Low-power Wide-dynamic-range Readout System for a 64-channel Multi-anode PMT of a Scintillation Gamma Camera

Satoru Iwaki
T. Tanimori, H. Kubo, K. Miuchi,
S. Kabuki, J. Parker, H. Nishimura, K. Hattori,
K. Ueno, S. Kurosawa, C. Ida, M. Takahashi,
N. Higashi, K. Nakamura, T. Sawano, K. Taniue

Dept. of Physics, Graduate school of Science, Kyoto University, Kyoto, Japan

11th iWoRiD, Prague, Czech Republic
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Electron Tracking Compton Camera (ETCC)

Sub MeV~ MeV gamma-ray imaging for …

- Astronomy (balloon experiment, SMILE)
- Medical Imaging

**micro-TPC**
- Gaseous Time Projection Chamber
  - Based on $\mu$-PIC as readout system
  - $\Rightarrow$ Track and energy of recoil electron

**Scintillation Camera**
- Pixel Scintillator Array
  + Multi Anode PMT
  - $\Rightarrow$ Position and energy of scattered gamma-ray

Reconstruct Compton Process
- Determine direction and energy of incident gamma ray event by event
2 source image ($^{137}\text{Cs}(662\text{keV})$ and $^{54}\text{Mn}(835\text{keV})$)
Scintillation Camera

**Pixel Scintillator Array (PSA)**
- GSO(Ce) crystal
- array: 8 × 8
- Pixel size: 6 × 6 × 13mm³
- Pixels are optically isolated with the ESR(3M)

**Multi Anode PMT H8500 (HPK)**
- anode: 8 × 8
- Size: 52 × 52 × 20mm³
- Effective area: 49 × 49mm² (89%)
- Gain: \(\sim 10^6\) @ -1000V
- Gain uniformity: \(\sim 1:3\)

PSA is optically glued to H8500 with OKEN-6262A grease

Signal size \(\sim 500\) pC @ 1MeV
SMILE

Sub-MeV gamma-ray Imaging
Loaded-on-balloon Experiment

SMILE-1 (Sep. 1st, 2006)

- 10 × 10 × 15 cm³ TPC 33 Scintillation Cameras
- Operation test of our ETCC @ 35km
- Background Measurement
  (Diffuse cosmic and atmospheric gamma)
SMILE-1 has been successful.

Scintillation camera
- Anode signal is grouped by chained resistor.
- Measured by discrete NIM/VME modules
- Energy Resolution: 11% @ 662 keV (FWHM)
- Dynamic range: 80 keV ~ 800 keV
- Power Consumption: 2.7 W/64 pixels

SMILE-2 (2011)

- (40 cm)³ TPC + 192 Scintillation Cameras
- Observation of Crab or Cyg X-1

We are developing a larger detector.
Requirements for scintillation camera

- Position resolution - Affect the angular resolution of Compton Camera
- Energy resolution - Affect the dynamic range of Compton Camera
- Dynamic range - Scintillator is activated with cosmic ray in the sky.
- Radiation hardness
- Power consumption - Power is limited in the sky.

<table>
<thead>
<tr>
<th></th>
<th>Number of MAPMT</th>
<th>Power Consumption [W/64pixels]</th>
<th>Energy Resolution (FWHM)@662keV</th>
<th>Dynamic Range [keV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMILE-1</td>
<td>33</td>
<td>2.7W</td>
<td>~ 11.0%</td>
<td>80-800</td>
</tr>
<tr>
<td>SMILE-2</td>
<td>192</td>
<td>&lt; 400mW</td>
<td>~ 11.0%</td>
<td>80-1000</td>
</tr>
</tbody>
</table>

We have improved new readout system with low power consumption.
Readout system with ASIC (VA/TA)

**CP80168 (Clear Pulse)***
- 32ch CMOS ASIC (by IDEAS ASA) *2
- 64ch readout
- Input dynamic range : ~35pC
- 80 us/64ch to read out
- Power Consumption : 1.05W

- Energy Resolution : ~11%@662keV (FWHM)
- Dynamic range : 30keV~800keV

- Narrow input dynamic range
- Large power consumption.
New Readout System

Head Amp Unit CP80190 (Clear Pulse)
- 64ch readout
- Using only discrete devices.
- Input dynamic range is variable by replacing feedback capacitor.
  (Adjusted to <750pC)
- Power Consumption: 1.2W
- 20s/64ch to read out

80057 Data Processor
(Clear Pulse)
VME module for 4 Head Amps
Power Consumption 1.5W

- Pre-Amp
  - $\tau = 5 \mu s$
- Shaper Amp
  - $\tau = 5 \mu s$
- Fast shaper
- Sample & Hold ADC
- Comparator
  - 64ch OR
  - $\times 64$
- FPGA
- Ext. Trigger
- Trigger out
- Data
- Control

52 mm
140 mm
Linearity of CP80190

- Input some test charge into CP80190

Linearity is kept from 50pC to 700pC (±0.5%)
⇒ Enough for our Scintillation Camera.
Reconstructed image and spectra of $^{137}$Cs.

- Reconstructed by Center of Gravity Method.
- Each 64-pixel is clearly resolved.

Energy spectra showing peaks at 32keV and 662keV with a full width at half maximum (FWHM) of 10.1%.
GSO + CP80190

Energy Resolution and Dynamic range

Energy Resolution (average):
10.6%@662keV (FWHM)

Dynamic range:
30keV~1.3MeV

Power Consumption:
1.55W/PMT

=> Too large power consumption for SMILE-2
Chained Resistors + CP80190

In order to reduce further the power consumption...

The number of readout ch is reduced to 1/16
=> total power consumption is reduced.
Chained Resistors + CP80190

- Each 64-pixel is clearly resolved

Reconstructed image and spectra

137Cs

662keV 10.5% (FWHM)

ProjectionX

662keV

10.5% (FWHM)
Res. = (10.5 ± 0.4) *(E/662)^(-0.47 ± 0.02)

Energy Resolution and Dynamic range

• Energy Resolution (average): 10.5% @ 662keV (FWHM)
• Dynamic Range: 80keV ~ 1300keV
• Power Consumption: 100mW/PMT

=> Satisfy all requirements of SMILE-2
LaBr$_3$(Ce) Scintillator

For next experiment after SMILE-2, or medical imaging, it is important to improve angular resolution of ETCC.

- Pixel size: $5.9 \times 5.9 \times 20\text{mm}^3$
- 8 x 8 array
- Glass window: Quartz (t 2.3 mm)
- Hermetic package: Aluminum (t 0.5 mm)

© Excellent Energy Resolution: $\sim 3\%@662\text{keV}(\text{FWHM})$
× Strong Hygroscopic

Energy Resolution measured with discrete NIM/VME modules is $5.8\%@662\text{keV}(\text{FWHM})$
CP80190 + LaBr₃ (single crystal)

- Energy Resolution:
  3.4% @ 662 keV (FWHM) (consistent with NIM/VME discrete readout system)
- Dynamic range: 80 keV ~ 1.3 MeV
CP80190 + LaBr₃ Array

Reconstructed image and spectra

\(^{137}\text{Cs}\)

- Each 64-pixel is clearly resolved

\[ \text{FWHM} = 5.2\% \]

\[ \text{32keV} \]

\[ \text{662keV} \]

\[ \text{Reconstructed image and spectra} \]
CP80190 + LaBr$_3$ Array

- Energy Resolution and Dynamic range

- Energy Resolution (average):
  \[ \text{Res.} = (5.7 \pm 0.4) \times \left(\frac{E}{662}\right)^{-0.58 \pm 0.07} \%

- Dynamic Range:
  80keV - 800keV
Summary ~For SMILE-2~

- We have developed ETCC which consists of gaseous TPC and scintillation camera.
- For next balloon experiment, we have developed a new readout system of scintillation camera with very low power-consumption and wide dynamic-range.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Energy Resolution (FWHM@662keV)</th>
<th>Energy Dynamic range</th>
<th>Power (/PMT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chained resistor and discrete NIM/VME modules</td>
<td>$\circ 11%$</td>
<td>$\Delta 80\text{keV} \sim 800\text{keV}$</td>
<td>$\times 2.7\text{W}$</td>
</tr>
<tr>
<td>CP80168 (VA/TA) (64ch readout)</td>
<td>$\circ 11%$</td>
<td>$\Delta 30\text{keV} \sim 800\text{keV}$</td>
<td>$\times 1.4\text{W}$</td>
</tr>
<tr>
<td>CP80190 (64ch readout)</td>
<td>$\circ 10.6%$</td>
<td>$\odot 30\text{keV} \sim 1.3\text{MeV}$</td>
<td>$\times 1.5\text{W}$</td>
</tr>
<tr>
<td>Chained resistor and CP80190 (4ch readout)</td>
<td>$\circ 10.5%$</td>
<td>$\odot 80\text{keV} \sim 1.3\text{MeV}$</td>
<td>$\odot 100\text{mW}$</td>
</tr>
</tbody>
</table>
Future Work

- For SMILE-2
  - Enlargement of the scintillation camera.
  - Install readout system in DAQ system of ETCC.

- In order to improve angular resolution of ETCC (for Medical imaging and next to SMILE-2)
  We have developed LaBr₃ arrays.
  - Energy resolution of the array (FWHM, @662keV):
    - Discrete modules (4ch readout): 5.8%
    - New readout system (64ch readout): 5.4%
  - Dynamic range: 80 - 800 keV
Thank you