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Comparison Between Scrambled and X-Y Crosswire Readout Techniques for SiPM (Silicon Photomultiplier) Arrays

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APPLICATION NOTE

When reading out a large number of detector elements, such as a multipixel SiPM array, it is often desirable to use some form of multiplexing in order to reduce the amount of readout channels. This document compares the performance of both the Scrambled Crosswire and standard "X−Y" Crosswire readout techniques. It explains the operation of each technique and highlights the advantages and disadvantages when used in a PET (Positron Emission Tomography) system.

SCRAMBLED CROSSWIRE READOUT

The Scrambled Crosswire Readout (SCR) was used in the SensL® Matrix9 system, is shown in Figure 1.

The Matrix9 detector head is comprised of nine 16-pixel arrays as shown in Figure 2.

- All 16 cathodes of each 4 × 4 array are joined together to provide 9 ARRAY detection channels. The 9 channels interface to simple threshold detectors that are used to determine which of the 9 arrays has detected an event.
- The corresponding Anode of each array is joined together to produce 16 PIXEL detection channels. Each of these channels has threshold detection as well as an ADC for energy readout.

This system is now discontinued, but the Matrix9 was formed of an SiPM sensor array with readout electronics, a board for registering coincidence events and then reconstructing an image.

1:1 Readout Operation

Figure 3 shows a block diagram outlining the required front-end interface electronics. This SCR architecture was designed to provide good 1:1 crystal readout with minimum channel count and support electronics. The 9 ARRAY threshold detector channels are used to determine which 4 × 4 array has detected an event. The 16 PIXEL threshold detectors are used to determine which of the 16 pixels within the array has detected an event. The ADC for the PIXEL channel is used to read the energy of the event.

Sub 3 mm Crystal Readout

One important feature of this architecture, and what gives the name SCR to the design, is that the pixels on each energy channel are spatially separated by a 4 × 4 array. This means that, providing there is only one event, the energy measured will be entirely from the specific PIXEL and not a sum of energies from any neighboring pixels.

Although the SCR architecture was primarily designed for 1:1 coupling this feature does allows light sharing to resolve smaller crystal sizes. A method for resolving crystals less than 3 mm is described in the Appendix of this document. It can be seen that this technique has a significant limitation of only being able to resolve when light sharing is limited to no more than 4 × 4 pixels (~12 mm × 12 mm on the Matrix9 detector head).

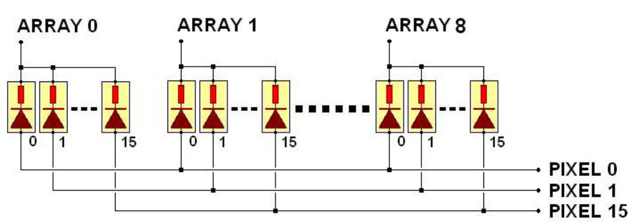

Figure 1.

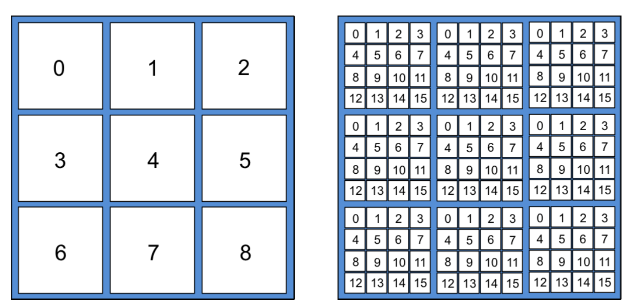

Figure 2.

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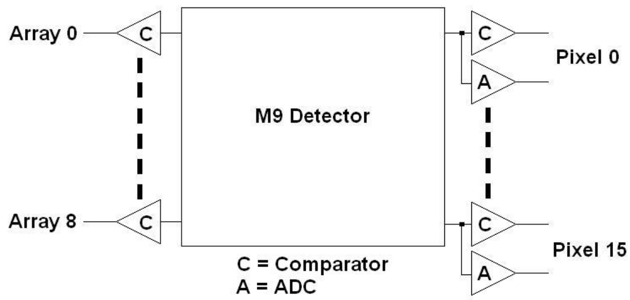


Figure 3.

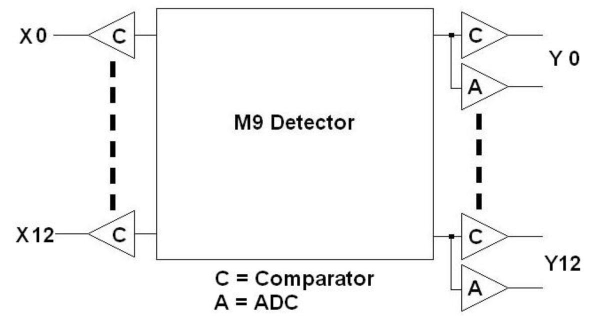


Figure 5.

X–Y CROSSWIRE READOUT

The XY Crosswire Readout architecture is shown in Figure 4. This architecture connects the SiPMs in a format similar to the interconnection between memory cells. The result is 12 X and 12 Y coordinate signal lines that can be used to detect the position of events within the array.

For 1:1 coupling the readout electronics require 12 threshold comparators on one side. These are used to detect when an event has occurred. The other side has threshold comparators and ADCs for energy readout.

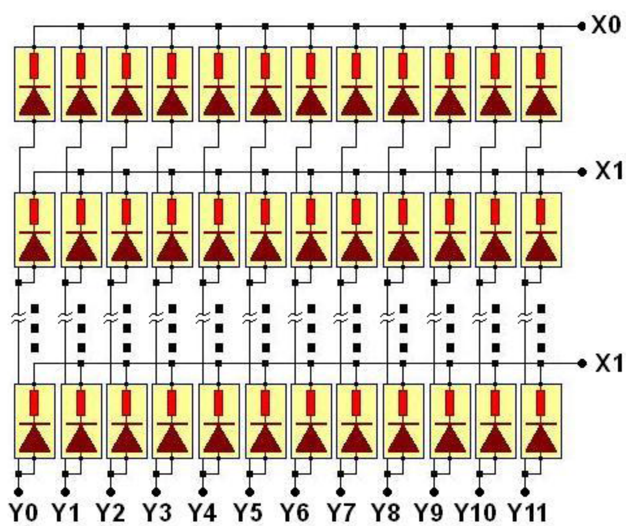


Figure 4.

1:1 Readout Operation

Figure 5 shows a block diagram outlining the required front-end interface electronics. Assuming that the X-side is threshold comparators only and the Y-side has comparators and ADCs, the X-side detects an event when the signal on one of the 12 lines reaches a programmed threshold. The Y-side comparators are now interrogated to determine which SiPM detected the event. Once the SiPM is detected the corresponding energy is read via the ADC.

It is important to note that in this architecture the threshold and energy channels daisy chain from one neighboring SiPM to another. This means that localized light sharing, as described in the Appendix for SCR, is not possible.

Sub 3 mm Crystal Readout

For sub 3 mm crystal readout it is necessary for this architecture to have ADC readout on both the X and Y channels. Figure 6 shows a block diagram outlining the required front end interface electronics. With 12 ADC readout channels on both X and Y the user can read the energy spread across the entire detector and, by using a suitable ‘centre of gravity’ algorithm, can resolve crystals down to 1 x 1 mm^2.

NOTE: This readout architecture does not limit the allowable area for light sharing.

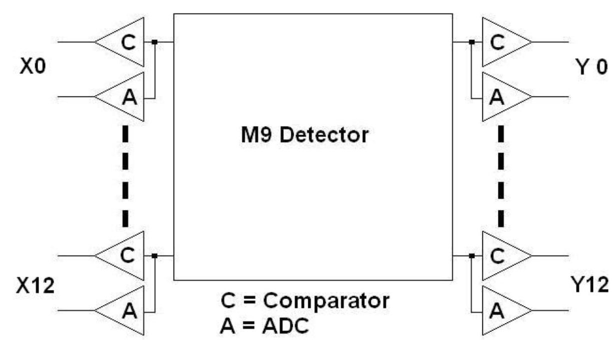


Figure 6.

SUMMARY

Table 1 shows a summary of the requirements and performance for the various options.

From this table it can be seen that:

- SRC has only a maximum of 9 SiPMs connected to a single readout channel. This results in less noise on the channel signal lines. Whilst for L(Y)SO this is not important, a reduction in SiPMs per channel is critical for BGO (weak signal).
- SCR requires more electronics than standard X–Y readout (1 Comparator and 4 ADCs). However, for this increase in electronics, region of interest light sharing is possible.
- X–Y (Full ADCs) requires 1 less comparator but 8 more ADCs when compared to SCR. However, for this increase in electronics the Matrix9 can carry out good 1:1 readout as well as unrestricted light sharing to achieve 1 mm crystal readout.

Table 1. THE NUMBERS PRESENTED HERE ARE FOR THE 12 X 12 PIXEL DETECTOR

	Electronics			Readout	
	Comparators	**ADCs**	**Max SiPMs per Channel**	**1:1**	**Sub 3 mm**
SCR	25	16	9	Yes	Yes (Limited)
X–Y	24	12	12	Yes	No
X–Y (Full ADCs)	24	24	12	Yes	Yes

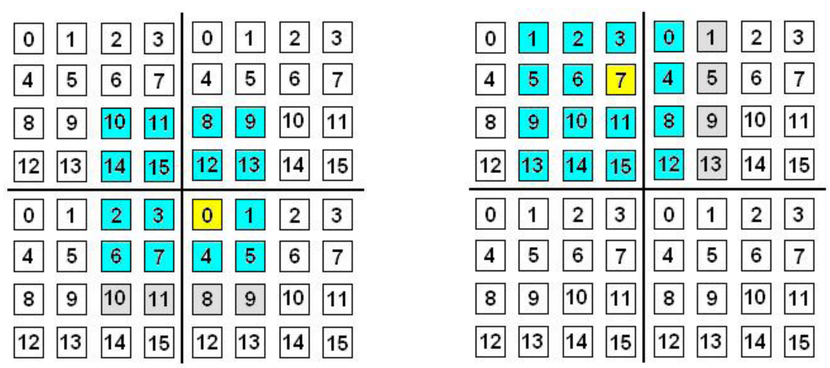
APPENDIX

Proposed Method for Sub 3 mm Pixel Readout

The readout of sub 3 mm crystals using a centre of gravity algorithm relies on being able to determine the relationship between the 16 energy values and the actual pixels they represent in the 144 pixel array. In the simplest case where a crystal block is placed over 1 of the nine 4 × 4 arrays the readout is very simple. Each of the 16 energies energy is associated with a specific pixel. In this case we have 1-to-1 readout. The problem arises when the event is over a region that crosses over the boundary of 2 or more arrays. Consider the architecture of the Matrix9 system. All 16 cathodes of each 16-pixel array are connected together to provide 9 ARRAY event lines. Each corresponding anode of each array is connected together to provide 16 PIXEL event lines.

First it must be assumed that the light sharing spreads over a region no greater than a block of 4 × 4 pixels. If the region is greater than the energy readout of a particular pixel would become the cumulative energy of a number of pixels. The Matrix9 must be placed in All Energies mode. In this mode, when an event is detected, the pixel coordinate is reported (Array, Pixel) followed by all 16 energies. The method proposed to achieve sub 3mm readout across the entire 144 pixel array is as follows:

When an event occurs, the Array/Pixel coordinate information is used to determine a coarse region of interest. Due to slight deviations in the electronics it is not assumed that this pixel is the strongest energy and is closest to the region of event. At this stage it is just assumed that this pixel is one of the 4 × 4. Now, with a good understanding of the readout architecture, it is possible to use the 16 energies to determine the 16 pixels that cover the event region. Once the 16 pixels are determined, the energies can be used in an Anger Logic type algorithm to resolve a sub 3 mm size pixel.



Consider Example 1

Here the event was detected as pixel 0 of the bottom right hand side array. The relative strengths of the 16 energies are now used to determine the actual 16 pixels of interest. In example 1 it is found that energies 14, 15, 12, 13 are greater than energies 10, 11, 8, 9 therefore the pixels of interest are 10, 11, 8, 9 at the top and not the pixels 10, 11, 8, 9 in grey. Energies 11, 15, 3, 7 are found to be stronger than 10, 14, 2, 6 therefore pixels 10, 14, 2, 6 to the left had side are selected … etc.

Consider Example 2

Here the event was detected as pixel 7 of the top left hand side array. The relative strengths of the 16 energies are now used to determine the actual 16 pixels of interest. In example 2 it is found that energies 2, 6, 10, 14 are greater than energies 1, 5, 9 , 13 therefore the pixels of interest are 1, 5, 9, 13 to the left and not the pixels 1, 5, 9, 13 in grey … etc.

Figure 7.

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