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

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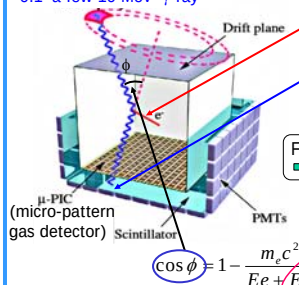
We have developed a low-power wide-dynamic-range readout system of a 64-channel multi-anode PMT for a scintillation camera. Each anode is individually read with the system that contains discrete devices of amplifiers, comparators, S/H ADCs, and FPGAs. The size of the system, designed for a two-dimensional array of Hamamatsu flat panel PMT H8500, is 5×5×16 cm^3. The input dynamic range is variable by replacing the SMD feedback capacitor of the preamplifier (e.g., ~700pC and ~4000pC for GSO(Ce) and $LaBr_3$(Ce) crystals, respectively). The total power consumption is 1.6W/64ch. The serialized ADC data are sent to a VME sequence module. With this system we have developed a gamma camera using an 8×8 array of GSO scintillator pixels with a size of 6×6×13 mm^3 and an H8500. We obtained flood field irradiation images at energies from 30 keV to 1.3 MeV. In addition, we used the readout system for an 8×8 array of LaBr3(Ce) pixels with a size of 6×6×15 mm^3.

1.Introduction

We have been developing a Compton camera for applications to medical imaging and a balloon-borne astronomical experiment [1].

0.1~a few 10 MeV γ-ray



$$\cos\phi = 1 - \frac{m_e c^2}{Ee + E\gamma} \cdot \frac{E\gamma}{Ee}$$

- Gaseous Time Projection Chamber
  3D track and Energy of Compton-recoil electron
- Scintillation camera
  Position and Energy of scattered γ-ray

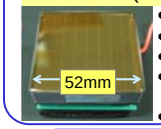
Full reconstruction of Compton scattering process event by event

For better angular resolution of Compton camera Δφ,
→ Better energy resolution of scintillator ΔEγ

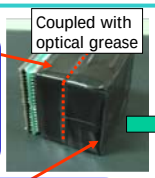
Requirements for readout system of scintillation camera
- Higher light yield of scintillator → Wide input dynamic-range
- Balloon-borne experiment → Low-power electronics

2.Scintillator+PMT

64ch MAPMT(HPK Flat-panel H8500)

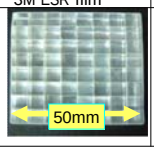
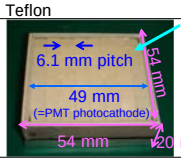


- 8×8 anodes
- Anode pitch: 6.1mm
- 12 stage metal channel dynode
- Size: 52mm×52mm (Photocathode coverage ~89%)
- Anode uniformity: min:max~1:3

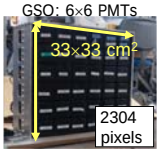


GSO: 3×3 PMTs

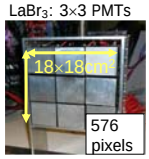
PSA (Pixel Scintillator Array)

	GSO(Ce)	$LaBr_3$(Ce)
Manufacturer	Hitachi Chemical	Saint-Gobain
Pixel size	5.9×5.9×13mm^3	5.8×5.8×15mm^3(Type A)[2], 5.8×5.8×20mm^3(Type B)
Array	8×8 pixels	8×8 pixels
Pixel pitch	6.1mm	6.1mm (= PMT Anode pitch)
Reflector	3M ESR film	Teflon
Both arrays were assembled with our own technique		

GSO: 6×6 PMTs

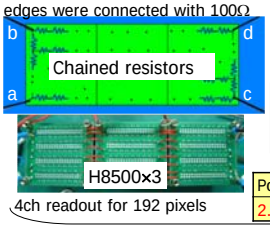


$LaBr_3$: 3×3 PMTs



3. Chained-resistor+Discrete-device Readout

At first we developed a readout system with discrete device. For reducing readout channels, anodes of 3 PMTs in horizontal row and both edges were connected with 100Ω resistor [3].



4ch readout for 192 pixels

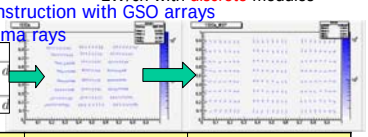
4ch (a, b, c, d) → Pre Amp → Shaping Amp → VME Peak-Hold ADC

τ = 5μs τ = 0.5μs

2W/ch with discrete modules

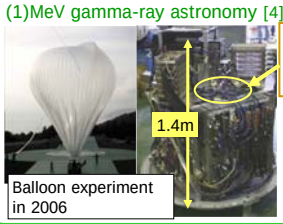
Position reconstruction with GSO arrays for ^{137}Cs gamma rays

$$x = \frac{c+d}{a+b+c+d}, \quad y = \frac{b+d}{a+b+c+d}$$



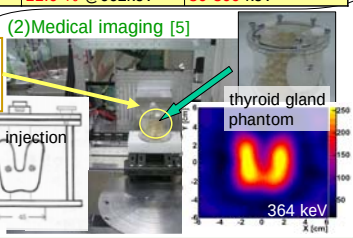
Power Consumption	Energy Resolution	Dynamic Range
2.7 W/64pixels	11.0 % @662keV	80-800 keV

(1)MeV gamma-ray astronomy [4]



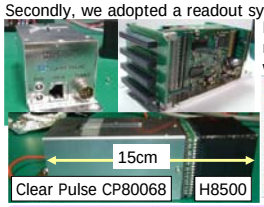
GSO scintillation camera

(2)Medical imaging [5]



4. ASIC+Attenuator Readout

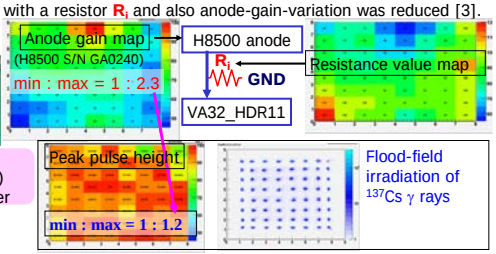
Secondly, we adopted a readout system with a commercial CMOS-ASIC.



IDEAS VA32_HDR11
Pre Amp. (Dynamic Range ~35pC)
Shaper, Sample & Hold, Multiplexer

IDEAS TA32CG2
Fast shaper, Discriminator

However, charge from each anode was larger than the dynamic range of ASIC. Therefore, each signal was attenuated to ~ 1/10 with a resistor R_i and also anode-gain-variation was reduced [3].



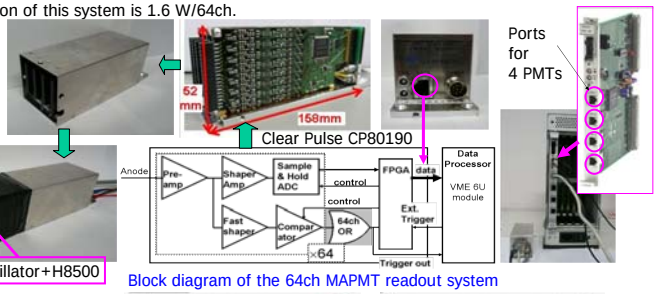
GSO array	Power Consumption	Energy Resolution (FWHM)	Dynamic Range
w/o attenuator	1.4 W/64pixels	13.0 % @662keV	100-700 keV
with attenuator	1.4 W/64pixels	11.7 % @662keV	30-900 keV

5. Low-power wide-dynamic-range readout system

The attenuation resistor connected to ASIC (IDEAS VA32_HDR11) is available for various scintillators with different light outputs. However, the attenuation worsens a signal to noise ratio. We therefore have developed a PMT readout system with discrete devices, which has low-power consumption and wide input dynamic range.

Circuit Architecture

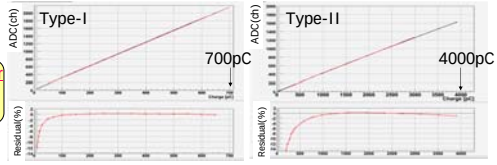
The input dynamic range is variable by replacing the SMT feedback capacitor of the preamplifier (700pC and 4000pC for GSO and $LaBr_3$ crystals, respectively). The S/H signal is digitized by a 12bit ADC. It takes 20 μs to process one event (64 channels). Then the 64ch data are serialized, and sent to a VME-6U sequence module by FPGAs via an Ethernet cable. The total power consumption of this system is 1.6 W/64ch.



Block diagram of the 64ch MAPMT readout system

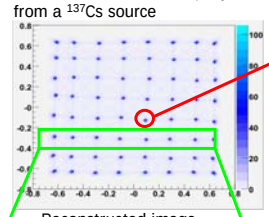
Dynamic Range & Linearity

Preamp. feedback capacitor
Type-I 330pF
Type-II 1800pF

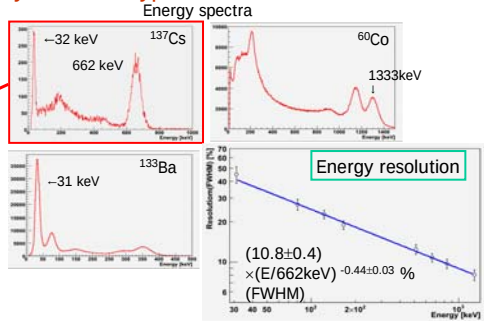


Performance of GSO array+H8500+Type-I readout

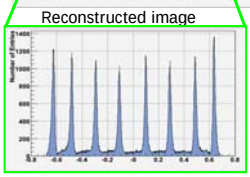
Flood-field irradiation of γ rays from a ^{137}Cs source



Energy spectra

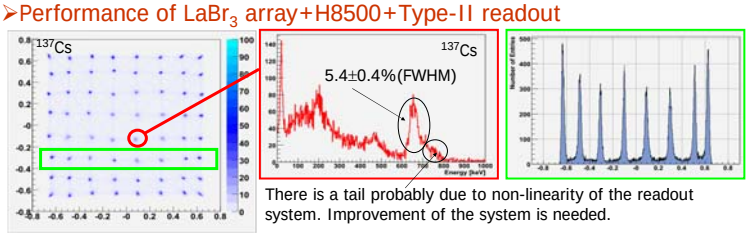


Reconstructed image



Power Consumption	Energy Resolution	Dynamic Range
1.6 W/64pixels	10.8 % @662keV	30-1300 keV

Performance of $LaBr_3$ array+H8500+Type-II readout

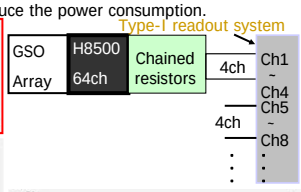


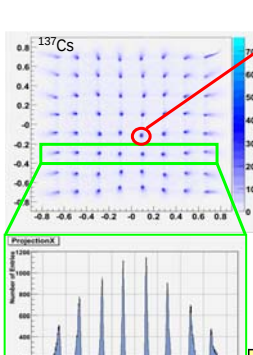
There is a tail probably due to non-linearity of the readout system. Improvement of the system is needed.

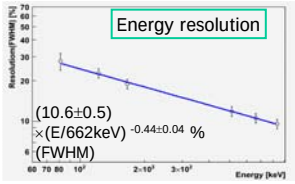
Performance of GSO array+H8500 +chained resistors+Type-I readout

We further investigated the performance with chained resistors in order to reduce the power consumption.

Type-I readout system







Power Consumption	Energy Resolution	Dynamic Range
0.1 W/64pixels	10.6 % @662keV	80-800 keV

References

[1] T.Tanimori, et al., IEEE2008 CC2-1; Hattori et al., NIMA, 581, 517 (2007)
[2] H.Kubo, et al., IEEE2007, CR, 4569
[3] K.Ueno, et al., NIMA, 591, 268 (2008)
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[5] S.Kabuki, IEEE2008 M06-199; R.Kohara, IEEE2008 M06-173