EXPERIMENTAL PERFORMANCE OF A HIGHLY-INNOVATIVE LOW-NOISE CHARGE-SENSITIVE PREAMPLIFIER WITH INTEGRATED RANGE-BOOSTER

A. Pullia, S. Capra
Dept. Of Physics, University of Milano, Milano, Italy
INFN, Milano, Italy
Outline

Area: Gamma and Particle spectroscopy with solid state detectors for research in nuclear physics

Nuclear spectroscopy setups and issues

The fast-reset technique

The multi-channel fast-reset CSP ASIC

Experimental results

Conclusions

GALILEO @ LNL

TRACE @ LNL
Spectroscopic Chain

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Solid-state detector

Charge-Sensitive Preamplifier

Amplifier and MCA or ADC with digital filtering

\[ i(t) = Q \cdot \delta(t) \]

\[ Q_{\text{Emitted}} \propto E_{\text{Event}} \]
Effects of the saturation on the signal shape of a CSP

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- Signal amplitude proportional to the energy deposited in the detector
- Decay constant determined by the RC product of the CSP

- Corrupted energy information
- Dead time that can be much longer than the decay constant of the preamplifier
Towards a progressive integration of the front-end electronics

**Discrete preamplifiers**
- Not suitable in case of high channel density
- Components tolerant to higher bias voltages → High dynamic range
- Higher power consumption
- Design flexibility

**Integrated preamplifiers**
- Suitable in case of high channel density
- Components tolerant to lower bias voltages → Low dynamic range
- Low power consumption
- Radio-purity
The Fast-Reset Integrated preamplifier

- Realized in AMS C35 technology
- 8 channels for anodic signals and 1 channel for cathodic ones
- Power consumption: 12 mW/ch
- Risetime: 10 ns (4 pF det. And 1 pF FB)
- Power supply: ±2.5V
- Area = 10mm²

- Carrier: PLCC68
- Digital slow control with I2C engine
- Separate power rails for cross-talk reduction
- Equipped with Fast-Reset circuit
- Only one external component: the feedback resistor
The Fast-Reset Integrated preamplifier

- The Fast-Reset preamplifier is a CSP equipped with a Schmitt Trigger and a Current sink
- For under-threshold signals it works like a normal CSP
- In case of saturation the current sink is activated
The Fast-Reset Integrated preamplifier

- The Fast-Reset preamplifier is a CSP equipped with a Schmitt Trigger and a Current sink.
- For under-threshold signals it works like a normal CSP.
- In case of saturation the current sink is activated.

External feedback resistor

From detector

Output

Schmitt Trigger

- $C_F$

Graph:

- $V_{out} [V]$
- Time [μs]
- $E_{Ge} = 1$ MeV
- $E_{Ge} = 40$ MeV
- Fast-Reset Mode

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The Fast-Reset mode:
Not only dead-time reduction
But also High-resolution Spectroscopy

Charge-conservation principle

Constant and controlled Current generator

High-resolution spectroscopy with Time-over-Threshold algorithm

\[ \Delta T = \frac{Q_{TOT}}{I_{RESET}} \]
The Fast-Reset mode:
Not only dead-time reduction
But also High-resolution Spectroscopy

Combining offline the information collected with the two operative modes we can reconstruct the energy spectrum over an extended range.

Energies under the saturation threshold
< 10 (40) MeV

Energies over the saturation threshold
> 10 (40) MeV

Amplitude

Time

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The Fast-Reset mode:
Not only dead-time reduction
But also High-resolution Spectroscopy

1.1 keV FWHM resolution

0.2% FWHM Resolution Or better

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Dependency of the energy measurement from the baseline value

- The digital TOT signal depends on the residual charge on $C_F$ before the reset process.
- **Need for an algorithm to correct this dependency**
- Off-line digital correction: easy to implement but expensive in computational terms.
Dependency of the energy measurement from the baseline value

Pile-up effects at medium counting rate

$1.3 \text{ KHz}$

$^{60}\text{Co}$ events @ $1.3 \text{ kHz}$ count rate

saturated pulser signal @ $5.97 \text{ MeV}$

CSP out

Comparator out

reset times distribution

$^{60}\text{Co}$ background events @ $1.3 \text{ kHz}$ count rate

pulser line @ $5.97 \text{ MeV}$

after tail-correction

before tail-correction
Dependency of the energy measurement from the baseline value

Pile-up effects at high counting rate

14.5 KHz

$^{60}\text{Co}$ events @ 14.5 kHz count rate

CSP out

Comparator out

$^{60}\text{Co}$ background events @ 14.5 kHz count rate

pulser line @ 5.97 MeV

after tail-correction

before tail-correction
An algorithm to correct the spectra from the baseline dependency

\[ E_{DET} \propto V_{REF} = \alpha[I_{RESET} \cdot T - C_F \cdot (V_2 - V_1)] \]

Need to generate an auxiliary signal with amplitude \( V_{REF} \) directly proportional to the energy of the last physical event (and that doesn’t depend on the residual charge of past events!)

AUXILIARY SIGNAL

CSP out

Comparator out
An algorithm to correct the spectra from the baseline dependency

\[ E_{DET} \propto V_{REF} = \alpha [I_{RESET} \cdot T - C_F \cdot (V_2 - V_1)] \]
An algorithm to correct the spectra from the baseline dependency

\[ E_{DET} \propto V_{REF} = \alpha[I_{RESET} \cdot T - C_F \cdot (V_2 - V_1)] \]
An algorithm to correct the spectra from the baseline dependency

\[ V_{\text{AUX}}|_{CG} = \frac{1}{C_{\text{AUX}}} \int_0^T I_{\text{RESET}} \, dt = \frac{I_{\text{RESET}} \cdot T}{C_{\text{AUX}}} \]
An algorithm to correct the spectra from the baseline dependency

\[
V_{aux|lpf} = \frac{C_{lpf}}{C_{aux}} \cdot (V_1 - V_2)
\]
An algorithm to correct the spectra from the baseline dependency

\[ E_{\text{DET}} \propto V_{\text{REF}} = \alpha [I_{\text{RESET}} \cdot T - C_F \cdot (V_2 - V_1)] \]

\[ V_{\text{AUX}} |_{CG} = \frac{1}{C_{\text{AUX}}} \int_0^T I_{\text{RESET}} \, dt = \frac{I_{\text{RESET}} \cdot T}{C_{\text{AUX}}} \]

\[ V_{\text{AUX}} |_{LPF} = \frac{C_{\text{LPF}}}{C_{\text{AUX}}} \cdot (V_1 - V_2) \]

\[ V_{\text{AUX}} = \frac{1}{C_{\text{AUX}}} \cdot [I_{\text{RESET}} \cdot T - C_{\text{LPF}} \cdot (V_2 - V_1)] \]

C_F = C_{\text{LPF}}
Experimental results: linearity test

- 2 pC to 10 pC charge signals injected on the input node of the CSP with a pulser through a 1 pF test capacitor
- The auxiliary TAC structure produces signals that are linear in amplitude with the energy!
Experimental results: linearity test

• 2 pC to 10 pC charge signals injected on the input node of the CSP with a pulser through a 1 pF test capacitor

• The auxiliary TAC structure produces signals that are linear in amplitude with the energy!
Experimental results: baseline rejection

- 3 pC charge signals injected on the input node of the CSP with a pulser through a 1 pF test capacitor. From 0 to 1 pC of residual charge on the input node.

- The auxiliary TAC structure produces signals that change in shape but keep the same amplitude!

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Experimental results: Resolution

- 2 pC to 10 pC charge signals injected on the input node of the CSP with a pulser through a 1 pF test capacitor. 100 signals acquired for each peak.
Experimental results: Resolution

Amplitude histogram

Peak resolutions

<table>
<thead>
<tr>
<th>Input Charge [pC]</th>
<th>Signal amplitude [mV]</th>
<th>Peak width FWHM [mV]</th>
<th>Peak width FWHM [%]</th>
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<tbody>
<tr>
<td>2</td>
<td>49.394</td>
<td>0.210</td>
<td>0.43</td>
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<tr>
<td>3</td>
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<tr>
<td>10</td>
<td>252.27</td>
<td>0.347</td>
<td>0.14</td>
</tr>
</tbody>
</table>

• 2 pC to 10 pC charge signals injected on the input node of the CSP with a pulser through a 1 pF test capacitor. 100 signals acquired for each peak.

BEST-CASE RESOLUTION OF 0.13% FWHM OF THE TOTAL ENERGY!
Conclusions

- A low-noise low-power CSP ASIC was presented with an innovative range-booster circuit
- The CSP meets the requirements of gamma spectroscopy (but also suitable for particle spectroscopy)
- The fast risetime enables to process the signals from this preamplifier with pulse-shape analysis algorithms
- An innovative technique was presented that extends the natural dynamic range of the preamplifier from 40 MeV to several hundreds of MeV
- The TTA algorithm was implemented in an analog circuit that performs the operation on-line and is not influenced by the signal’s baseline
Perspectives

New ASIC preamplifier for signals with opposite polarities already submitted to the foundry

Extended tests on the chip (higher pulser energies, test with actual detector and cryogenic operation)

Finalization before end 2018 of the first TRACE detector array
Thank you

Special thanks to my supervisor Alberto Pullia
Many thanks to Giovanni Vito for the help in the experimental tests
Experimental tests with detector (previous chip version)

Silicon detector 1 mm thick, 32 active channels, Am-Cu-Pu mixed alpha source

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Low-pass filter

From CSP

LPF

R

R/2

R/4

R/8

C

2C

4C

To TAC

Measurement of Voltage [V]

Delay [ns]

τ = 30 ns

τ = 50 ns

τ = 60 ns

τ = 100 ns
A signal risetime with time constant comparable to the one of the LPF (or higher) induces some errors in the rejection algorithm.