Evaluation of the SensL SPMMatrix for Use as a Detector for PET and Gamma Camera Applications

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Abstract*– The SPMMatrix from SensL (SensL, Cork, Ireland) is a large area photodetector consisting of a 4 × 4 array of SensL SPMArray4 detectors, each a 4 × 4 array of silicon photomultiplier (SiPM) pixels, giving a total of 256 SiPM pixels. In addition, the device has 32 amplifiers and analog-to-digital conversion (ADC) channels and a FPGA-based data acquisition board. The anodes of the SiPMs are chained together according to an array/pixel wiring scheme developed by SensL to reduce the number of readout electronics channels to 32. In this work we conducted a preliminary evaluation of the SPMMatrix device to assess its suitability for PET and gamma camera applications. One commercially manufactured 4 × 4 array of 3.17 × 3.17 × 10 mm^3 LYSO crystals was coupled to one of the 4 × 4 SiPM pixel arrays, effectively giving a one-to-one coupling of the scintillator crystal and SiPM pixels. A custom data acquisition program that allowed acquisition of all 32 ADC channels was used to acquire data from the device. A ^{68}Ge source was used for all testing. High quality flood images were obtained from the SPMMatrix device, with all crystals being well resolved. Two methods were investigated for determining the energy resolution. The better method, using the hardware sum of the pixels in one SPMArray4 detector, gave an energy resolution of 17%. The resolution degraded to 21% when the energy value was calculated by a software sum of the pixel values. This decrease in energy resolution is likely due to the contribution of dark noise from the pixels in the other arrays and due to the array/pixel multiplexing strategy. In comparison, the same LYSO array tested with a single SPMArray4 detector and NIM electronics gave an energy resolution of 14.6%.

I. Introduction

Geiger mode avalanche photodiodes (GAPDs), commonly called silicon photomultipliers (SiPMs) are being extensively investigated for PET and gamma camera imaging applications due to their favorable characteristics including high gain, good timing performance, and low operating bias voltage [1-4]. The insensitivity of SiPMs to strong magnetic fields also makes possible the integration of PET and magnetic resonance imaging (MRI) [5]. SiPM devices are typically only a few mm^2 in size, so a key to the practical use of these SiPM devices is the ability to tile them into large area arrays. Arrays of this type are now commercially available from several manufacturers. In this work we examine the performance of the SPMMatrix from SensL (SensL Inc., Cork, Ireland) and evaluate its suitability for PET and gamma camera applications.

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II. Materials and Methods

A. SPMMatrix

The SPMMatrix consists of a 4 × 4 array of SensL SPMArray4 detectors, each with a 4 × 4 array of 3.17 mm × 3.17 mm SiPM pixels, giving a total of 256 SiPM pixels arranged in a 16 × 16 array with a total active area of 61.3 mm × 61.3 mm. Fig. 1 shows a photograph of the SPMMatrix detector. The SPMMatrix unit includes all electronics required to read out the detectors, with 32 channels of shaping and analog to digital conversion (ADC) along with a FPGA based data acquisition board. At the present time, the SPMMatrix electronics are optimized for use with the LYSO and LSO scintillators. The signals from the 256 SiPM pixels are multiplexed according to an array/pixel summing strategy. Sixteen of the channels, A0…A15, are array channels where each channel is the sum of all 16 pixels in an array (Fig. 2).

The other sixteen channels, P0…P15, are pixel channels, where pixels of the same relative position in each of the arrays are summed (Fig. 3). For example, the output of pixel number 0 from each of the 16 arrays are summed into one channel, namely channel P0. This multiplexing scheme necessitates a more complex position decoding scheme than traditional row/column multiplexing designs.

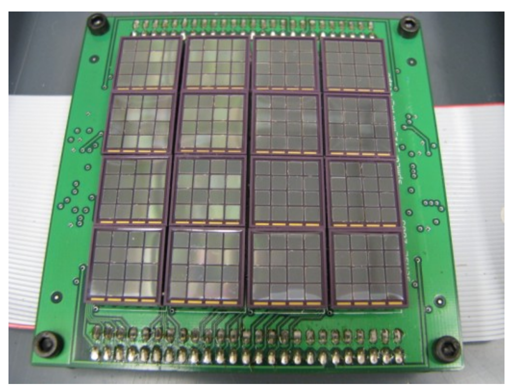

Fig. 1. Photograph of the SensL SPMMatrix showing the 4 × 4 array of the 4 × 4 SiPMs. This results in a 16 × 16 SiPM pixel array with a total area of 61.3 mm × 61.3 mm.

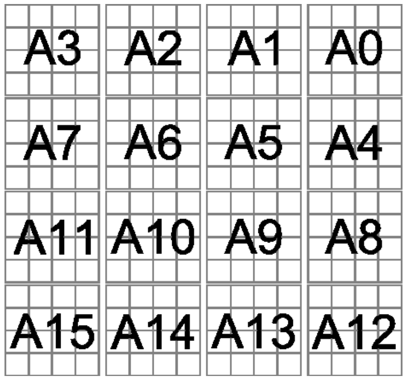

Fig. 2. The anodes of the pixels within the same array are summed into one channel. There are 16 arrays, so there are 16 of these array channels, numbered from A0 to A15.

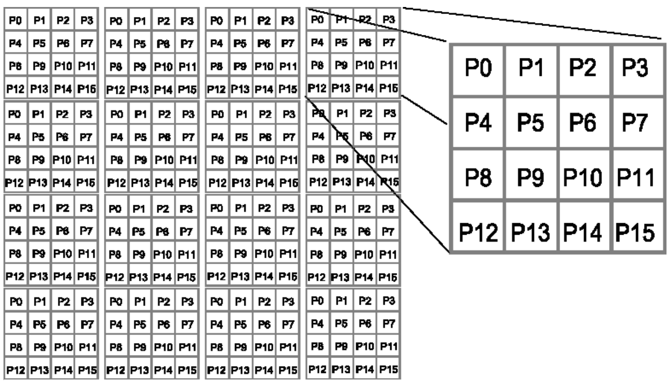

Fig. 3. Pixels of the same relative position in an array are summed together. The label on each pixel represents the channel that it is multiplexed into. For example, all those 16 pixels labeled P0 in this diagram are summed into pixel channel P0.

B. Data Acquisition

In this evaluation work, one commercially produced LYSO array, consisting of a 4 × 4 array of 3.17 mm × 3.17 mm × 10 mm crystals (Proteus Inc., Chagrin Falls, OH), was coupled with optical grease to one of the SPMArray4s in the device (Fig. 4). The crystals were flood irradiated with a ^{68}Ge source. Data were acquired using a custom program written in LabWindows/CVI (National Instruments, Austin, TX) that allowed acquisition of all 32 ADC values for each event. For each acquisition, 1 million events were acquired. Flood images were created from the data and the photopeak position and energy resolution were calculated for each crystal using analysis programs written in Matlab (MathWorks, Natick, MA).

C. Generating the Flood Histogram

The position of an event was calculated by putting the 16 pixel channel ADC values in the centre of mass formula. This simulates in software the positioning algorithm of Anger logic. Based on the calculated position, events were sorted into a flood histogram. In this evaluation, only one crystal array was coupled to one of the detectors. In more practical situations where the detectors are all populated by crystals, a simultaneous scintillation event in crystals on different SPMArray4 detectors will pose a challenge in event positioning. This is because a pixel channel is a mix of signals from all 16 detector arrays, and hence the information about the source of signal is lost in this mixing process.

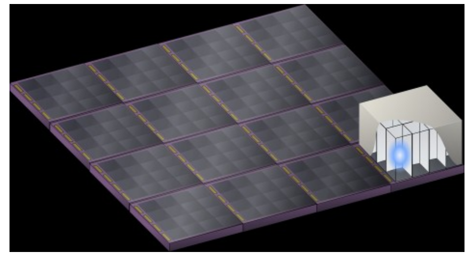

Fig. 4. One 4 × 4 array of 3.17 mm × 3.17 mm × 10 mm LYSO was coupled to one of the SiPM arrays in the device.

D. Calculation of Energy Spectrum

Two methods of obtaining the energy information from the 32 channels of data were investigated. The first method uses the maximum ADC value of the array channels, A0…A15, as the value for energy. The second method sums the ADC values of the strongest pixel together with its 8 neighbouring pixels, using the pixel channel data. The addition of neighbor pixels is necessary because even though there is a one to one coupling between the crystal and the SiPM, the epoxy layer on the detector surface allows for light spread across multiple pixels. The true energy will only be recovered if the ADC values of the neighbouring pixels are added to the strongest pixel.

E. Testing Effects of Test Array Bias Voltage

The bias voltage of each array can be individually adjusted. To test the effect of bias voltage on the flood image and the energy spectrum, we increased the test array's bias setting from 33.0V (low) to 34.65V (medium) then to 36.3V (high), while maintaining the other arrays at the low setting. The voltage values were chosen to utilize the maximum range of the bias voltage permitted by the SPMMatrix device driver. It is important to note that the bias voltage setting is not the same as the actual bias voltage applied to the detector. To get the voltage on the detector, one needs to measure the current consumed by the bias power line, a measurement not performed in this evaluation.

F. Altering Bias Voltage of the Idle Arrays

To see the effect of dark current noise from the other arrays, the bias voltage of the test array was fixed and the bias voltage of the other arrays was altered. This mimics a situation in which the bias is optimized for each array in the detector.

III. Results

A. Flood Histogram Images

Since each pixel channel contains signals from all 16 arrays, the noise from the idle arrays has an impact on the accuracy of the calculated position. As shown in Fig. 5, when the idle

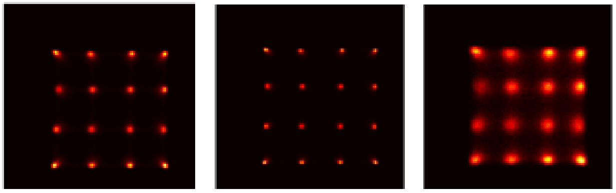

Fig. 5. Flood image of the 4 × 4 LYSO, zoomed in to show only the portion with the crystal array. (*Left*) All arrays having the same bias voltage (*Middle*) The test array, i.e. array on which the LYSO was coupled, has high bias, and all idle arrays have low bias voltage. (*Right*) Test array has low bias, and idle arrays have high bias voltage.

arrays were turned down, the crystals were better resolved in the flood histograms. On the contrary, turning the idle arrays high and the test array down led to a clear degradation in the quality of the flood histogram.

B. *Energy Spectra for each crystal*

Fig. 6 shows the energy spectra for each of the 16 crystals in the array calculated using the array channel. The average energy resolution is 17%. In comparison, Fig. 7 shows the energy spectra for the same data set calculated using the pixel channels, with an average energy resolution of 21%. It is clear from Fig. 6 and Fig. 7 that the energy resolution is better if the energy values were obtained from the array channel. Due to the array/pixel summing strategy of SPMMatrix, adding neighbouring pixels introduces the dark current noise from the other arrays, since a pixel channel ADC value represents a sum of 16 pixels, one from each of the 16 arrays. This approach to calculating energy thus potentially incorporates the dark noise of 144 pixels.

C. *Testing Effects of Test Array Bias Voltage*

As expected, the level of the 511 keV photopeak increased with increased bias voltage (Fig. 8). The magnitude of increase was comparable to that observed when testing individual arrays with NIM electronics. Additionally, the energy resolution improved slightly with increasing bias.

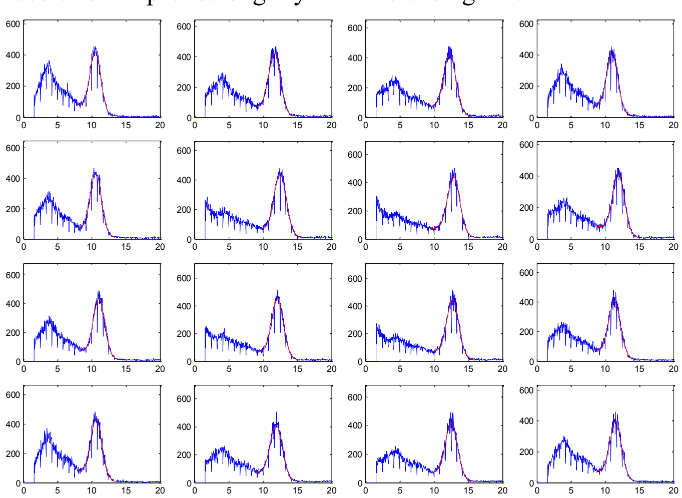

Fig. 6. The energy spectrum of each crystal after segmentation of the flood image. The energy value is obtained from the array channel. The energy resolution of centre crystals is 16%, and that of corner and edge crystals is 17%.

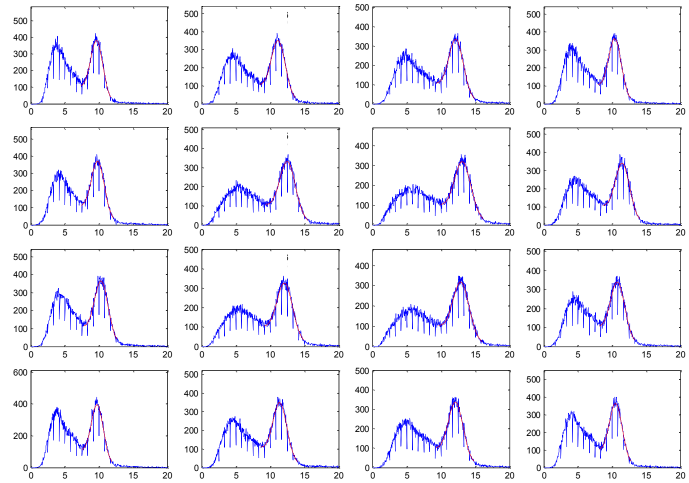

Fig. 7. The energy spectrum of each crystal after segmentation of the flood image. The energy value shown here is obtained by software-summing the pixel channel of the event crystal and the channels of neighbouring pixels. The energy resolution is 21%.

D. *Altering Bias Voltage of the Idle Arrays*

Altering the bias voltage of the idle arrays appeared to affect the photopeak position of the test array (Fig. 9). This was due to a common ADC baseline voltage supplied to all 32 channels, and this baseline voltage was affected by the global dark current originating from all 16 arrays in the device. The baseline voltage serves as a reference point for the differential amplifier in each channel. Therefore, a change in baseline voltage results in a change in the ADC value as well.

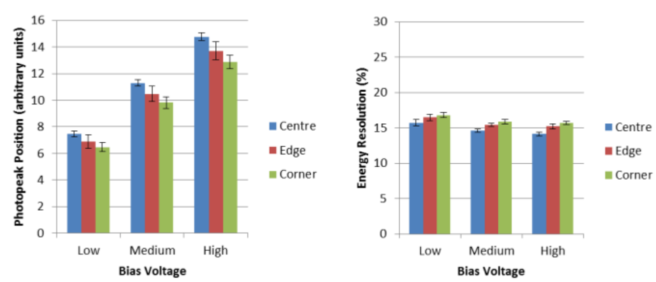

Fig. 8. The test array's bias setting was increased from 33.0V (low) to 34.65V (medium) then to 36.3V (high), while maintaining the other arrays at the low setting. The energy value was obtained from the array channel. Left figure shows the photopeak position of the 511 keV photon, while the right figure shows the corresponding energy resolution. Values are averages of the 4 centre crystals, 8 edge crystals, and 4 corner crystals, with error bars indicating the standard deviation.

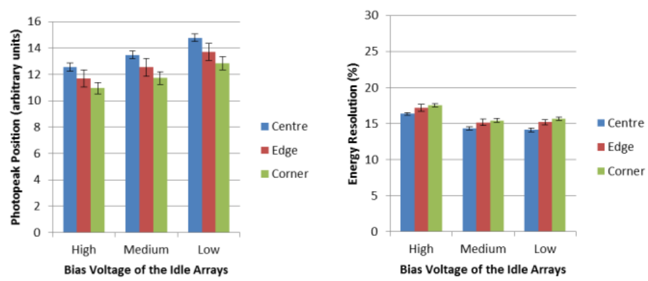

Fig. 9. Results of fixing the bias voltage of the test array at the highest setting and lowering the bias of the idle arrays. The energy value was obtained again from the array channel. Likewise, left figure shows the photopeak position of the 511 keV photon, while the right figure shows the corresponding energy resolution. Values are averages of the 4 centre crystals, 8 edge crystals, and 4 corner crystals, with error bars indicating the standard deviation.

IV. Conclusion

The SensL SPMMatrix is capable of decoding an array of 3.17 mm × 3.17 mm × 10 mm LYSO crystals when it is coupled to one of the SiPM arrays. When all SiPM arrays had the highest bias voltage, the energy resolution of 511 keV photon was 17% if obtained from the array channel. When using the pixel channels for energy, the resolution degraded to 21%. This suggests that when collecting data from the entire array it will be important to acquire both the array and pixel channels for optimum performance.

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