Realizing Real-Time Capabilities of an Embedded Control System for Fast-Neutron Scintillation Detectors

Michael D. Aspinall[1], Malcolm J. Joyce[2], Alice Tomanin[3], Anthony Lavietes[4], Frank D. Cave[5], Romano Plenteda[4], and Vytautas Astromskas[2], *Member, IEEE*

[1]Aston University, Birmingham, United Kingdom,
[2]Lancaster University, Lancaster, United Kingdom,
[3]Joint Research Centre (JRC), Ispra, Italy,
[4]International Atomic Energy Agency (IAEA), Vienna, Austria,
[5]Hybrid Instruments Ltd, Lancaster, United Kingdom,

Introduction

Scintillation detectors offer a single-step detection method for fast neutrons and necessitate real-time acquisition, whereas this is redundant in two-stage thermal detection systems using helium-3 and lithium-6. The relative affordability of scintillation detectors and the associated fast digital acquisition systems have enabled entirely new measurement setups that can consist of sizeable detector arrays. These detectors in most cases rely on photo-multiplier tubes which have significant tolerances and result in variations in detector response functions. The detector tolerances and other environmental instabilities must be accounted for in measurements that depend on matched detector performance.

Recent advances made to a high speed FPGA-based digitizer technology developed by Hybrid Instruments Ltd (UK) and Lancaster University (UK), with support from the European Joint Research Centre (Ispra) and the International Atomic Energy Agency (Vienna) are presented. The technology described offers a complete solution for fast-neutron scintillation detectors by integrating multichannel high-speed data acquisition technology with dedicated detector high-voltage supplies. This unique configuration has significant advantages for large detector arrays that require uniform detector responses. We report on bespoke control software and firmware techniques that exploit real-time functionality to reduce setup and acquisition time, increase repeatability and reduce statistical uncertainties.

HV Adjustment

The MCA mode facilitates the user to quickly and easily adjust HVs to match the response of multiple detectors based on the Pulse Height Spectrum (PHS).

This would be performed by aligning the response from multiple detectors exposed to a gamma only source with a defined photo peak, e.g. Cs-137. For a large number of detectors an auto-calibration utility in the software environment has been developed.

Figure 2 demonstrates the effect that a 100 V step change on the detector's HV has on the detector gain by comparison of Cs-137 PHS.

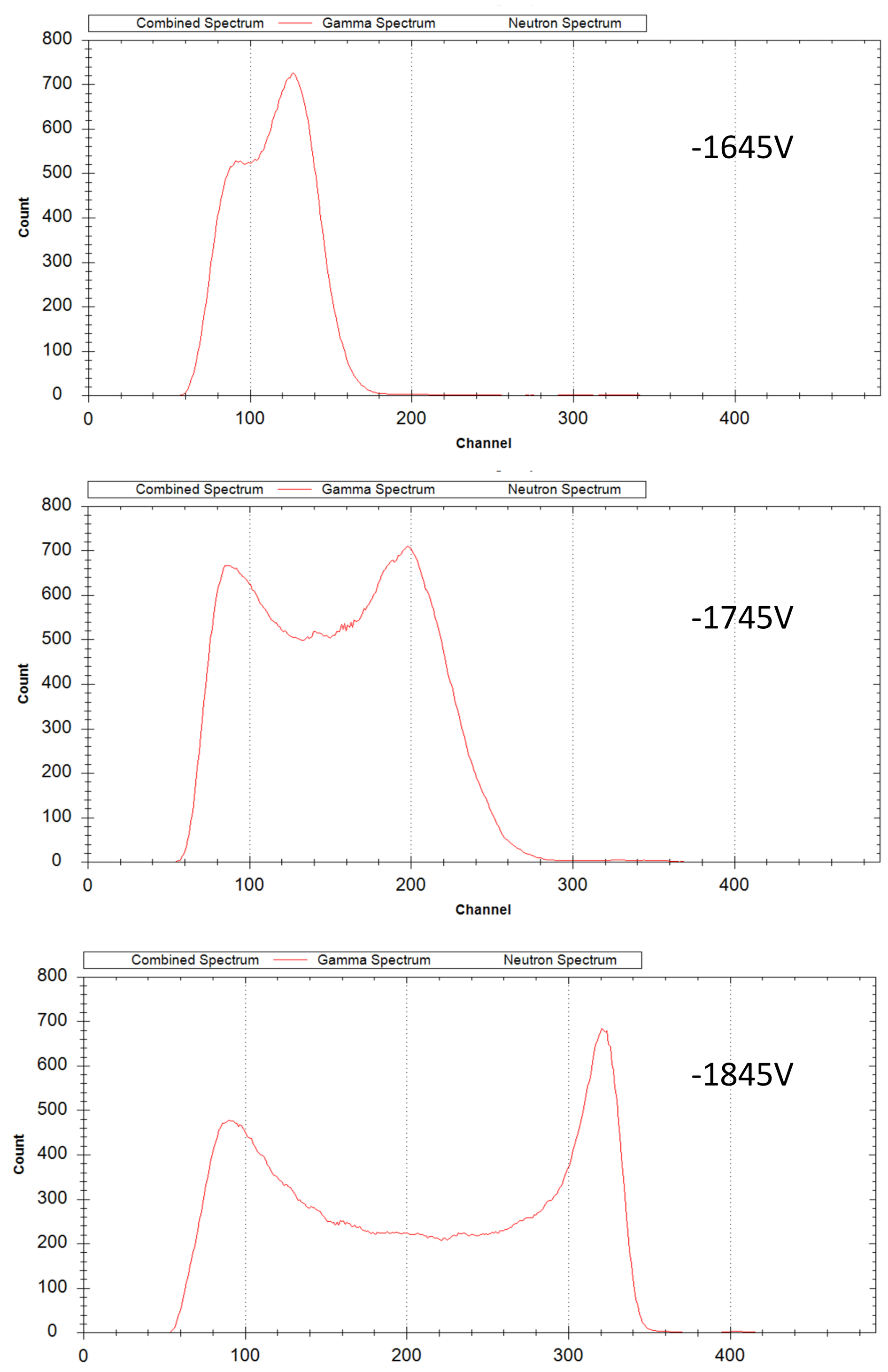


Fig. 2. Cs-137 spectrum with 10-point FIR filter acquired from an EJ309 liquid scintillator operated with a negative bias of 1645, 1745 and 1845 V in descending order. The photon peak locations are at channel 130, 200, and 320, respectively, on the MCA.

Mixed field analyser (MFA)

The front panel of the quad-channel MFAx4.3 mixed field analyser is shown in figure 1. The dimensions of the system are 350 mm x 260 mm x 110 mm, weighting 4.6 kg.

Fig. 1. The front panel of the quad channel mixed-field analyzer (model no. MFAx4.3).

Inputs and Outputs (front panel)	
Signal Input	HV supply
Two TTL Outputs per channel	
Ethernet Port	RS-232
Power Supply	JTAG
LED Indicators	Power Switch

Two digital output streams

Two **Transistor-Transistor Logic (TTL)** digital outputs per input channel for real-time, high throughput processing;

Ethernet port for direct PC interface and use of the GUI software environment

Two main distinguishing features of the MFAx

Real-time PSD at high throughput rates

- PSD algorithm is implemented directly and entirely in VHDL that executes on the FPGA processing core.
- The incident events and the associated TTL outputs are synchronized in time. The time between a trigger event to digital output is between 400 ns – 500 ns with a timing jitter of 6 ns.
- Discrimination rates of 10 million pulses per second (MPPS) for single channel and 3 MPPS per channel on quad-channel digitizer are achieved.

Close integration of controllable HV supply per high-speed digital input channel.

- Real-time data can be analysed by the software and used as feedback to auto-adjust detector response based on supplied HV.
- The users are able to control the detectors' HV directly from the MCA interface. This provides an indication of the result of newly applied HV on the PHS within minutes.

Finite-impulse-response (FIR) filter

The MCA software interface now offers a real-time embodiment of a FIR filter. The smoothing effect that this has is beneficial for both human and computer interpretation, in better determining the MCA channel number of the photo peak. The magnitude of the filter can be set at any time whilst acquiring data, and the filtering influence is displayed in real time. The effect of FIR filter is shown in figures 5 and 6.

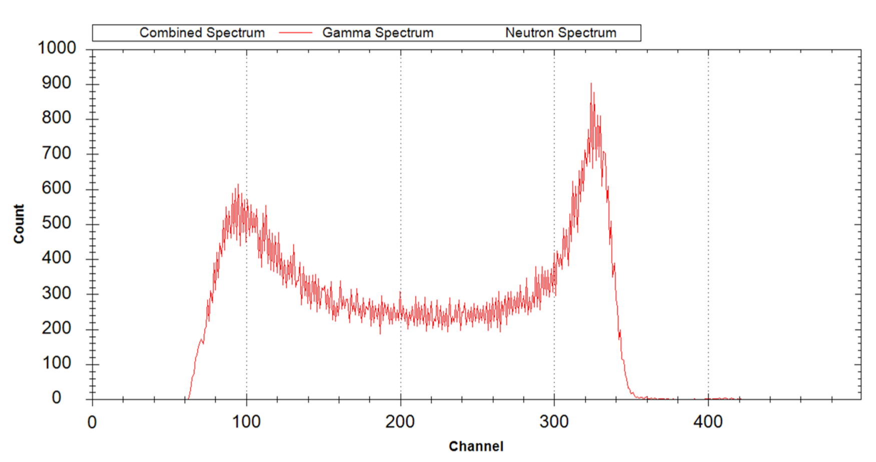


Fig. 5. The multi-channel analyzer (MCA) graphical-interface with unfiltered gamma-only pulse-height spectrum of data acquired from an EJ309 liquid scintillator positioned 45 mm from a Cs-137 source.

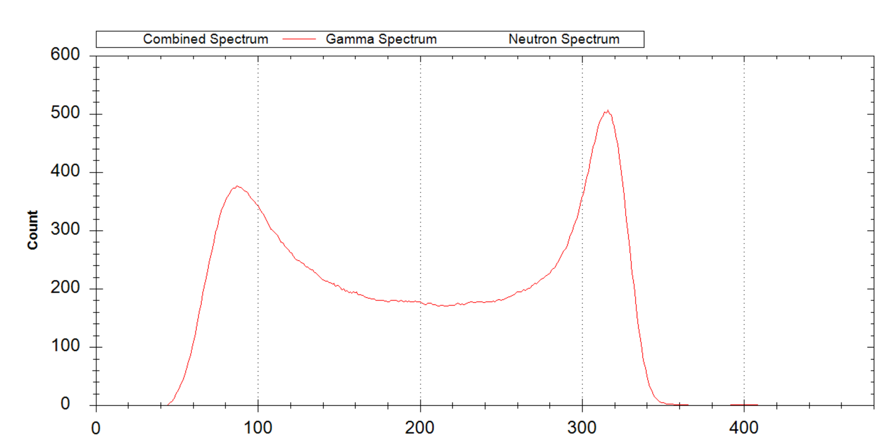
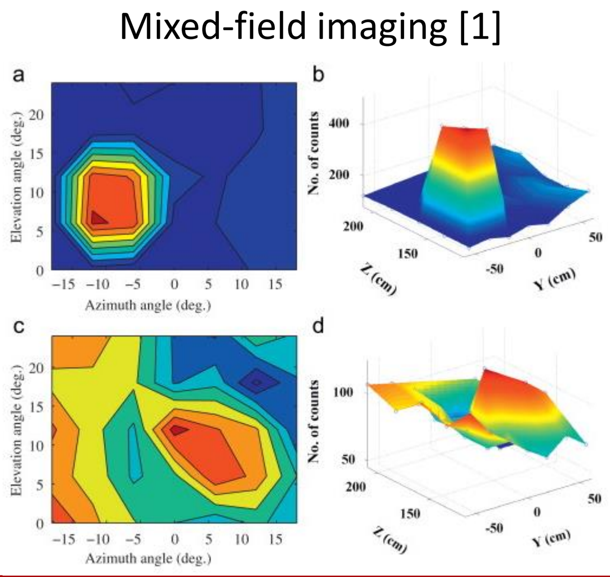


Fig. 6. The multi-channel analyzer (MCA) graphical-interface with 20-point moving-average filtered gamma-only pulse-height spectrum of data acquired from an EJ309 liquid scintillator positioned 45 mm from a Cs-137 source.

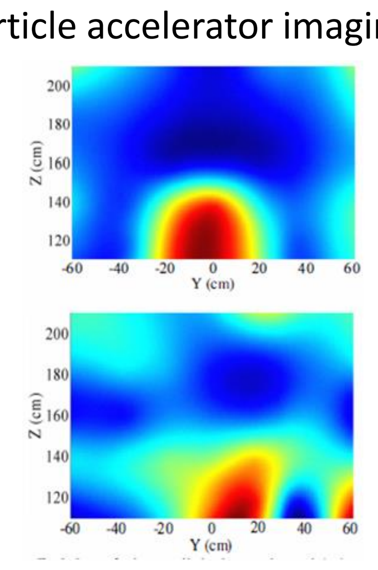
Applications of system

- The laboratories at IAEA Headquarters, Vienna, Austria.
- The IAEA Seibersdorf laboratories, Austria.
- The Atominstitut, Vienna, Austria.
- The laboratories at the Karlsruhe Institute of Technology, Germany.
- The Rokkasho Nuclear Fuel Reprocessing Facility, Japan.
- The AREVA MOX fuel manufacturing plant, France.
- The safeguards laboratories at the JRC in Ispra, Italy.

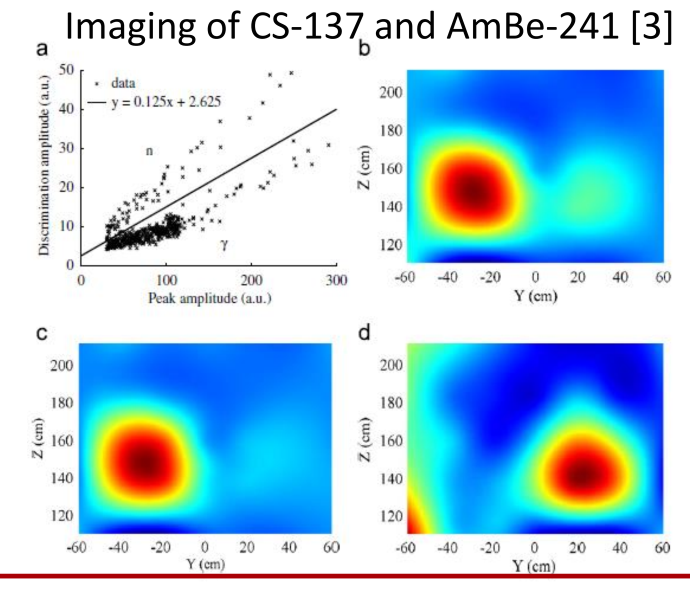
Mixed-field imaging [1]



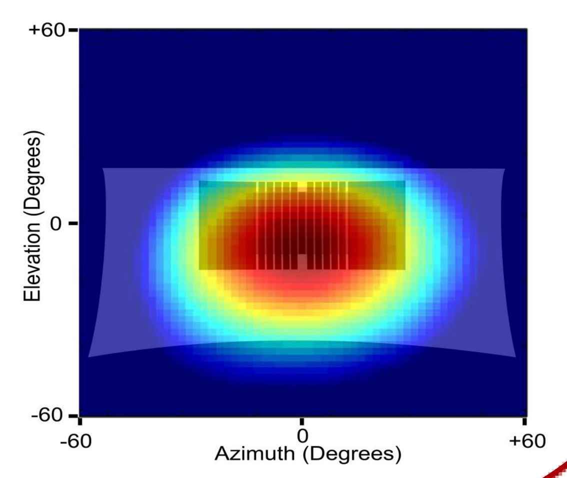
Particle accelerator imaging[2]



Imaging of CS-137 and AmBe-241 [3]



Reactor imaging [4]



References:
1. Combined digital imaging of mixed-field radioactivity with a single detector', K. Gamage et al., Nuclear Instruments and Methods in Physics Research, (2010) **A635** (1) , pp. 74-77.
2. 'Real-time, digital imaging of neutrons and gamma rays with a single fast liquid scintillation detector', M. J. Joyce et al., IEEE Nuclear Science Symposium Conference Record (2012), pp. 602-606.
3. 'A digital approach to neutron-gamma imaging with a narrow tungsten collimator aperture and a fast amplitude liquid scintillation detector', Gamage et al., Applied Radiation & Isotopes (2012) **70** (7), pp. 1223-1227.
4. 'A mixed-field imaging approach to reactor monitoring', J. Beaumont et al., IEEE Nuclear Science Symposium, Seattle (2014).