A High-speed Adaptively-biased Current-to-current Front-end for SSPM Arrays

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Outline of Presentation

• Motivation for Solid State Photomultipliers (SSPM)
• SSPM Background
• ASIC Design Challenges and Avalanche Photodiode (APD) Background
• ASIC Design
• Results
• Future work
### Motivation for using SSPM’s

<table>
<thead>
<tr>
<th>PMT</th>
<th>SSPM</th>
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<tbody>
<tr>
<td>High gain</td>
<td>High gain</td>
</tr>
<tr>
<td>Sub-ns timing resolution</td>
<td>Sub-ns timing resolution</td>
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<tr>
<td>Vacuum tubes</td>
<td>Silicon</td>
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<tr>
<td>Discrete parts</td>
<td>Integrated</td>
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<tr>
<td>High power (bias voltage can exceed 1kV)</td>
<td>Low Power (bias voltages ~35V)</td>
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<td>Large, expensive</td>
<td>Small, cheap</td>
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Motivation (continued)

- Insensitive to magnetic fields, which allows for hybrid PET/MRI imaging
- Complementary imaging techniques reveals structure and function simultaneously
Background: SSPM Arrays

• Large variety of SSPM detectors
  – Capacitance ranges from 20pF to 900pF
  – Output currents ranges from 20µA to 20mA
• For example: numerous arrays made by RMD, Inc. based in Watertown, MA.
Background: ASIC Design Challenges

• Large capacitance range and output current range
• To reduce number of outputs, our group uses resistive charge division network but directly connecting SSPM to network degrades timing resolution

$$\tau = RC = (100\Omega)(900pF) = 90\text{ns}$$

• ASIC must handle large dynamic range without degrading performance of SSPM
Single Photon Avalanche Diode Background (SPAD)

- Produced by RMD, Inc. in AMS high-voltage 0.35µm technology
- Independent digital micropixel signals within macropixel sum together to produce analog signal
- Can be used for photon counting
**SPAD Model**

- $R_{\text{Quench}}$ stops avalanching process
- $R_{\text{Breakdown}}$ models resistance during avalanche
- $C_{\text{Junction}}$ models depletion cap

- E.g.: $R_{\text{Quench}} = 100\, \text{K}\Omega$, $R_{\text{Breakdown}} = 20\, \text{K}\Omega$
- $C_{\text{Junction}} = 200\, \text{fF}$
Proposed Solution

• Isolate macropixel cathode by using a current conveyor

\[ \tau_{\text{new}} = R C_{\text{parasitic}} \ll R C_{\text{pixel}} \]  \quad \text{Minimal timing resolution loss}
Front-End Circuit

- Feedback amplifier gain controlled by starving current which ensures stability with pixel capacitances from 20pF up to 900pF and currents from 20uA up to 20mA
Complete ASIC

• Comprised of:
  - 16 Current-to-current front-ends
  - Resistive charge division network
  - 4 Transimpedance amplifiers
  - 4 100Ω Output buffers
Results – Micrograph
Results – Measurement Setup

Out: 4 Channels bundled together to simulate 600pF pixel

LSO crystal

6x6 SSPM pixel array

ASIC Output

ASIC

\[ V_{10\Omega} \]

Ge-68 511keV
Results – Measurement Setup

- Ge-68
- ASIC Outputs
  - Ch. A
  - Ch. B
  - Ch. C
  - Ch. D
Results – Transient Plots

Risetime for this pulse: ~12ns

Degradation <2ns
Results – Position Plot

• Measured output of ASIC shows good separation. Input from emulator board.
Results – Crystal Decoding

• Distortion comes from test measurement setup. The multi-purpose PCB used, which is not optimized for our experimental setup.
Results – Energy Spectra

• For Na-22 source, energy resolution (FWHM) at 511keV peak is 20.4% for detector and 20.6% for detector and ASIC.
Results – Linearity

• Less than 4% deviation with large and small loads

![Graph showing linearity results with data points and regression lines for 450 pF and 900 pF loads.](image)
## Results - Summary

<p>| | |</p>
<table>
<thead>
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<tbody>
<tr>
<td>Rise time degradation</td>
<td>&lt;2ns</td>
</tr>
<tr>
<td>Input capacitance range</td>
<td>20pF to 900pF</td>
</tr>
<tr>
<td>Total # of Inputs</td>
<td>16</td>
</tr>
<tr>
<td>Total # of Outputs</td>
<td>4</td>
</tr>
<tr>
<td>Power</td>
<td>~12 mW/ channel, ~300mW full chip</td>
</tr>
<tr>
<td>Noise (rms)</td>
<td>&lt; 1 mV&lt;sub&gt;rms&lt;/sub&gt;</td>
</tr>
<tr>
<td>Noise (FWHM)</td>
<td>&lt;1% added in quadrature to LSO crystal</td>
</tr>
<tr>
<td>Linearity</td>
<td>&lt;4% deviation</td>
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Future Work

• Improve measurement setup
• Integrate SSPM and ASIC monolithically
• Increase the number of read-out channels from 16 to 64
• Add temperature stabilization and correction circuits for SSPM
• Use inside of MRI for hybrid PET/MRI imaging
Acknowledgements

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Detectors made by
Thank you for your attention