# A symmetric resistive voltage division circuit for SiPM array readout

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*Abstract*— **The purpose of this study is to investigate the behavior of a compact SensL's silicon photomultiplier array (SPMArray4) photodetector for possible application in Gamma or PET probes used for localization of cancer nodes. SPMArray4 photodetector coupled to a) a CsI:Na (1x1x6mm$^3$ pixel size) b) a BGO (2x2x5mm$^3$ pixel size) crystal pixellated scintillators. Evaluation was carried out with $^{22}$Na isotope emitting mainly at 511KeV. A symmetric resistive voltage division matrix was applied - for the first time according to our knowledge - reducing the array 16 outputs to 4 position signals. The exact values of the resistors as well as the summing amplifiers used in the summation and division stages are illustrated. Moreover, experimental evaluation in terms of sensitivity and energy resolution are reported. Raw images of the crystals maps acquired shown clearly visualization of the discrete 1mm$^2$ scintillator elements. All the measurements were applied at room temperature ~25$^0$C, without additional cooling circuit.**

***Keywords: Nuclear Imaging, Silicon Photomultipliers, Positron Emission Tomography, Gamma – Beta probes***

## I. INTRODUCTION

Silicon Photomultipliers (SiPMs), also known as multi-pixel photon counters (MPPCs) or solid-state photomultipliers (SSPMs), represent an alternative solution that to a large extent combines the advantages of PMTs and APDs [1]. They have high gain (equal than PMTs) and operated at low bias voltages (<80V) [2]. They are relatively insensitive to magnetic fields and thus are a good candidate for MR combined applications as PET/MRI detectors [3]. On the other hand, SiPMs require careful temperature control for stable operation because their gain is sensitive to temperature variations [4-5]. However, many studies are reported that do not require cooling to achieve adequate signal-to-noise levels [6]. Excellent timing properties of SiPMs make them also promising for time-of-flight PET imaging applications [7-8]. SiPM discrete arrays are very flexible and have the potential to be a suitable photodetector for Gamma or PET probes used for localization of cancer nodes. In this study, we report results for the SensL SPMArray4 (4x4 element array of 3x3mm$^2$ SiPMs) optical detector coupled to a) CsI:Na and b) BGO pixellated scintillators for possible application as Gamma and PET nuclear probes, respectively. Evaluation was carried out with $^{22}$Na isotope emitting mainly at 511KeV. A symmetric resistive voltage division matrix was applied - for the first time according to our knowledge - which reduces the array 16 outputs to 4 position signals. The exact values of the resistors as well as the summing amplifiers used in the summation and division stages are given. Experimental evaluation in terms of sensitivity, energy and spatial resolution is reported. All the measurements were applied at room temperature ~25$^0$C, without additional cooling circuit.

## II. MATERIALS AND METHODS

SensL's scalable silicon photomultiplier array (SPMArray4) is a commercially available, solid-state, large array detector based on silicon photomultiplier technology [9]. Its 16 elements (4x4 element array of 3.16 x 3.16mm$^2$ pixel pitch area with 3640 number of microcells per pixel) are tiled in an array, which is mounted in a low profile ceramic package. SPMArray4 optical detector has been developed using Ni free processing and low magnetic susceptible materials. The pixel array is over-molded with epoxy to completely encapsulate the pixels, bondwires and substrate bondpads. This optical detector array offers 4 side tileable packaging to allow the SPMArray4 to be tiled for larger area detection systems.

The SensL SPMArray4-A0 preamplification electronics and a SPMArray4-A1 evaluation board providing 16 individual pixel voltage outputs were also used for monitoring. More information about those modules information's can found at company website [9]. A custom resistive voltage divider network reduced the number of 16 pad signals to 8 signals (4X and 4Y) [10-11]. The network applied at the X direction is shown in figure 1.

The signals further reduced from 4X+4Y to 2X+2Y using a resistive division network illustrated in figure 2 (shown only at the X direction) [12].

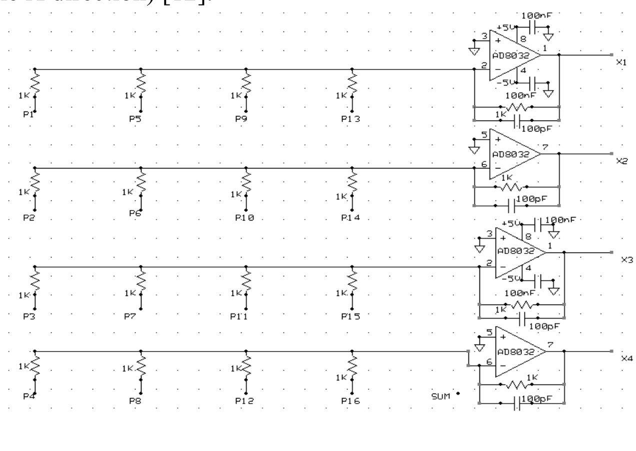


Fig. 1 A custom resistive voltage divider network reduced the number of 16 pad signals provided by the SPMArray4-A1 evaluation board to 8.

The four voltages arriving at the resistive divider ends ($X_A$, $X_B$, $Y_C$ and $Y_D$) were finally amplified by two 519 of Mech-Tronics Nuclear dual amplifiers. The acquisition system is based on a FAST 7070 analog to digital converter (ADC) module connected to a FAST multiparameter acquisition system operating in the Windows environment (MPA/WIN). The multiparameter system controls the four ADCs (dependent mode) and acquires data in list mode through a 1 Mbyte first in - first out register (FIFO) inside the MPA card.

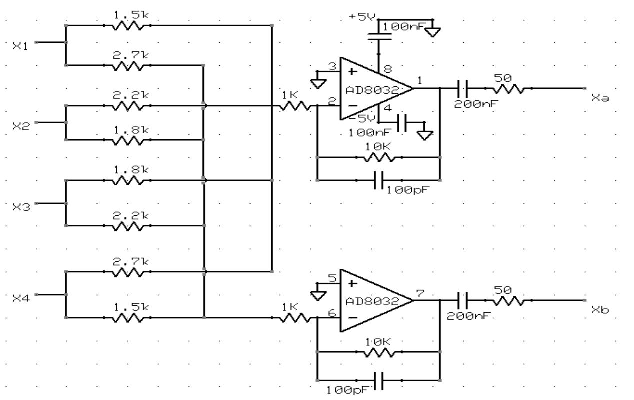


Fig. 2 A custom division network of amplitude weighting resistors (for X direction only) and amplifiers reduced the 8 signals to 4. The division network used for the Y four signals was the same.

Initially raw images of the two crystals maps acquired with 1) a $^{22}$Na source irradiating a BGO array (2x2x5mm$^3$ pixel size) crystal and 2) a $^{22}$Na source irradiating CsI:Na array (1x1x6mm$^3$ pixel size), coupled to the SPMArray4 using optical grease. The CsI(Na) scintillator array has 1mm glass window entrance. BGO and CsI(Na) scintillator arrays were purchased by Hilger Crystals Co. [13].

## III. Results And Discussions

In figure 3 raw images of the BGO and CsI(Na) array are shown. The scintillator arrays were optically coupled with optical grease (BC-630) to the SPMArray4 entrance window.

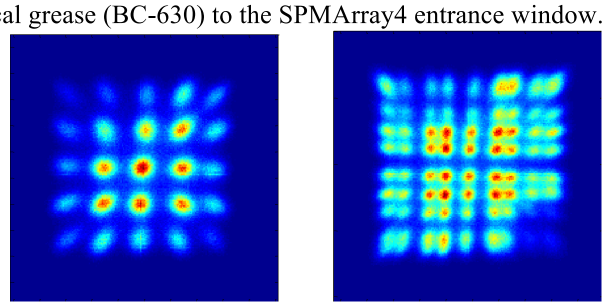

Fig. 3 Raw images of 2x2x5mm$^3$ BGO and right 1x1x5mm$^3$ CsI:Na scintillators optically coupled to the SiPM entrance window with optical grease (BC-630).

Worst images were acquired with an additional coupling of 1mm UV fused silica plate (PFS-1551) [14] and grease between the surfaces of scintillator - glass - SiPM entrance window. Optimal coupling remains a key goal for future work.

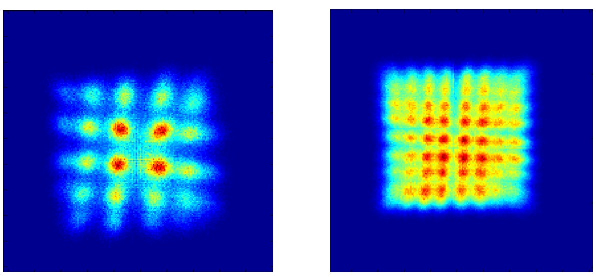

Fig. 4 Raw images of 2x2x5mm$^3$ BGO and right 1x1x5mm$^3$ CsI:Na scintillators optically coupled with an additional UV fused silica plate to the SiPM entrance window and optical grease (BC-630) between surfaces.

Table I shows the results of the measurements regarding, spatial and energy resolution and system sensitivity of the detector with a CsI:Na and BGO discrete crystals coupled only with optical grease.

TABLE I. CHARACTERISTICS OF DETECTOR

| SPMArray4 based detector characteristics | 2 x 2 x 5mm$^3$ BGO | 1 x 1 x 5mm$^3$ CsI:Na |
|---|---|---|
| Crystal array pitch (mm) | 0.4 | 0.25 |
| FWHM Spatial Resolution (mm) | 3 | 2 |
| FWHM Energy Resolution (%) | ~22 | ~19 |
| Sensitivity (Cps / Mbq) | 180 | 150 |

## IV. Conclusion

In the present study, we investigated the behavior of a flexible SensL's silicon photomultiplier array (SPMArray4) photodetector for possible applications in Gamma or PET probes. A low cost symmetric resistive voltage division matrix reduces the 16 output pads to 4 position signals was applied for first time. Acquired raw images of the crystals maps shown clearly visualization even of the discrete 1mm$^2$ scintillator elements. Moreover, experimental evaluation in terms of sensitivity, and energy resolution are reported. Experimental evaluation with Tc-99m source as well as the optimal coupling between scintillators array and SiPm's entrance window remains a key goal for future work.

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