Front-End ASICs for CZT and Si Multi-Element Detectors

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Outline

I. Circuit Solutions
II. ASICs for CdZnTe Sensors
III. ASICs for Si Sensors
Typical front-end channel

- pixel
- charge preamplifier
- high-order filter
- baseline stabilizer
- amplitude and timing extractor
- back-end processing & data concentration
- to external ADC

- high reliability
- ease of use
- spectroscopic quality
- data concentration optimization
Input MOSFET optimization

\[ ENC^2 = \frac{A_1}{\tau_P} \left( C_p + C_i + C_g \right)^2 + A_2 A_f \left( C_p + C_i + C_g \right)^2 + A_3 \tau_P \left( I_p + I_{rst} \right) \]

\( g_m, C_g, A_f \), are functions of input MOSFET width \( W \) and power \( P \)
Input MOSFET optimization

Technology
- 0.50µm
- 0.35µm
- 0.25µm
- 0.18µm

n-channel MOSFET, $\tau_P=1\mu s$, $C_p+C_i=3pF$

$ENC [\text{rms e}]$

$C_g / (C_p+C_i)$

Power $P [W]$
Continuous reset of the preamplifier

L/W>>1, strong inversion, saturation

V_{gr}

- current gain equal to $N$
- fully linear
- **self-adapts** to leakage current
- minimum noise contribution
Continuous reset of the preamplifier

**Channel integral linearity error [%]**

- Injected charge [fC]
- Channel integral linearity error [%]

\[
\tau_p \approx 1\,\mu s \\
\text{Gain} \approx 200\text{mV/fC} \\
C_{\text{load}} \approx 200\text{pF} \\
C_p + C_i \approx 1.5\text{pF} \\
I_p \approx 1\text{nA}
\]

**Output vs pixel leakage current**

- Time [µs]
- Channel output voltage [V]

\[
C_p + C_i = 3\text{pF} \\
Q = 11\text{fC} \\
\text{Gain} = 200\text{mV/fC} \\
I_p = 250\text{pA} \div 70\text{nA}
\]
First generation of front-end ASICs

other features

- plug & play
- per-channel test capacitor
- programmable gain
- programmable peaking time
- high output drive capability
- high stability vs temperature
### Generation of front-end ASICs for CZT

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>General purpose</td>
<td>3</td>
<td>16</td>
<td>0.6, 1.2, 2.0, 4.0</td>
<td>30, 50, 100, 200</td>
<td>18</td>
<td>30+20/pF</td>
<td>LFOV Gamma Camera SFOV Gamma Camera Nuclear Safeguards</td>
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<tr>
<td>Medium speed</td>
<td>3</td>
<td>4</td>
<td>0.4</td>
<td>200</td>
<td>18</td>
<td>29+27/pF</td>
<td>Down Hole Well Logging X-Ray Diffraction Gauges</td>
</tr>
<tr>
<td>High speed bipolar</td>
<td>3</td>
<td>8</td>
<td>0.2</td>
<td>240</td>
<td>18</td>
<td>42+44/pF</td>
<td>Bone Densitometry Pulse Mode CT Industrial X-Ray</td>
</tr>
<tr>
<td>High capacitance</td>
<td>12</td>
<td>8</td>
<td>0.6, 1.2, 2.0, 4.0</td>
<td>30, 50, 100, 200</td>
<td>35</td>
<td>57+10/pF</td>
<td>Industrial Strip Detectors Backscatter Gauges Large Area Detector</td>
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Technology: 0.5µm CMOS SP3M
CZT – ASIC spectra measurements

**241Am spectrum**
- FWHM ≈ 4.5% at 59.5keV
- CZT 3x3x7 mm³
- Peaking Time $\tau_p \approx 1.2\mu s$

**57Co spectrum**
- FWHM ≈ 3.8% at 122keV
- CZT 3x3x7 mm³
- Peaking Time $\tau_p \approx 1.2\mu s$
CZT – ASIC applications

Solstice Gamma camera

- 96 CZT crystals
- 3072 pixels
- 192 front-end ASICs
- 1.3M events/second
- average FWHM 3.8% at 122keV

eZ-SCOPE hand held Gamma camera

- 1 CZT crystal
- 256 pixels
- 16 front-end ASICs
- 4.8M events/second
- average FWHM 4.0% at 122keV
CZT – ASIC applications

Bone Densitometry – GE Lunar Detector

- 16 CZT crystals
- 16 pixels 3 x 7 x 3 mm$^3$
- 2 front-end ASICs
- DEXA (Dual Energy X-ray Absorptiometry)
- ASICs replaced 17 circuit boards (over 500 components) and improved performances
Typical fluorescence EXAFS measurement geometry

Sample

Detector

- Resolution
- Rate

sensor

electronics
  - front-end
  - processing
  - readout
Optimum pixellation

ENC \div \sqrt{(C_p(N) + C_i)^{\gamma+1} \frac{\text{Rate}}{N} \left( \frac{P}{N} - P_2 \right)^\gamma}

\gamma = 0.5 \ldots 1

- charge sharing (\approx 20 \mu m/side) and trapping (gap/side): empirical
Si n-type high resistivity wafer 250µm thick, 
N = 384  p⁺ ≈1mm×1mm pixels, 
gaps  10µm, 30µm, 50µm
Beam through

sensor

sample
Sensor – ASIC photo

quadrant
Highly segmented detectors

Benefits:
- Position Resolution
  - pixel pitch $\sim 1/\sqrt{N}$
- Energy Resolution:
  - $C_{DET} \sim 1/N$
  - $I_{DARK} \sim 1/N$
  - Pulse Shaping time $\sim N$
- Rate capability
  - pileup $\sim 1/N$

Drawbacks:
- Interconnect density
  - density $\sim N$
- Electronics channel count
  - cost $\sim N$
  - power $\sim N$
Front-end channel overview

- Pixel
- Charge preamplifier
- Low-noise reset
- High-order settable filter
- Output baseline stabilizer
- 1 threshold 2 window
- 6-bit DACs for fine adjustment
- 24-bit
- Discriminators & counters
- SPI
- Readout

Technology CMOS 0.35µm 3.3V 2P4M
charge preamplifier  shaper with BLH  discriminators and DACs  counters

ASIC photo

32 channels, 3.6 × 6.3 mm²
Energy resolution

FWHM_{Si} [eV]

Rms Electrons

Peaking time [s]

+25°C
-15°C
-35°C
no sensor

≅ 60pA
≅ 5pA
≅ 1pA

≈ 1pA
≈ 5pA
≈ 60pA
Si – ASIC spectra measurements

$^{55}$Fe Energy Spectrum

- temperature -35°C
- rate 10kHz
- peaking time 4µs
- FWHM (Mn-Kα) 205eV
- electronic noise 167eV (20e-)

channels & discriminators enabled
counters disabled
Current EXAFS detector

head - preamplifiers

≈ 100 channels, > 350 eV, < 1 MHz

rack – shapers …
New EXAFS detector

\[ \approx 400 \text{ channels, } < 300 \text{ eV, } > 10\text{MHz} \]