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
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)


Examples of ASICs in Space (2)

- **BepiColombo, launch Aug. 2013** to Merkur: Takashima/Takahashi


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

- CdZnTe substrate
- CdZnTe crystals
- Protective cover
- XA ASICs
- Connector to ADC and DAQ
- ASIC substrate
- Signal connector to ASIC inputs
Radiation Detector Principle (2)
ASIC Layout

Size: 8040 um x 7375 um x 725 um
# XA-ASIC Basic Functionality

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

**Basic Functionality: Input, Processing, Output.**
ASIC Architecture
ASIC Channel Architecture
## Electrical Performance Specifications

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

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

detector

ASIC

low–power differential amplifier

Vfp

to shaper

bias voltage

current

pre–amplifier
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.
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 necessary due to the large real estate size for this component.
- Another strategy is to periodically download the configuration register.
- The best strategy is determined by the radiation environment.

Summary

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