New Modular Readout for Radiation Imaging Applications

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Abstract

We have developed and tested a radiation imaging detector module for use in tileable radiation imaging devices such as gamma cameras. The module combines nine SensL SPMArray4 four-side scalable silicon photomultiplier (SiPM) arrays in a 3×3 layout, producing a tileable 48×46 mm² detector with four coordinate signal outputs. SPMArray4 is one of the first commercially available SiPM arrays (size 15.81×15.31 mm²), comprised of 16 SiPM elements 3.17×3.17 mm² each, tiled into a 4×4 low profile ceramic package free of magnetic material, with a fill factor of about 57% (200 μm septa). The readout circuit is small enough to fit in two 48×46 mm² PCBs. Thus the detector module may be used, for example, as the replacement for the Hamamatsu flat panel position sensitive PMT tubes in larger size gamma cameras, and as a convenient building block for construction of radiation imaging detectors with a low number of the output signal lines. We present results of the module performance tests in which the position resolution in the range 1.3-2.0 mm was demonstrated both with a cooled setup and at the room temperature.

Device and Method

The designed readout circuit provides analog signal processing and data compression in the readout electronics front-end, converting signals from the 144 individual SiPM elements into just four analog outputs connected to the external Data Acquisition system, without loss of the positional and energy information in a scintillation event. Fig. 1 shows the block diagram of the circuit.

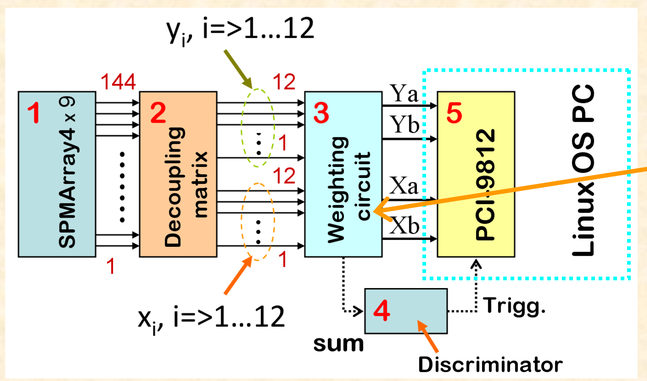


Fig. 1

The signal weighting circuit provides analog weighted sum of 12 X and 12 Y projected coordinates. The circuit functions for the Xa and Xb outputs are as follows:

$$Xa = G \cdot \sum_{i=1}^{12} x_i \cdot i \qquad Xb = G \cdot \sum_{i=1}^{12} x_i \cdot (13 - i) \qquad (1),$$

where G is the gain factor common for all x_i and y_i.

The event position in X and Y are then found from:

$$X = \frac{Xa - Xb}{Xa + Xb} \qquad Y = \frac{Ya - Yb}{Ya + Yb} \qquad (2)$$

The first readout module is assembled on a single PCB with all readout electronics components mounted on the top, for easy troubleshooting and testing. Fig. 2 shows the photo of the module with nine SPMArray4s.

SPMArray4

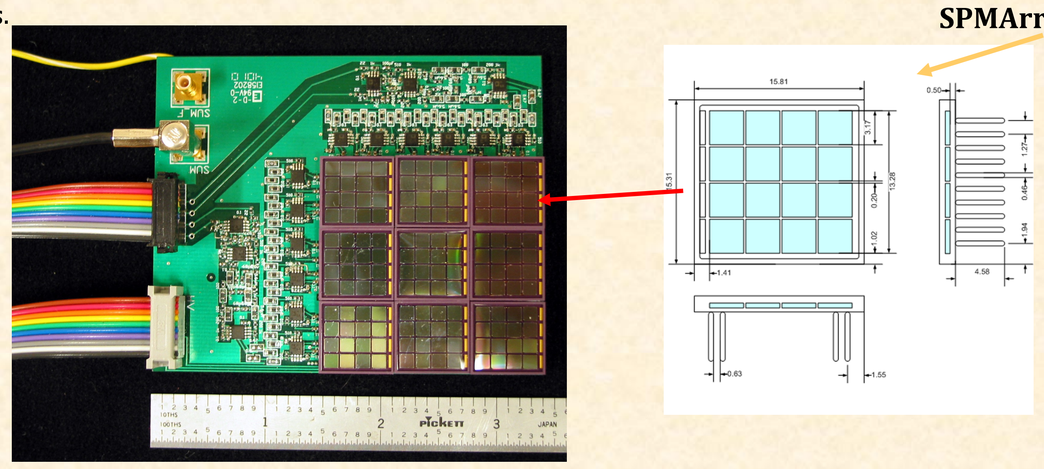


Fig. 2

The two IDC-10 connectors are used for the connection to the power supply and to the Data Acquisition system (DAQ). For evaluation purposes, the individual SiPM bias voltage lines were installed for possible SPMArray4's gain equalization. Evidently such equalization is not required, and the production readout board will carry only one IDC-10 connector for all power and data lines. Readout electronics operation was tested using the pixelated LYSO scintillator crystal arrays made by the Proteus in Ohio, USA (http://www.apace-science.com/proteus/lyso.htm). Fig. 3

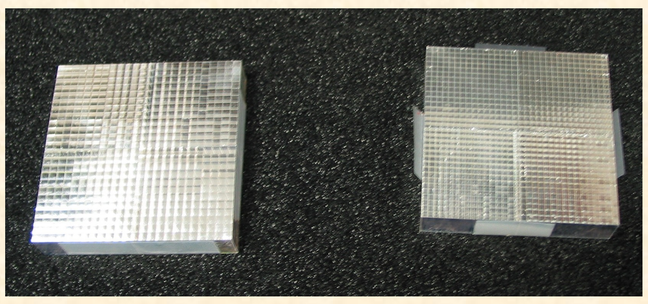


Fig. 3

The scintillator array on the left is made out of four 10 mm thick pixelated tiles, with 1.51 mm square pixels placed with 1.69 mm pitch. The scintillator on the right is also made out of four 10 mm thick pixelated square blocks, with 1.1 mm square pixels, placed with 1.27mm pitch.

shows the two scintillators used in initial test of the designed module.

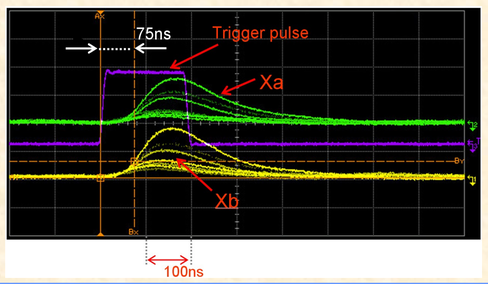


Fig. 4

Coordinate signals and trigger pulses from the module with a LYSO scintillator irradiated with 511 keV gammas from a ^{22}Na source. Both coordinate pulses are delayed relative to the "fast sum" output inside the readout module. Delay is built in for the convenience in triggering in the single-sample DAQ systems.

Data Acquisition and Test Setup

The dedicated data acquisition system was built using a mini PC computer running Linux with the ADLINK PCI-9812 data acquisition card [8]. Every signal was digitized several times using 20 MHz multisampling mode, starting from the single threshold discriminator. Multiple data capture allowed us to extend the effective dynamic range of the ADC over its 12-bit range, which provided extra signal quality information for additional pile-up and noise detection and discrimination. The signal processing technique and software were developed by Lintech Instrumentation LLC. The X and Y positional information in every event was extracted from the recorded raw data samples by means of the multi-parameter least-square fits of the measured Xa(t), Xb(t), Ya(t), and Yb(t) functions of time t to the formulae (2). Signal amplitude was measured through the interpolation of the sum Xa+Xb+Ya+Yb. Such multisampling procedure permits to extend the effective dynamic range of the ADC over 12-bit, and provides some extra signal quality information for additional pile-up and noise detection and discrimination. The signal processing technique and software were produced by Lintech Instrumentation LLC. The DAQ system acquires the raw information from the SiPM array readout module, stores the data on the hard drive, and provides partial on-line data and image processing. Fig. 5 shows an illustration of a reconstructed signal during the data processing.

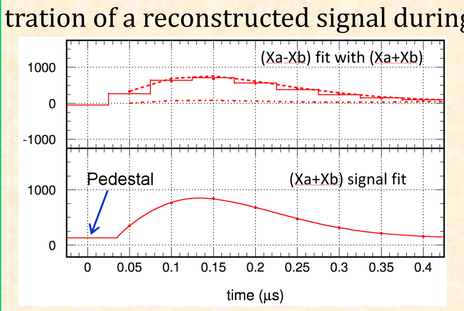


Fig. 5

Reconstruction fit of signals recorded from SiPM array readout module during signal processing.

Initial Results

SensL suggests operation of SPMArray4 with bias voltage +29.5 V and with external cooling down to 5-10 °C . Our test setup included Peltier cooler capable of cooling down the working module to 17 °C. Most of our test measurements were done at this temperature. However, initial tests of the readout module without cooling also showed encouraging results. When used with bright scintillator crystals (LYSO or brighter), the detector may achieve 2 mm resolution for 511 keV gamma radiation imaging even operating at room temperature. Cooled setup demonstrates ~1.27mm spatial resolution with ^{22}Na radiation source. This result could be improved by using optimized light spreader and by cooling the device down to the recommended 5-10°C. Fig. 6 shows selected images and energy distribution curves obtained with designed readout module, SiPM array and different LYSO scintillators.

Fig. 6

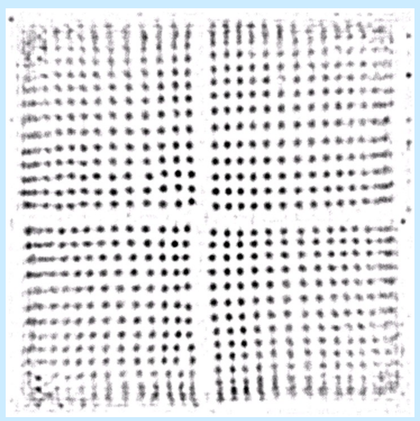
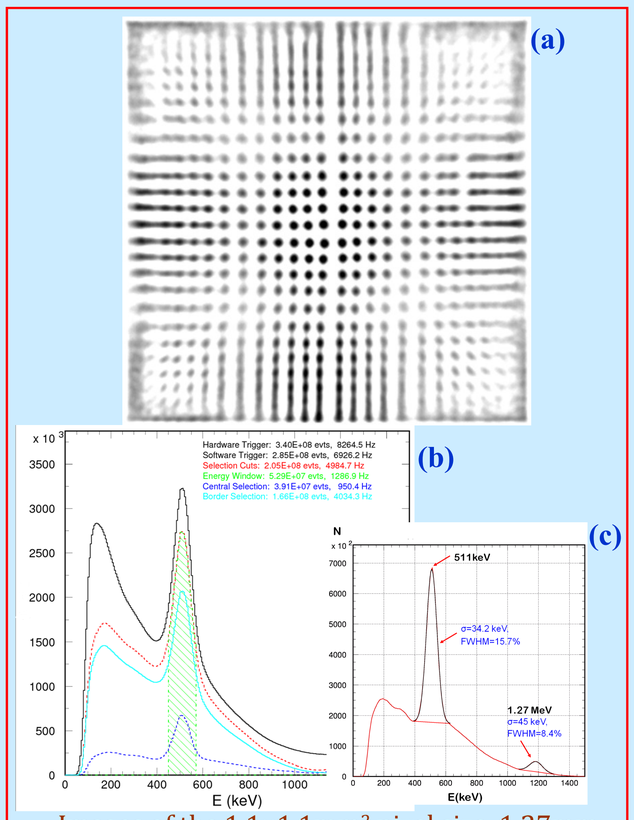
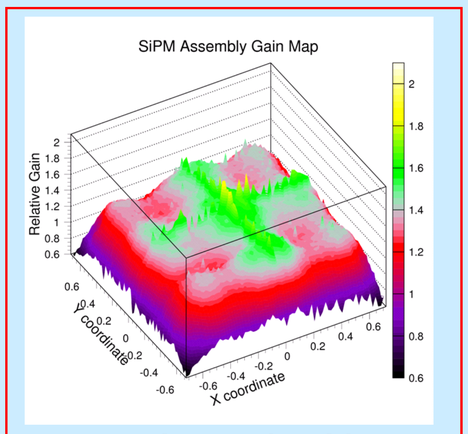


Image of the 1.51×1.51mm² pixel size LYSO scintillator array, 1270 keV gammas from a ^{22}Na source is selected. Device cooled to 17 °C. 29.2V SiPM bias



Images of the 1.1×1.1mm² pixel size, 1.27mm pitch LYSO scintillator array (a), the ^{22}Na radiation source energy distributions using different selection cuts (b), with the central detector area selection shown separately (c). 17°C, and 30V SiPM array bias



Gain uniformity plot of the 1.51×1.51mm² pixel size LYSO scintillator array at 17°C.

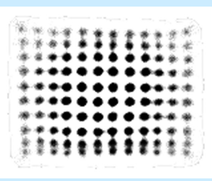


Image of the 1.51×1.51 mm² pixel size, 1.69mm pitch LYSO scintillator array, placed in the central detector area. Obtained at 25°C (no cooling,) with a ^{228}Th gamma source.

Conclusion

New compact readout module with convenient five wires per module signal output for use with the array of nine SensL's SPMArray4s has been developed and tested. Best performance was obtained with a 1.27mm pitch pixelated LYSO crystal scintillator array and cooled setup. Non-cooled setup at room temperature proved to be suitable for applications requiring 2 mm spatial resolution. However, better device performance will be possible at a lower operation temperature and with a better optimized light spreader.

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