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FAST DIGITIZER CARD WITH INTEGRATED PEAK ANALYSIS ALGORITHM

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Abstract. *The newly developed spectrometric system combines a digital multichannel analyzer and peak analysis. The fast digital (FD) card is built on programmable gate arrays (FPGA) and fast 12-bit analog-digital convertor (ADC) with a sampling frequency of (100 - 1000) MS/s. The FD card contains integrated high voltage module, preamplifier, digital interface for communication with a PC and advanced algorithms for peak analysis of the measured spectra. This system can be integrated directly into radiation detectors and perform spectrometric measurements and evaluations.*

Keywords: *Digital multichannel analyzer (MCA), Fast analog-digital convertor (ADC), Field programmable gate arrays (FPGA), Peak analysis, Radiation detector*

1. Introduction

In this paper, we describe the development of a fast digital multichannel analyzer (MCA) with peak analysis for gamma ray characterization. We have been developing fast digitizer cards since 2010. During this time, we developed digitizer cards for neutron/gamma analyzers for measuring radiation fields around linear and medical particle accelerators, as well as digitizer cards for neutron/gamma stationary probes for the radiation situation monitoring, e.g. in spent nuclear fuel stores or in experimental reactors.

Fast digitizing cards are built on programmable gate arrays (FPGA) and fast (12 – 16) bit analog-digital convertor (ADC) with a sampling frequency of (100 - 1000) MS/s. The fast digital MCA follows on from the previous development of the DIM-09 and NGA-01 digitizer cards [1]. These cards use modern technologies and are capable of processing data with transfer speed higher than 40 Gbit/s. They contain integrated high voltage module, preamplifier, digital interface for communication with a PC and advanced algorithms for peak analysis of the measured spectra.

A newly developed fully digital MCA enables fast sampling of input signals, better high resolution, pulse shape analysis and high count rate processing. Due to the integrated spectral analysis, it allows a wide range of applications in ionizing radiation dosimetry. The digital MCA card has been implemented into a volume activity gamma detector. The radiation detector equipped digital MCA has been tested in the laboratory of VF NUCLEAR company and the results are presented.

2. Fast spectrometric digitizer card

The digital MCA is designed for connecting scintillation detectors with a photomultiplier and a positive supply high voltage, see Figure 1.

Figure 1. Digital MCA spectrometric module.

The signal path starts with the HV source, which provides power to the photomultiplier. The high voltage is supplied to the input of the amplifier, from where it is connected to the detector through a common power and signal cable.

The signal from the detector is amplified by a charge amplifier. Through an amplifier with variable gain and an amplifier adjusting the signal to symmetrical it is connected to a fast AD converter.

The AD converter is 16 bit with a sampling frequency of 125 MHz. The digitized signal is connected into the FPGA circuit. The processor part of the spectrometer module is implemented by a dual-core microcontroller MIMXRT1176. The less powerful M4 core is dedicated to the control of the spectrometer

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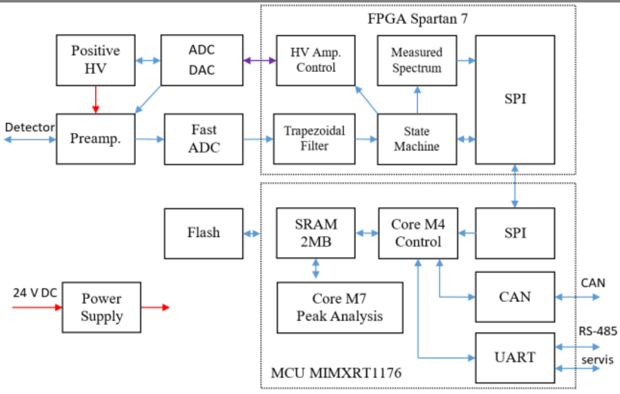


Figure 2. Scheme of digital MCA spectrometric module.

module. The more powerful M7 core is dedicated to peak analysis.

The main function implemented in the Spartan-7 FPGA is real-time signal processing. It is based on a trapezoidal filter [2]. A trapezoidal filter is an impulse response system that converts pulses with an exponential tail into trapezoid-shaped pulses.

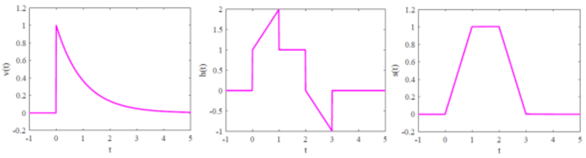


Figure 3. Trapezoidal filter: Idealized input signal, impulse response and output signal.

The trapezoidal filter is implemented in a discrete recursive form [3] in the FPGA. Similar implementations were published, e.g., [4]. The pulse amplitude is proportional to the input energy and scanned at the trapezoid's top flat part. The pulse amplitudes are stored in an amplitudes histogram directly in the FPGA memory. The histograms are two - for odd and even elementary periods. Each time, One histogram is intended for current amplitude counting, and the second is available for the microcontroller via an SPI communication.

3. Peak analysis algorithm

The peak analysis algorithm consists of three parts. In the first part of the analysis, a Savitzky-Golay filter [5] has been applied to the measured spectrum. Savitzky-Golay returns the smoothed spectrum. From the smoothed spectrum peak parameters such as position, left and right inflection points, peak start and peak end are determined.

The parameters calculated in the first part of the analysis have been used for the Gauss-Newton iterative method. It fits a Gaussian function to the expected peaks in a small number of steps. The multiplet parameters such as peak position, FWHM, peak amplitude and peak area are the results of this method.

In the third part of the analysis, multiplets are assigned to radionuclides listed in the radionuclide library. Each peak found is assigned an energy line

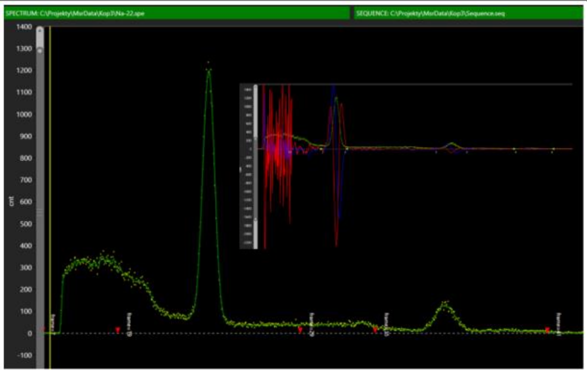


Figure 4. Splitting the spectrum into intervals after applying the Savitzky-Golay filter.

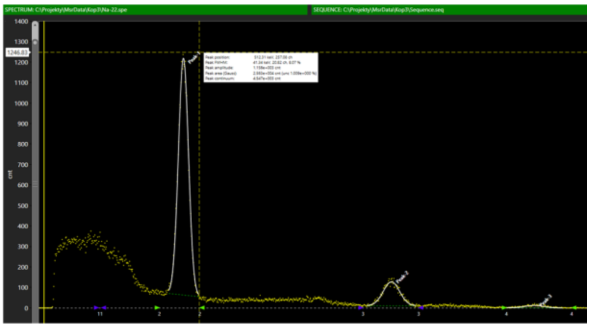
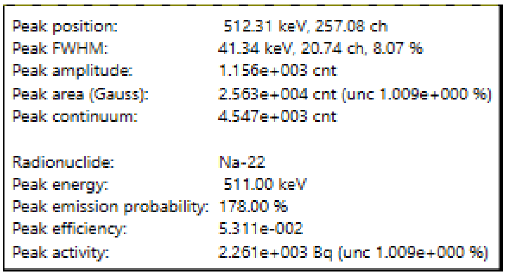


Figure 5. Application of Gauss-Newton iterative method.



Peak position:	512.31 keV, 257.08 ch
Peak FWHM:	41.34 keV, 20.74 ch, 8.07 %
Peak amplitude:	1.156e+003 cnt
Peak area (Gauss):	2.563e+004 cnt (unc 1.009e+000 %)
Peak continuum:	4.547e+003 cnt
Radionuclide:	Na-22
Peak energy:	511.00 keV
Peak emission probability:	178.00 %
Peak efficiency:	5.311e-002
Peak activity:	2.261e+003 Bq (unc 1.009e+000 %)

Figure 6. Scheme of digital MCA spectrometric module.

from the radionuclide library according to the energy calibration. Subsequently, a check of the yields with respect to the efficiencies for all energy lines of each radionuclide is performed. Finally, the activity for each identified energy line is calculated, see Figure 6.

The peak analysis algorithm can be applied to a spectrum of any number of channels with any detector resolution.

4. Experimental setup

A prototype of the digital spectrometric system was installed in the laboratory of the VF NUCLEAR company, see Figure 7.

The radiation detector GD-51 was placed in the assembly of the liquid activity monitor LAD-21. The ionizing radiation is collimated by lead shielding. The collimation is in the horizontal direction, thus eliminating the influence of the level on the measurement sensitivity.

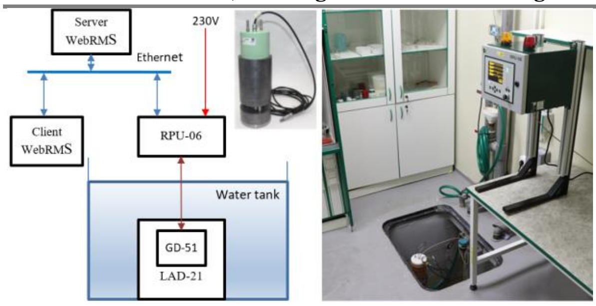


Figure 7. Layout of the installed spectrometry system.

The signal from the detector is connected to the RPU-06 data acquisition and processing unit. The main component is a digital spectrometric module (DIM-15) with peak analysis and evaluation of measured spectra.

The data from the RPU-06 are uploaded by the WebRMS server application.

5. Measurement results

After installation of the digital spectrometric system in the water tank, measurements were carried out to determine energy, efficiency and FWHM calibration. The certified reference materials containing the radionuclides F-18, Co-57, Co-60, I-131, Cs-137, and Am-241 were used for the measurements. The high voltage on the detector was set with respect to energy range from 100 keV to 1.7 MeV, see Figure 8.

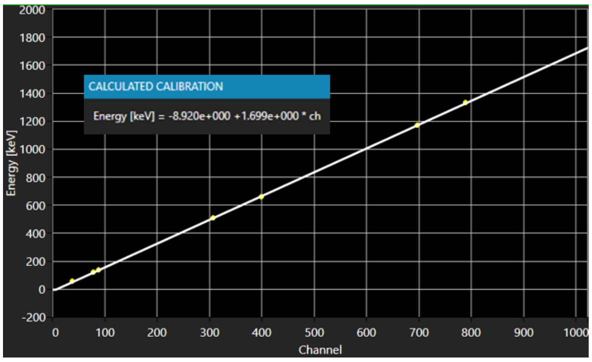


Figure 8. Energy calibration.

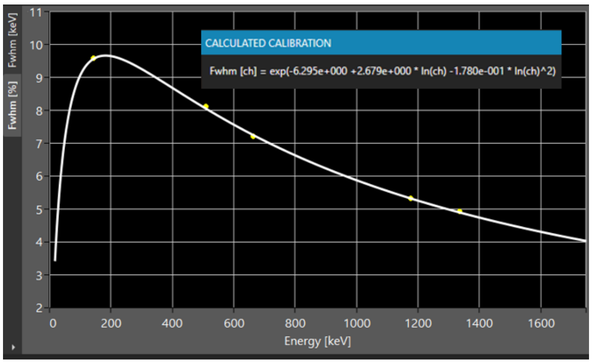


Figure 9. FWHM calibration.

The control measurements were performed using the medical radionuclide Tc-99m. A sample of Tc-99m has been taken from the water tank and measured on an HPGe detector. Reference activity of 1.141E+07 Bq/m3 was evaluated in the sample, see Figure 11.

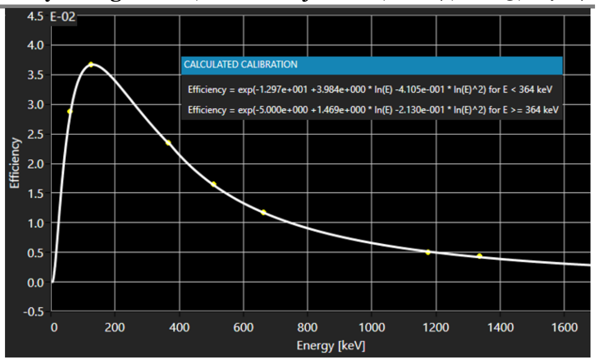


Figure 10. Efficiency calibration.

The calculated volume activity of Tc-99m measured using a newly developed spectrometric system was 1.173E+07 Bq/m^3, see Figure 12. Request of international standards for this type of the spectrometric measurement is ± 10 %.

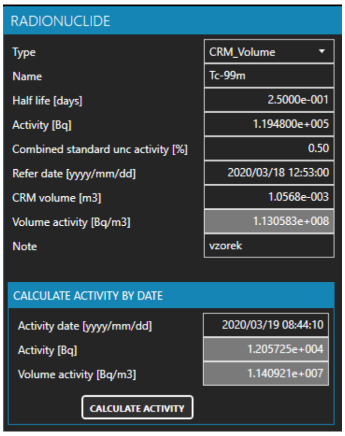


Figure 11. Ref. volume activity determine via HPGe detector.

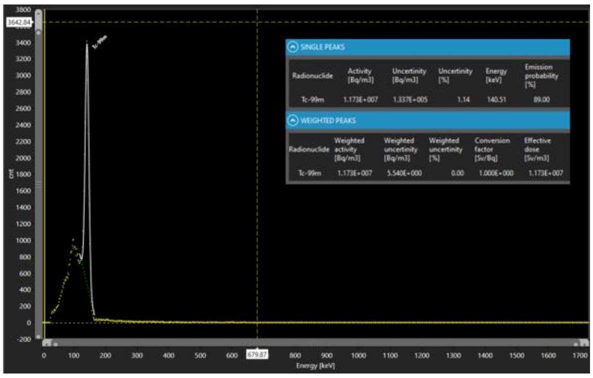


Figure 12. Volume activity of the Tc-99m evaluated using a newly developed spectrometric system.

6. Conclusion

An integrated spectrometric system combining a digital multichannel analyzer and peak analysis into one device was developed, tested and verified. This system can be integrated directly into radiation detectors for spectrometric measurements and evaluations.

This system will find application in the laboratories of atomic and nuclear physics, research institutes with particle accelerators, radioactive waste storages, nuclear medicine facilities, etc.

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