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Multichannel Energy and Timing Measurements with the Peak Detector/Derandomizer ASIC*

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Abstract **The Peak Detector/Derandomizer ASIC (PDD) provides threshold discrimination, peak detection, time-to-amplitude conversion, analog memory, sparsification, and multiplexing for 32 channels of analog pulse data. In this work the spectroscopic capabilities of the chip (high resolution and high rate) are demonstrated along with correlated measurements of pulse risetime. Imaging and coincidence detection using the PDD chip will also be illustrated.**

I. INTRODUCTION

THE Peak Detector/Derandomizer ASIC, first described in [1], is an efficient analog data concentration engine for multichannel radiation detector systems. It accepts random pulse data on 32 input channels and produces a single derandomized output having peak amplitude, timing, and channel address information. The operating principle of the PDD is illustrated in Fig. 1. The circuit contains a set of eight peak detectors and associated time-to-amplitude converters (PD/TACs) which are shared among 32 input channels. Fast discriminators and arbitration logic route pulses from any input to any available PD/TAC. The PD/TACs store amplitude, timing, and address data for each pulse and present them to the output upon receipt of a "read request" signal from the data acquisition system

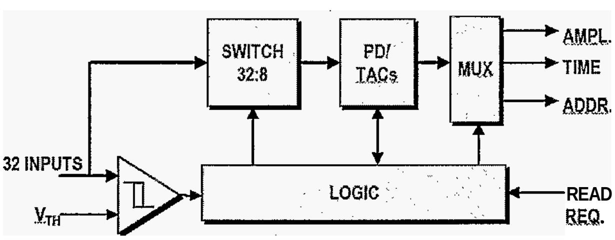

Fig. 1. PDD block diagram.

The multiple PD/TACs effectively sparsify and buffer the data resulting in exceptionally low deadtime. The buffering capability of the PD/TAC array derandomizes the data, allowing the amplitude and time digitizers (external) to operate at a rate close to the average input rate.

II. SPECTROSCOPY

A. *High resolution, single channel*

Earlier work [1,2] demonstrated the speed and accuracy of the PDD with laboratory pulser input. In Fig. 2 the performance of the PDD in acquiring high-resolution spectra in a realistic experimental setting is demonstrated. The detector is a Si p-i-n array cooled to –27°C and illuminated by an ^{55}Fe source giving a rate of 1.5kHz per channel. A single channel is amplified by a low-noise preamplifier/shaper with 4μs peaking time [3] and the shaped signal is sent to one input of the PDD. The PDD read request rate is about 3kHz in this measurement. In Fig. 2 the pulse height spectrum obtained using the PDD is compared with one acquired by direct input of the shaped pulses into a commercial multichannel analyzer. Aside from a small inefficiency near threshold the two spectra are identical, illustrating the accuracy of the on-chip peak detectors and the lack of crosstalk from digital activity occurring on the ASIC.

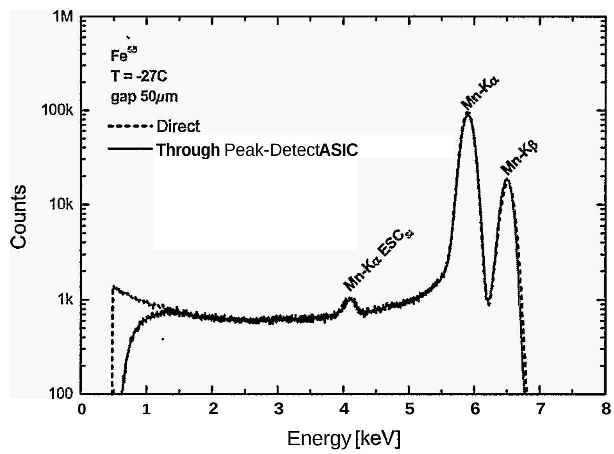

Fig. 2. ^{55}Fe spectrum, single channel Si detector, with and without PDD ASIC

B. *High rate, inultichannel*

Fig. 3 shows a set of 32 ^{241}Am spectra simultaneously acquired from an array of 32 CdZnTe detectors (3 x 7 x 3 mm^3). X-rays are incident on the detector cathodes and the anode signals are amplified by a multichannel ASIC preamp/shaper with 600 ns peaking time [4]. The 32 shaped signals are fed into the inputs of the PDD. Overall rates in the low MHz range have been achieved using this setup. Since each event is tagged with its amplitude and address, separate spectra for each of the 32 channels can be plotted.

C. *Biparametric spectra with CZT*

The time-to-amplitude converters in the PDD can be configured to measure the risetime of the pulse simultaneously with the amplitude. Fig. 4 shows the spectrum of ^{241}Am in the

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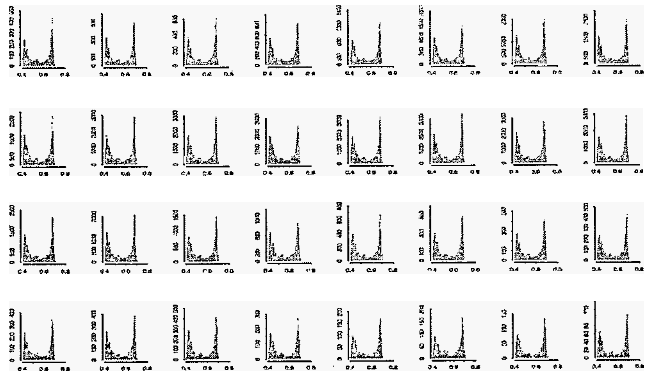

Fig. 3. ^{241}Am spectra in CZT. Simultaneous acquisition of data from 32 channels.

same set of 32 CZT detectors with amplitude and risetime plotted on the horizontal and vertical scales respectively. The majority of 59.5 keV photons convert near the cathode, and the complete charge collection of electrons leads to the full-energy photopeak (bright spot at upper right). X-ray events where conversion occurs closer to the anode have incomplete charge collection and shorter risetimes. Events with partial charge collection can be identified in the band extending downward and to the left of the photopeak.

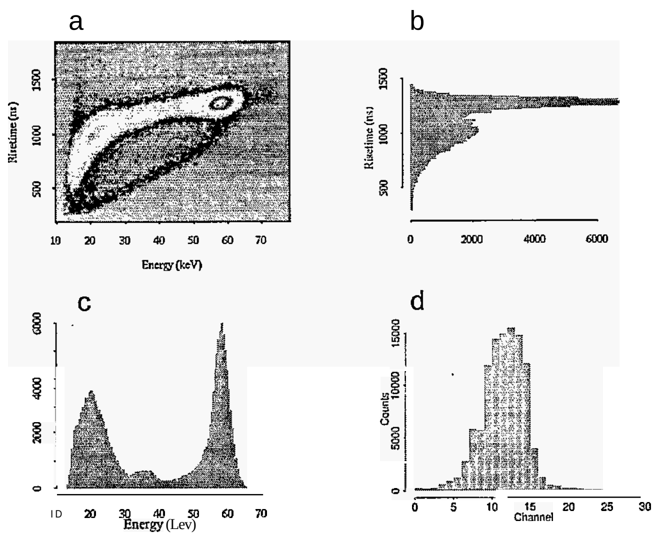

Fig. **4.** Biparametric spectrum of ^{241}Am on CZT. (a): Risetime (vertical axis) **vs.** energy (horizontal), intensity indicated by color (logarithmic). (b), (c): projections of the risetime (b) and energy (c) distributions. (d) histogram of counts per channel.

Correction techniques based on such biparametic spectra can be used to improve peak efficiency and line shape in CZT [5]. With the PDD, one can acquire biparametic data from 32 channels with a single pair of digitizers operating at the average event rate, without additional triggering or multiplexing hardware. Fig. 5 shows biparametric spectra for all 32 channels.

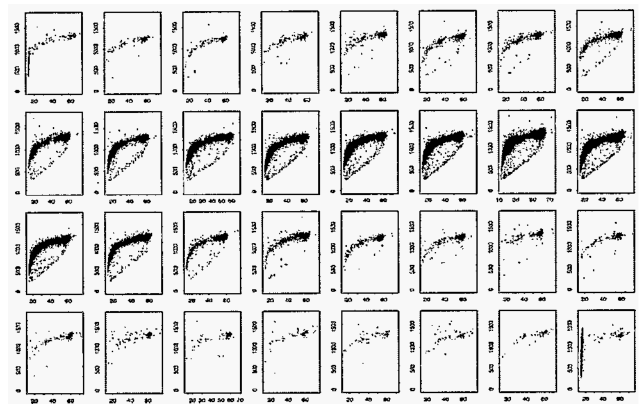

Fig. *5.* Biparametric spectra from 32 channels.

III. OTHER IMAGING AND TIMING APPLICATIONS

A. Pixellated ***detectors***

The PDD is ideally suited for use with array detectors. **A** test set employing pixellated 4 x 4 CZT detectors has been constructed (Fig. ***6*** and Fig. 7).

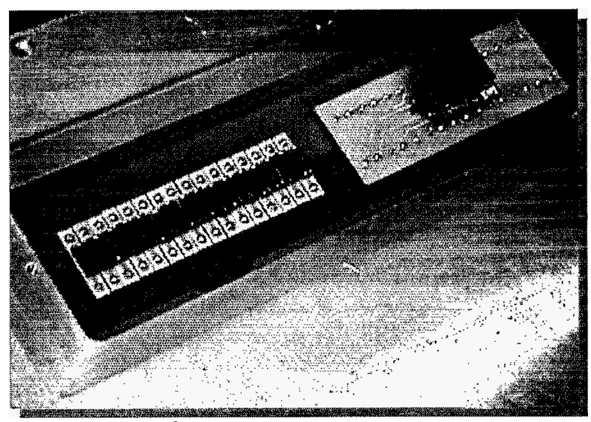

Fig. ***6*.** Detector side of test board showing sixteen individual planar CZT detectors (left) and a pixellated CZT detector (right).

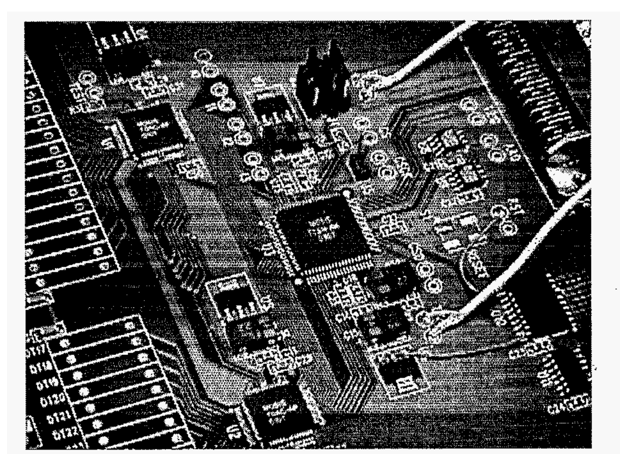

Fig. 7 ASIC side of test board showing PDD ASIC (large package in center), two 16-channel preamp/shaper ASICs [4] (left), buffer amplifiers and serial digital interface.

Fig. **8** shows the results of illuminating the detectors on the test board with ^{241}Am gamma rays from an uncollimated source positioned a few centimeters from the detectors. Energy and time spectra for the individual and pixel detectors are similar in this setup. Five pixels failed to operate due to faulty connections to the test board.

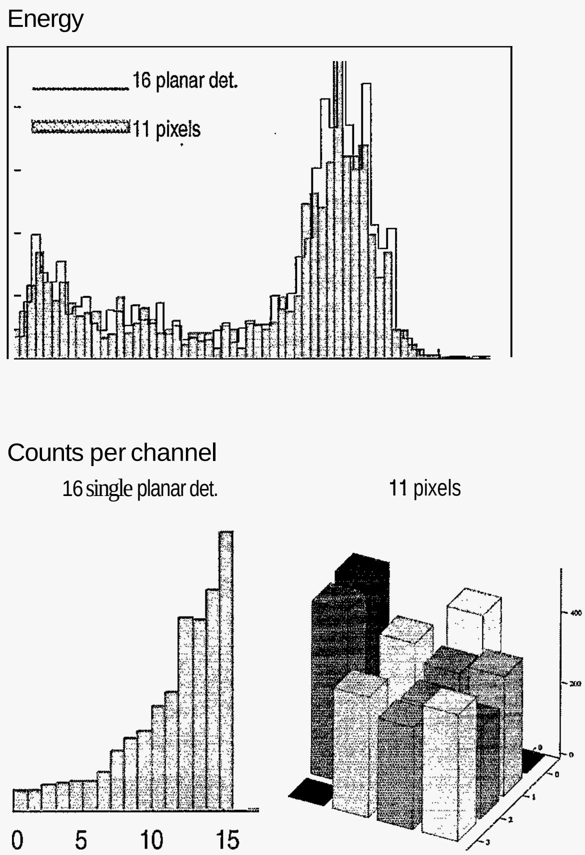

Fig. 8. Simultaneous acquisition of spectra from individual and pixellated CZT detectors. Uncollimated '"Am source located a few cm from detector surface.

B. *Measurement of arbitration speed and efficiency*

One can generate accurate timestamps for each event by using the TAC to measure time of occurrence of the pulse peak relative to the read request [1]. This allows accurate coincidence detection of events occurring in different PDD ASICs clocked by the same read request. For example, to detect coincidences in non-neighboring detector channels, as in scintillator/APD detectors used in small animal PET detectors, separate PDD ASICs would be used to acquire data from channels separated by 180".

In the present PDD ASIC architecture, only one input channel at a time can be connected to a PD/TAC. If two incoming pulses cross threshold simultaneously, one will be rejected by the arbitration logic. There are applications for which this behavior is undesirable. For instance, in interpolating position-sensitive detectors charge-sharing results in simultaneously-occurring pulses in two or more neighboring channels. Loss of neighboring events in the cluster impairs the interpolation accuracy. To measure the ambiguity window of the arbitration logic, two pulses were injected into channels 0 and 24 of the PDD ASIC as shown in Fig. 9. After each pair of pulses a burst of 16 read requests was sent. The delay between pulses was varied in 1 ns increments. After several hundred pulses per time step, the output data was analyzed to determine if both the CHO and CH24 events were seen, and in which order.

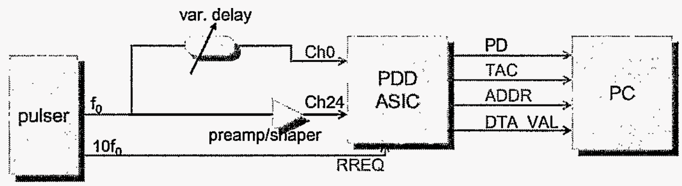

Fig. **9.** Dual-pulse arrangement to measure the speed and efficiency of the PDD ASIC's arbitration logic.

Fig. 10 shows the results. For events separated by more than about 8 ns, there is a greater than 75% chance that neither event will be lost due to arbitration. The inefficiency in detecting closely-spaced pulses is never greater than 50%. Otherwise the arbitration logic correctly distinguishes the order of occurrence of both events.

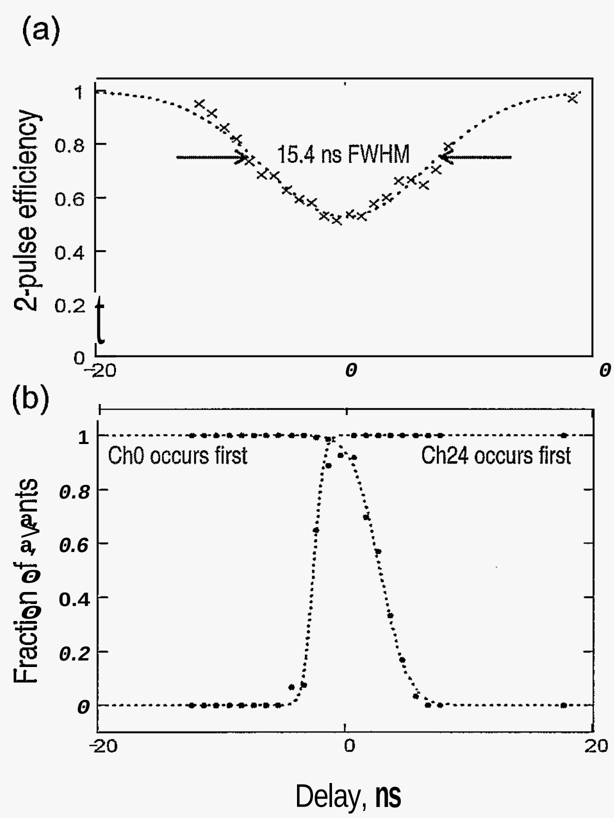

Fig. 10(a) Efficiency of detecting pulses on both Ch0 and Ch24. (b) Red curve: fraction of events where Ch0 is timestamped as having occurred first. Blue curve: Ch24 gets the first timestamp.

Fig. 11 shows the tracking accuracy of the PDD ASIC. time-to-amplitude converter for near-simultaneous events. The TAC values were converted to time and plotted as a function of the delay of the Ch0 pulser relative to the read request clock. As expected, the TAC tracks the delay of the pulse on Channel *0* with an accuracy of a few nanoseconds. The pulse on Channel 24 is found to be stable with respect to the read request clock.

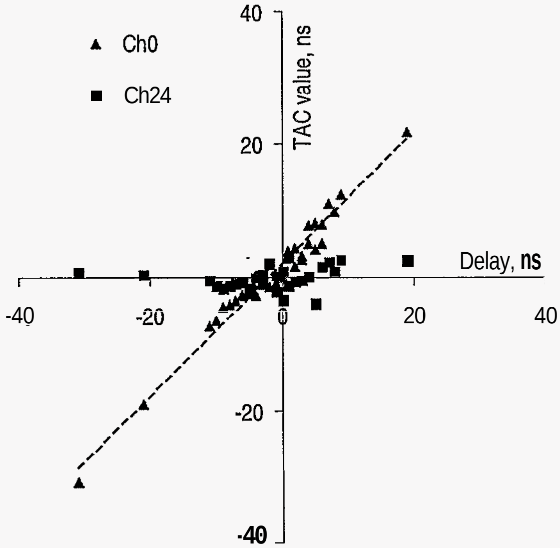

Fig. 11: TAC measurement of time of occurrence of pulses on Channel 0 and Channel 24 with respect to the read request clock. The TAC accurately tracks the delay of the Channel 0 pulser.

IV. FUTURE WORK

The PDD ASIC has been shown to be a versatile and efficient data concentrating engine. A new circuit under development (Fig. 11) will incorporate the PDD core with preamplifiers and shaping amplifiers to provide a fully-integrated spectroscopy signal chain with added timing capabilities. In conjunction with solid-state detector arrays and a small form factor microcontroller, this new chip will enable the development of compact, self-contained, low power, high resolution detectors.

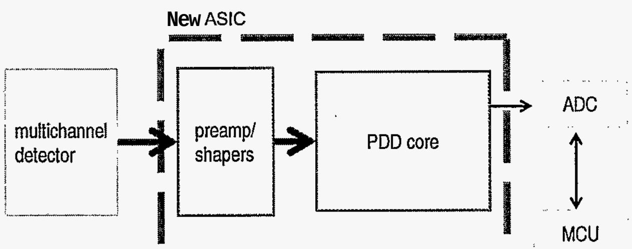

Fig. 11. New ASIC under deveopment incorporating PDD core with detector-specific preamp/shapers.

To extend the range of application of this circuit concept, we are designing a new version of the arbitration logic which will accept up to two simultaneous events within the same PDD. With this modification, the efficiency for simultaneous events will be greatly increased and the PDD ASIC will be suitable for position-sensing interpolating detectors and for measuring energy in split events.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

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