Charge Multiplexing Readout for Position Sensitive Avalanche Photodiodes

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***Abstract*— A technique to charge-multiplex multiple position sensitive avalanche photodiodes (PSAPD) has been studied. We have observed that with multiplexing, the spatial resolution is slightly degraded, but the energy and time resolution are not affected. We are building high resolution PET systems that use numerous PSAPDs, and we would like to use multiplexing to reduce the number of electronic readout channels and complexity. This charge multiplexing technique will reduce the number of readout channels required by a factor of two. A PSAPD is a new silicon semiconductor photodetector that may be used to replace a photomultiplier tube in PET or SPECT systems. It is a planar avalanche photodiode with a resistive coating that allows continuous positioning over the entire active area. The resistive sheet of the PSAPD splits the charge signal amplified by an avalanche process of the diode into four spatial channels. The top contact contains the hole signal which is equal in magnitude to the sum of the 4 spatial channels. The PSAPD can be multiplexed in a way that sums the spatial channels but leaves the top channel independent. PSAPDs are currently fabricated with active areas that range from 8 x 8 mm^2 and higher. The proposed PET system detectors comprise 1 mm lutetium oxyorthosilicate (LSO) crystals coupled to extra thin PSAPDs. Non-multiplexed, these detectors have achieved excellent spatial resolution (<1mm^2), energy resolution (<10%), and time resolution (<2 ns). Unlike a position-sensitive PMT, the electronic amplification of a PSAPD is only on the order of 1000, which makes it challenging to charge multiplex multiple devices.**

***Index Terms*— Multiplexing, Position Sensitive Avalanche Photodiode, PSAPD, Positron Emission Tomography, PET**

I. INTRODUCTION

POSITION Sensitive Avalanche Photodiodes (PSAPD) are an excellent semiconductor photodetector for detection of gamma rays using scintillation crystals [1], [2]. The PSAPD is a beveled edge planar avalanche photodiode with a resistive sheet fabricated on the anode and an optical window on the cathode. The PSAPD can be biased from 1700-1800V, has a quantum efficiency of 60% for light with a wavelength 420 nm, operates with a charge gain of about 1000 from an avalanche process, and has approximately 1000 *e*rms noise at room temperature. Continuous positioning is determined by measuring the signals from four contacts that are patterned on the corners of the resistive sheet.

The four corner (V_{corner}) channels record the spatial signal. The cathode (V_{top}) also records the sum electron signal. Except for slight gain variations due to charge loss in the readout signal path

$$Energy \propto V_{TOP} = \qquad V_{corner}$$

Positron Emission Tomography(PET) requires high energy gamma ray detectors that have excellent spatial, energy and time resolution. Several groups are investigating replacing the photomultiplier tube(PMT) of PET with a semiconductor position senstive avalanche photodiode [3]–[5]. A PMT is a relatively bulky device that has a quantum efficiency of ~15%, a gain of 10^6, and very low noise. Multichannel Position sensitive PMTs and arrays of small PMTs have been able to read out large arrays of pixellated scintillation crystals with 1.2 mm spatial resolution and <2 ns timing resolution [6]. However, PMTs have a difficult time of getting good light collection efficiency and recording the depth of interaction in the long thin scintillation crystals needed for high resolution gamma ray detection. The PSAPD may be thinned down to 230 μm and packaged on a flex tape. The PSAPD and tape may be inserted between the long thin LSO crystals [7] and positioned edge-on with respect to the incoming gamma ray photons. In this configuration, a very large amout of light may be collected, high spatial resolution, and depth of interaction may be recorded. The edge-on design has >90% light collection efficiency, ~10% energy resolution, ~2 ns time resolution, and 3 mm DOI resolution [8]. A clinical PET system using PSAPD detector modules will require thousands of electrical readout channels.

Electrical multiplexing of the signals in PMTs was very successful in reducing the number of channels that must be readout from the data acquisition [9]. Our group investigated different charge multiplexing techniques for position sensitive photomulitplier tubes [10]. The lessons learned from this previous work on symmetric charge division were applied to multiplexing PSAPDs.

II. MATERIALS

The spatial channels for the four PSAPD devices are connected to ground through a 1 Meg Ohm resistor to remove the leakage current and to bias the device(see Fig. 1). The top cathode channel is connected through a 1 Meg Ohm resistor to the -1750 V HV supply. Each flex tape has two PSAPD devices with all 5 channels brought out to pads. Two flex devices are mounted on a PCB board for testing(see Fig. 2). 1nF Capacitors are used to couple all channels to Cremat 110 charge sensitive preamplifiers. The spatial channels from

Manuscript received January 20, 2002; This work was funded in part by NIH R21 EB003283 and NIH R21 CA098691.

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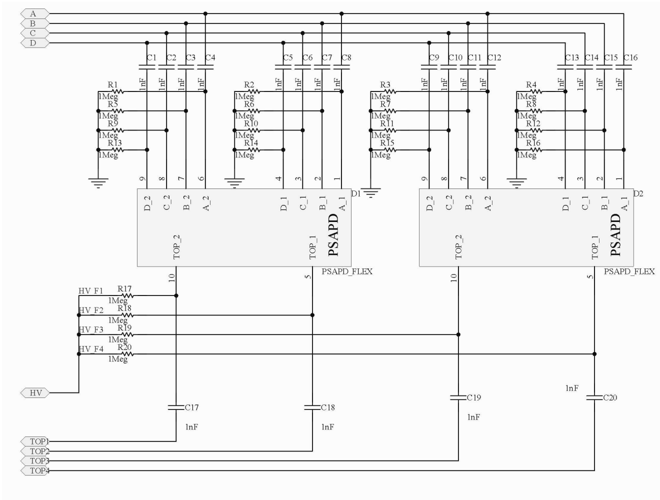


Fig. 1. Schematic of multiplexing circuit. Each flex device holds two PSAPD chips. The 16 total spatial channels of all PSAPDs are capacitively multiplexed into four spatial channels and AC coupled to charge sensitive preamplifiers. The top cathode connections of the PSAPDs are brought out independently.

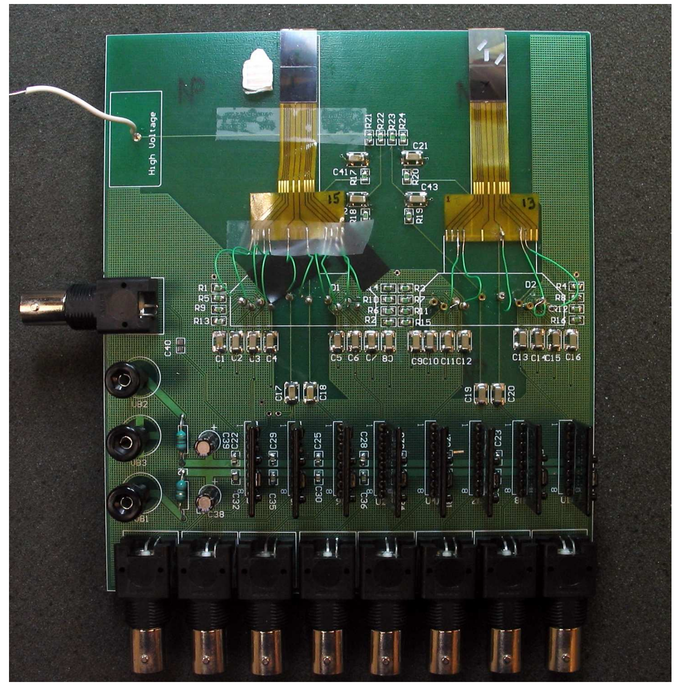


Fig. 2. PCB Interface board for the two flex PSAPD carriers. The PSAPD devices are AC coupled to Cremat 110 charge sensitive preamplifiers. The 8 outputs of the interface board 9 mm x 9 mm in size with 8 mm x 8 mm of photosensitive area.

each of the two PSAPD devices per flex are tied together and connected to the same set of 4 Cremat preamplifiers. The top cathode channels are kept independent and each go to a single Cremat preamplifier. The total 8 channels then go to a data acquisition system that performs triggering, Gaussian shaping, and digitization. Un-multiplexed, the data acquisition would require 16 total channels.

We placed different size arrays of LSO crystals on each of the PSAPDs. To test energy resolution, we used a 3 x 3 array of 2 mm x 2 mm x 3 mm LSO crystals coupled through the smallest face to a ceramic PSAPD incorporated into the multiplex circuit and covered in several layers of teflon reflector. To test spatial resolution, we used a 8 x 3 array of 1 mm x 1 mm x 3 mm LSO crystals coupled largest face on to the thin flex PSAPD. The ceramic device is the same 8 mm x 8 mm PSAPD but that has been packaged in a ceramic carrier.

III. Methods

Flood acquisitions with a 10 μCi ^{22}Na source (511 keV and 1275 keV) placed at 1 cm distance were taken before and after adding a second 8x8 mm^2 PSAPD device to the multiplexed socket (Fig. 2). The effect of multiplexing on spatial resolution was studied by measuring the peak-to-valley ratio for a profile through the middle of the crystal position histogram for both the ceramic and the thin flex multiplexing experiment. A 3x3 2x2x3 mm^3 LSO crystal array was used on the ceramic device. A 8x3 1x3x1 mm^3 LSO crystal array was used on the thin flex device. The individual crystals seen in raw flood acquisitions were segmented using a minimum distance-to-peak qualifier algorithm and energy gated to produce the final crystal positioning histogram (Fig. 3(a)). Individual crystal energy resolutions were compared only for the 2 mm x 2 mm x 3 mm crystals for the ceramic device multiplexing experiment (Fig. 4(b)).

IV. Results and Discussion

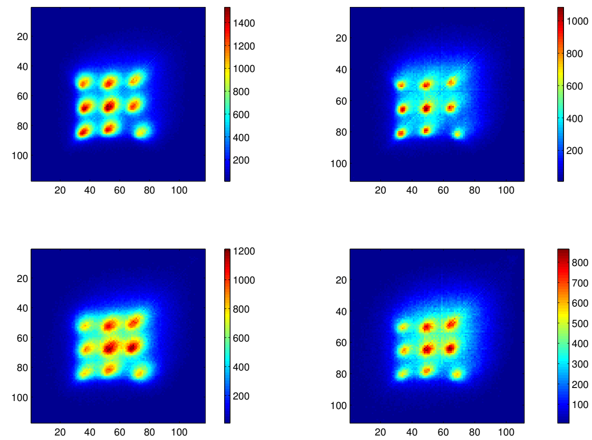
The energy resolution of the device before (11.6%) and after multiplexing (11.7%) was unchanged (see Fig. 4(b)). The low input impedance of a charge sensitive amplifier shields the noise from crosstalking over the energy channels. The slight gain decrease in the energy channel of the multiplexed circuit is due to some capacitive loading. The effect of capacitive loading can be seen in the spatial response from the slight compression of the profile in Fig. 4(c). Noise from each of the PSAPD is collected by the low impedance of the preamp, and does not travel up the capacitor of the neighboring PSAPD device. The noise from each of the PSAPD devices does add in quadrature, which results in reduced spatial resolution of the device as can be seen in the reduced peak-to-valley ratios in 4(a) and 4(c).

V. Conclusion

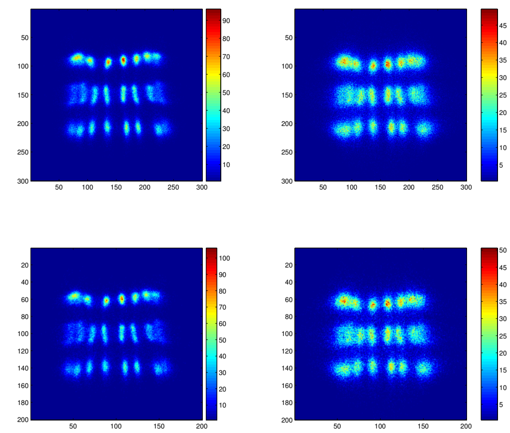
We reduced the number of channels by a factor of two by capacitive multiplexing of PSAPDs with the loss of some spatial resolution quality but without any degradation in energy resolution. Further evaluation will attempt to multiplex 4 thin flex devices onto 8 data acquisition channels and analyze coincidence point spread function and time resolution.

Acknowledgment

The authors would like to thank RMD, Inc for fabrication and useful comments for PSAPD devices. The PCB boards were fabricated with generous discounts from PCB Express (www.pcbexpress.com).

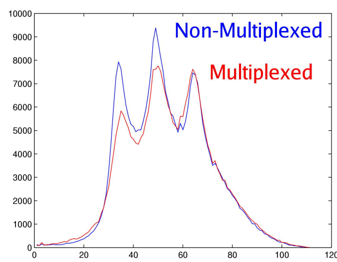


(a) 3x3 array of 2 mm x 2 mm x 3 mm LSO crystals un-multiplexed **LEFT** and multiplexed **RIGHT**

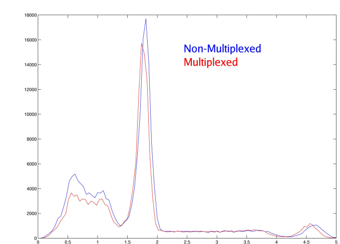


(b) 8x3 array of 1 mm x 1 mm x 3 mm LSO crystals un-multiplexed **LEFT** and multiplexed **RIGHT**

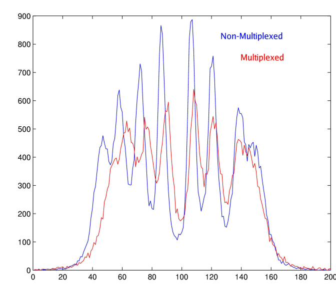
Fig. 3. Flood histograms were taken with a ^{22}Na source. Histograms energy gated with 2xFWHM **(TOP)**, or left raw **(BOT)**. Histrograms on the **LEFT** are un-multiplexed, while histograms on the **RIGHT** are multiplexed. Multiplexing had little effect on the 2 mm x 2 mm x 3 mm array. The 1 mm x 1 mm x 3 mm array has noticable crystal identification loss but the individual crystals are still able to be resolved.



(a) Peak-to-valley ratio for 3 x 3 array of 2 mm x 2 mm x 3mm LSO crystals



(b) Energy Resolution of 3 x 3 array of 2 mm x 2 mm x 3 mm LSO crystals



(c) Peak-to-valley ratio for 8 x 3 array of 1 mm x 1 mm x 3 mm LSO crystals

Fig. 4. Devices are un-multiplexed in **BLUE** and multiplexed in **RED**. Peak-to-valley ratios were measured by taking the profile through the center crystals in a flood histogram. Peak-to-valley ratio went from 2.5:1 to 2.0:1 for the 2 mm array before and after multiplexing(4(a)), while they went from 4:1 to 2.5:1 for the 1 mm array(4(c)). Energy resolution was 11.6 +/- 0.1 % and 11.7 +/- 0.1 % before and after multiplexing(4(b)). The energy resolution was virtually unchanged, while the crystal id degraded. The reduction in peak-to-valley ratio is due to propagation of noise from multiple devices.

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