A Scalable FPGA-Based Digitizing Platform for Radiation Data Acquisition

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Regulating the proliferation of nuclear materials has become an important issue in our society. In order to detect the radiation given off by nuclear materials, systems implementing detectors connected to data processing modules have been developed. We have implemented a scalable, portable detection platform with a data processing module about the size of an external DVD hard drive. The data processing component of our system utilizes real-time data handling, the potential for growth, and behavior modifications through custom FPGA code editing. The size of the system is dynamic, so additional input channels can be implemented if necessary. In this work, we present a scalable, portable detection system capable of transmitting streaming data from its inputs to a PC or laptop. The data arrives at the inputs of the data capturing module, is processed in real time by the onboard FPGA and then is transferred to a computer via a PCIe cord in discrete packets. The maximum transfer rate from the FPGA to the PC is 2000 MB/s. The Detection for Nuclear Non-Proliferation Group at the University of Michigan will use the detection platform to achieve pre-processing of radiation data in real time. Such pre-processing includes pulse shape discrimination, pulse height distributions, and particle times of arrival.

Objectives and Advantages

Detection of special nuclear materials is the ultimate objective of this study. Here are some of the applications stemming from the ability of such detection:

- Nuclear non-proliferation
- Safeguards
- National security

An FPGA-based data detection platform has highly beneficial qualities, including:

- Scalability
- Portability
- Can be easily reprogrammed to achieve desired handling of the incoming data

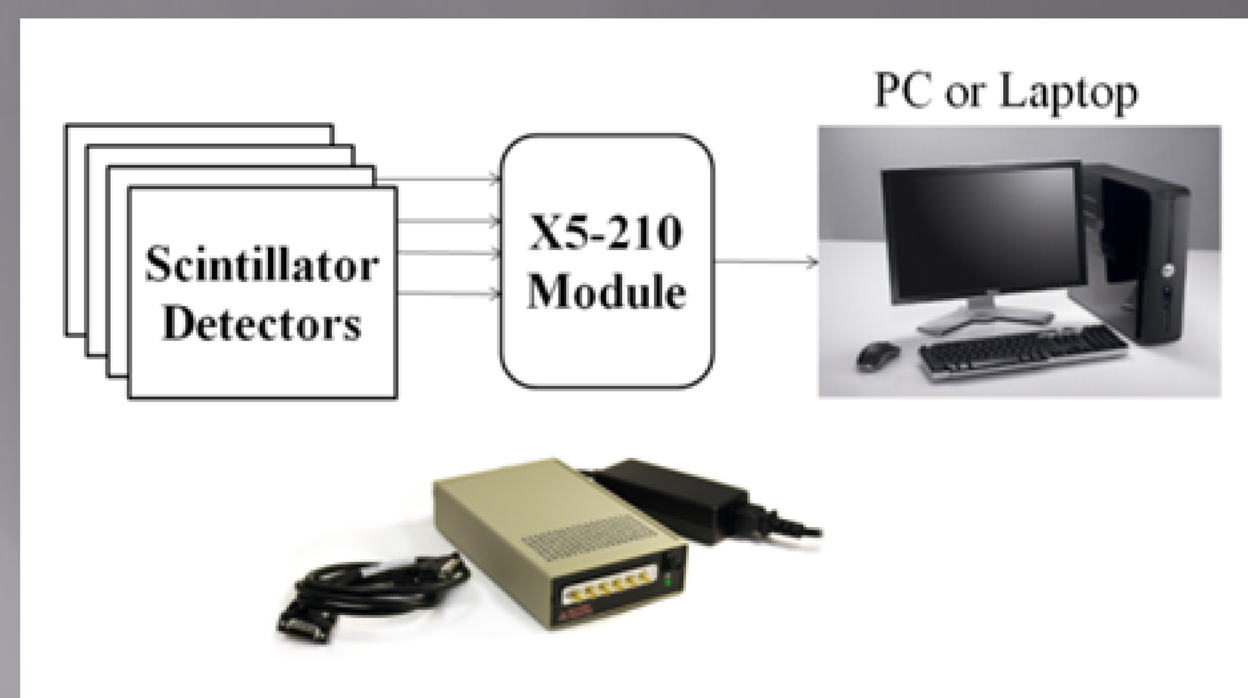

Figure 1. Overall data capture system.

Scalability

The scalability of our data capturing platform is beneficial in case there is ever a need to correlate times of pulse arrivals from multiple detectors, or if multiple data sources need to be processed at the same time.

- Expanding the system only requires the addition of more data processing modules.
- The X5-210 module connects to the back of a PC or laptop through a PCIe expansion card, so additional PCIe slots can be added to a PC or laptop to accommodate multiple PCIe expansion cards.
- By adding more modules, more channels can be included.
- The dimensions of the FPGA-based data processing module are 28.5 x 106 x 160 mm, which makes transportation of the system easy.

Measurement System and Analysis

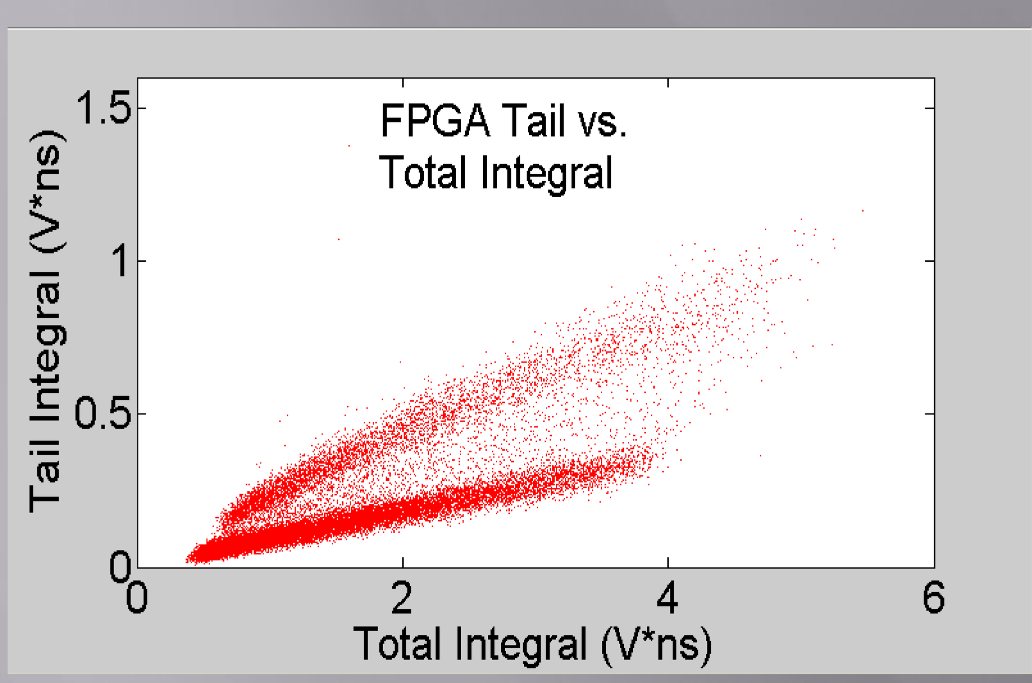

Figure 2. FPGA measurement results obtained with a Cf-252 source placed 30 cm from an EJ-309 liquid scintillation detector. Neutrons produce larger tail integrals than gamma rays which can be clearly seen in Fig. 2. The measurement threshold was set to 130 keVee (keV electron equivalent).

Measurement system:

- Four liquid scintillators
- FPGA-based data sampling digitizer
  - 250-MHz
  - 4-channel
  - 14-bit
  - Effective resolution (ENOB) = 11.7 bits

Measurement analysis:

- Neutron and gamma-ray pulse shape discrimination (PSD)
- Pulse-height distributions (PHDs)
- Time-correlated quantities such as cross-correlation functions, multiplicities, etc.

Figure 3. The University of Michigan developed a measurement system capable of acquiring the data on particles given off by radiation sources (left) with standard liquid scintillation detectors (bottom right) and a 250-MHz Innovative Integration (II) X5-210m digitizer (right).

FPGA Description

The FPGA processes the incoming analog-to-digital-converter (ADC) data stream.

- The FPGA can be programmed to achieve the desired handling of the information.
- As data streams from the ADC channels into the FPGA, the data values are synchronously compared to a programmable trigger threshold value and when the input values achieve the user-specified comparison, a trigger event occurs and data capture begins.

FPGA Architecture

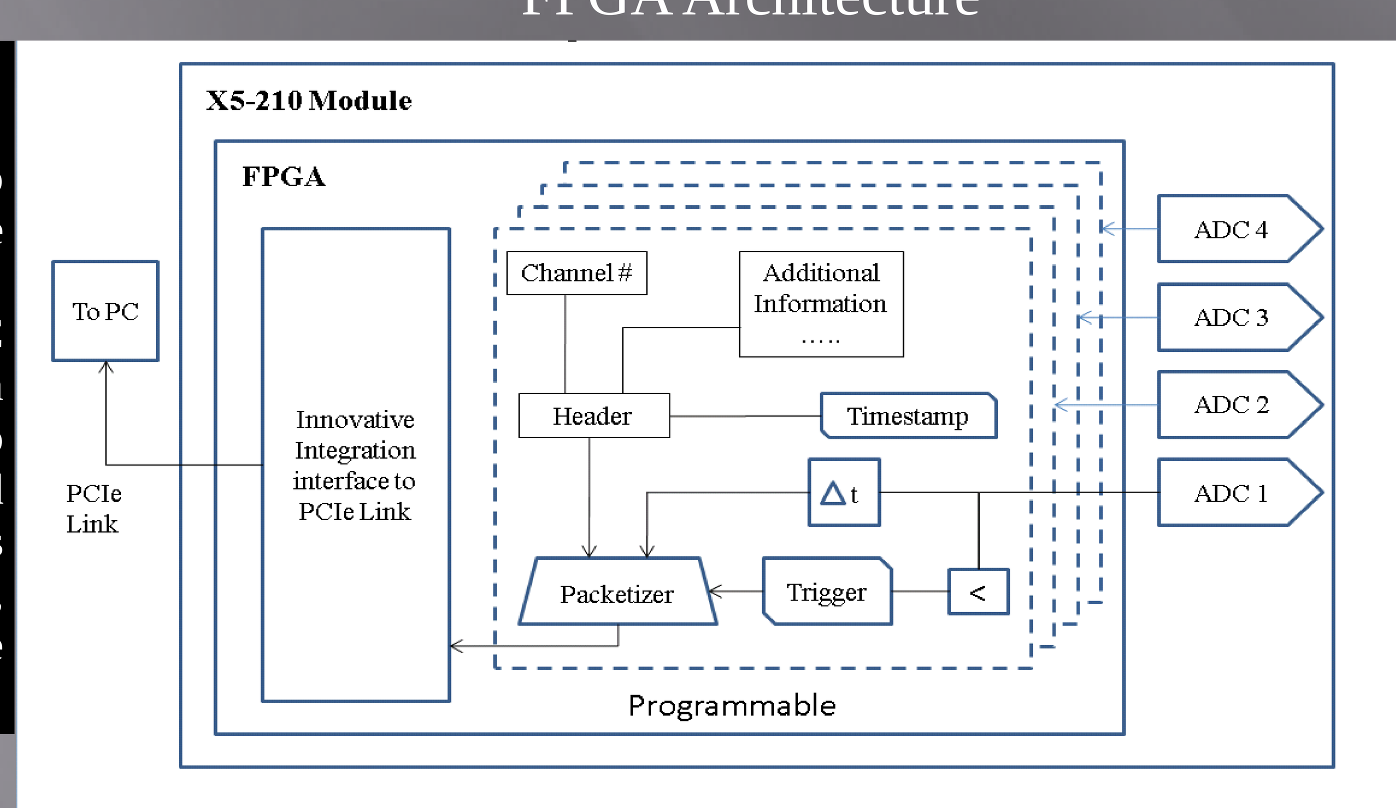

Figure 4. FPGA Architecture.

FPGA Pre-Trigger

When a trigger event occurs, if we began capturing the incoming data at that exact moment in time, we would miss the beginning of the overall waveform.

- A pre-trigger on the FPGA buffers the incoming data for a programmable number of samples.
- When a trigger event occurs, the start time of the data acquisition becomes the trigger time minus the pre-trigger interval.

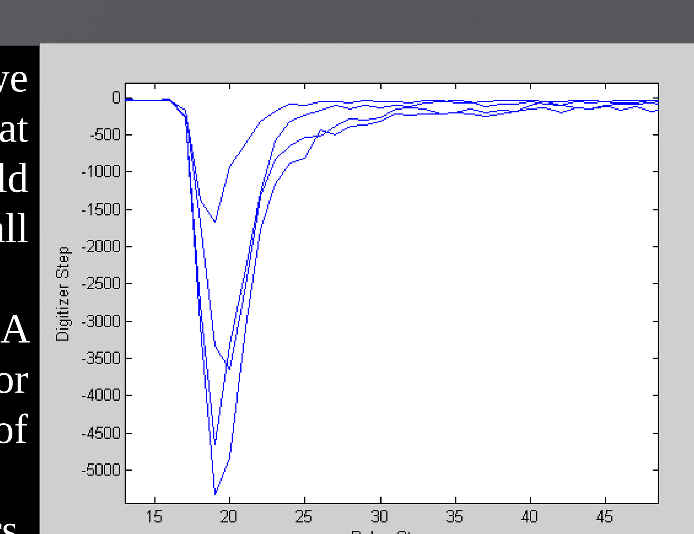

Figure 5. Pulses measured with the FPGA and a Cf-252 neutron source. The pulses were digitized with the X5-210m digitizer at 250 MHz.

FPGA Header Information

Every trigger event, a specified number of samples (typically 256) are captured and sent to the data-acquisition PC or laptop.

- The first four of these data samples contain header information specific to the pulse.
- The header information includes a timestamp of the trigger event, the channel number of the channel which triggered, plus supplementary, unused bits available for future expansion.
- More than four samples can be used in the header and so additional information can also be included, if needed.

Conclusions

- FPGA-based detection platforms used for identifying special nuclear materials are highly advantageous in their scalability, portability, and ability to be reprogrammed according to user-desired directives.
- FPGA-based platforms can clearly distinguish between neutron and gamma-ray particles based on the tail-to-total integrals of the pulse shapes created by the particles, as shown in Figure 2.
- Eventually, real-time detection of special nuclear materials will be achieved.

Future Work

- The FPGA will eventually be able to process incoming data streams in real time, discriminate detected particles based on their pulse shape and send the identification results to the PC without having to store the data values of the entire waveform.
- The method of identifying pulses and their associated particles by use of correlation algorithms implemented on the FPGA will be further explored. This work will result in a more accurate particle identification scheme.

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