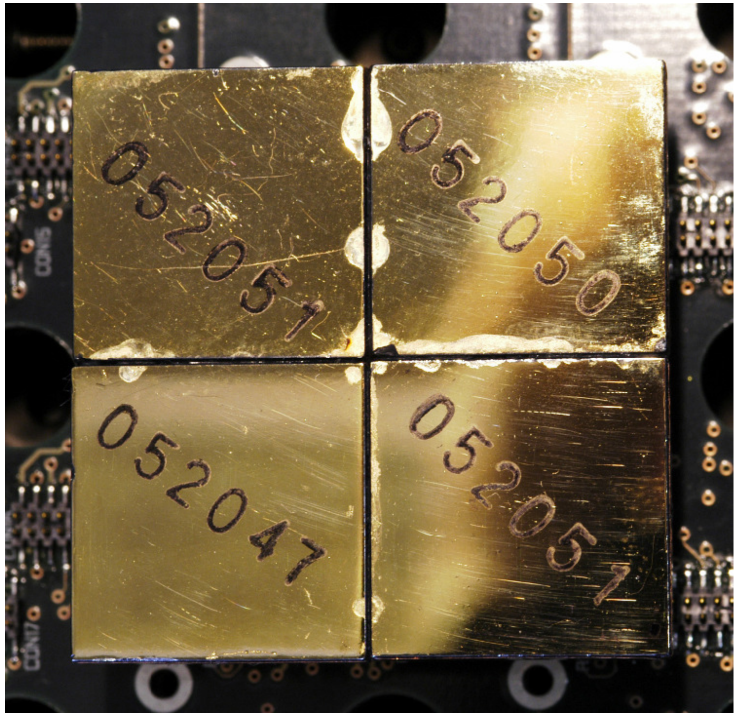


Observation:

5.4-keV FWHM energy resolution at 122 keV, all pixels summed

Count Imaging





Observation:
Center pixels high counts (red), edge pixels low count (blue), some edge pixels are damaged.

Radiation Tolerance

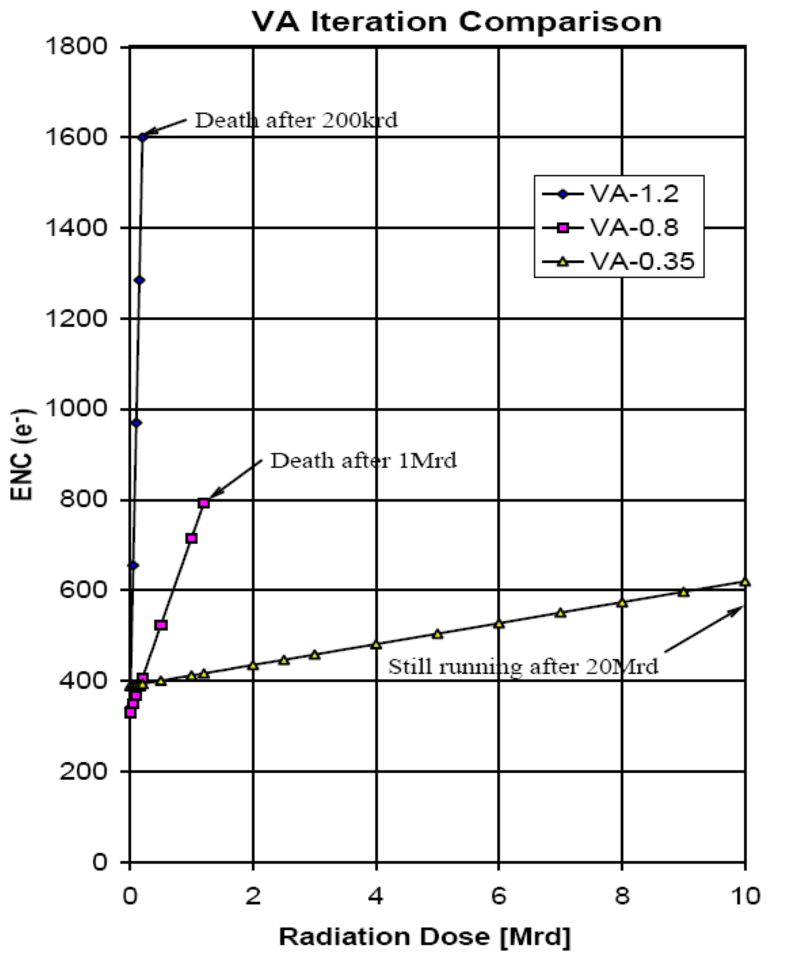


Fig 1: Summary of noise performance versus radiation dose (1MeV γ) for three generations of Belle SVD VA, indicating significant enhancement of radiation tolerance.

Reference: H.Aihara, M. Hazumi, H. Ishino, J. Kaneko, Y. Li, D. Marlow, S. Mikkelsen, D. Nguyen, E. Nygaard, H. Tajima, J. Talebi, G. Vamer, H. Yamamoto, and M. Yokoyama, ”Development of Front-end Electronics for Belle SVD Upgrades”, IEEE, Proc. Nucl. Sci. Symp. Conf. Rec. 2000, Vol. 2, 9/213 – 9/216.

Single-event Upset (SEU)

- SEU is known to be a problem for ASICs in space applications.
- Some of our ASICs are using SEU-safe flip-flops
- The SEU flip flops are only used when strictly neccessary due to the large real estate size for this component.
- Another strategy is to periodically down load the configuration register.
- The best strategy is determined by the radiation environment.

Reference: Samo Korpar, Peter Krizan, Sasa Fratina, ”SEU Studies of the Upgraded Belle Vertex Detector Front-End Electronics”, Nucl. Instr. Meth., A 511 (2003) 195–199.

Summary

- We developed an ASIC for read-out of pixelated radiation sensors, suitable for:
  - space applications
  - nuclear medicine
- Reduced power dissipation
- Improved radiation tolerance

Acknowledgments

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