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FPGA embedded multichannel analyzer

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HIGHLIGHTS

- An MCA embedded into a FPGA was designed, built and evaluated.
- To hand and visualize the spectra a VI was designed.
- The obtained pulse height spectra are alike to spectra measured with commercial MCA.

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ABSTRACT

An multichannel analyzer has been designed, and its performance has been evaluated. The multichannel analyzer is embedded into a Field programmable gate array. The design incudes the virtual instrument in order to hand and to visualize the pulse height spectrum. Two commercially available multichannel analyzers using a NaI (Tl) and HPGe detectors were used to obtain the pulse height spectra of ^{137}Cs, ^{60}Co and ^{152}Eu sources and were compared with the pulse height spectra obtained with the embedded multichannel analyzer, being alike the spectra obtained with the commercial multichannel analyzer. Our design is smaller, low cost and it has options to add other features.

1. Introduction

In nuclear metrology nuclear spectrometry is considered the backbone of radiation measurements, because radiation fluence and energy can be determined (Adler et al., 2010; Ibarra and Pabón, 2015). Nowadays, nuclear spectrometry is carried out with a multichannel analyzer (MCA).

Essentially, MCA has two main systems: the discriminating system where the radiation intensity is stored in terms of its energy, and the visualization system where the user can handle the pulse height spectrum (Dambacher et al., 2011). Digital signal processing has become an important alternative to analog design; thus, digital signal processing has become an option to include the advancement and development of technologies in nuclear spectrometry (Lee et al., 2013).

The use hardware description languages available on the ZedBoard development boards, of the SoC (System on Chip) Zynq family of Xilinx (Xilinx); which combine in the same integrated circuit, hardware and software having a reconfigurable device (Field Programmable Gate Arrays: FPGA) and an ARM microprocessor offers several advantages in digital signal processing. The aforementioned SoC family can be configured with the high-level synthesis tool Vivado allowing the design embedded systems with a high level of abstraction (Bobin et al., 2012; Lanh et al., 2014). A SoC is an element that integrates all the modules of a system in a single chip or circuit, which greatly reduces the size of the device. In contrast, in FPGAs there are no specific application modules until they are described by the programmer using the logic blocks it contains. (Rajsuman, 2000).

The objective of this work was to design and to evaluate a MCA with 4096 channels for nuclear spectrometry using a ZedBoard development board, the Vivado development suite, and a virtual instrument (VI) to control the MCA. The design reduces the cost and size of the device, compared to commercial MCA.

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Table 1
Block description of the multichannel analyzer in Vivado.

Block Name	Block Description
top_multicanal_0	Multichannel analyzer block
rst_processing_system7_0	Resets to the default values
processing_system7_0	Logical connection between the PS and the PL
processing_system7_0_axi: periph	Communicates the peripherals with the PS using the AXI protocol
axi: gpio_0	Output for the beginning of the readings
axi: gpio_1	Output to start the sampling process
axi: gpio_2	Output to synchronously reset the entire top_multicanal_0 module
axi: gpio_3	Data input from memory
axi: gpio_4	Address input from memory
axi: gpio_5	Output to turn on the LEDs that indicate the start and end of the process

2. Materials and methods

2.1. Development of the architecture for the FPGA

The architecture was described in the VHDL language. The development board that was used to synthesize this design was a ZedBoard Zynq-700 SoC Z-7020 kit, which has an XC7Z020 FPGA, which has as main features the following: 53200 LUTs (Look Up Tables), 106400 Flip- Flops, 200 I / O pins, 32 BUFG (global clock buffers), 140 blocks of 36 Kb of RAM and 220 digital signal processors (DSPs). This board has two ARM Cortex-A9 CPUs located in the processing system section, which can be enabled to integrate with modules designed in the programmable logic section (Apu, 2016; Crockett et al.,).

In addition, a digital analog converter by Analog Devices was used, which is mounted on a Digilent peripheral module (Pmod). This converter has 1 MSPS (millions of samples per second), two channels with parallel sampling with a resolution of 12 bits each, and an operating range of 0 V to VCC, which in this case is from 0 to 3.3 (Ada Pmod Xilinx et al., 2011).

The design for the multichannel analyzer was created in the development software Vivado (2015.4), to be implemented in the ZedBoard. The main entity of the design consists of 10 blocks, Table 1 briefly details the operation of each block.

2.2. Programming the application for the ARM

The software application was created in C programming language, through the Software Development Kit (SDK) development platform. The purpose of this application is to carry out the interconnection between the architecture developed for the FPGA and the VI. Its main features are to activate the start and end of the sampling, as well as the collection and restoration of memory data.

2.3. Virtual instrument for the multichannel analyzer

Using the LabVIEW graphical programming platform, the multichannel analyzer's virtual instrument was designed, and it was used as interface for the handling, control and visualization of data. This instrument uses the VISA communication protocol, through a USB port that emulates a serial port, thus having communication with the development board. The front panel of the virtual instrument has a friendly interface as can be seen in Fig. 1.

2.4. MCA performance evaluation

To evaluate the MCA performance several tests were carried on: A pulse generator was used and the linearity was determined.

Gamma-ray pulse height spectra were obtained using a NaI(Tl) and an HPGe detectors and were compared with the spectra measured with Ortec and Canberrra commercial MCA.

3. Results and discussion

3.1. Architecture for the FPGA

The then block of the main entity is shown in Fig. 2, the block named *top_multicanal_0* was described in the VHDL language and the remaining blocks were provided by the development environment.

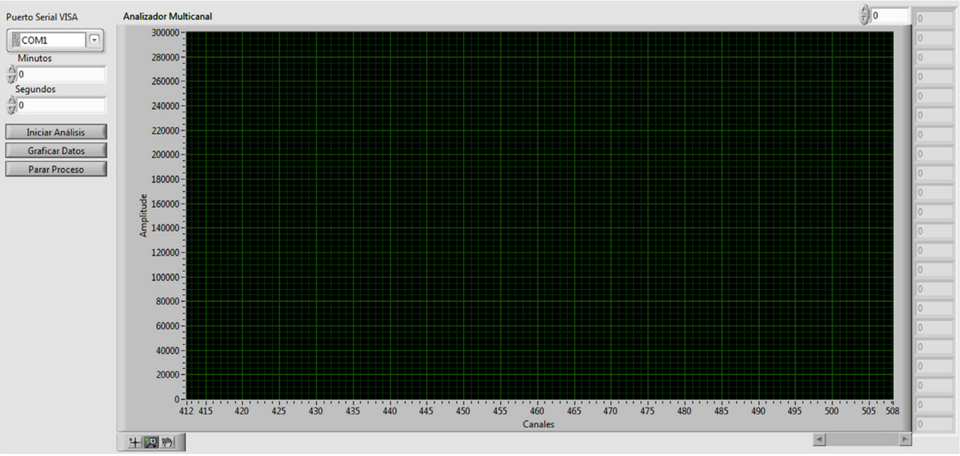
Fig. 3 shows the architecture of the multichannel analyzer with the 10 entities that perform different processes ranging from the conversion of the pulses to digital values, to the storage of the necessary values in memory. These entities that make up the architecture were elaborated in the hardware description language VHDL, using the Vivado development platform, where they were correctly interconnected in order to be able to package them.

3.2. Characterization of the multichannel analyzer

3.2.1. MCA linearity to function generator pulses

Pulses from 0 to 3.3 V, in steps of 0.1 V, produced by a function generator were input to the MCA, and the output signals in the channels were obtained.

In Fig. 4 the correlation between the input pulses voltage and the channel is shown, here is also included the linear fit whose correlation coefficient is 0.9999.



Puerto Serial VISA: COM1
Minutos: 0
Segundos: 0

Fig. 1. Multichannel analyzer user interface.

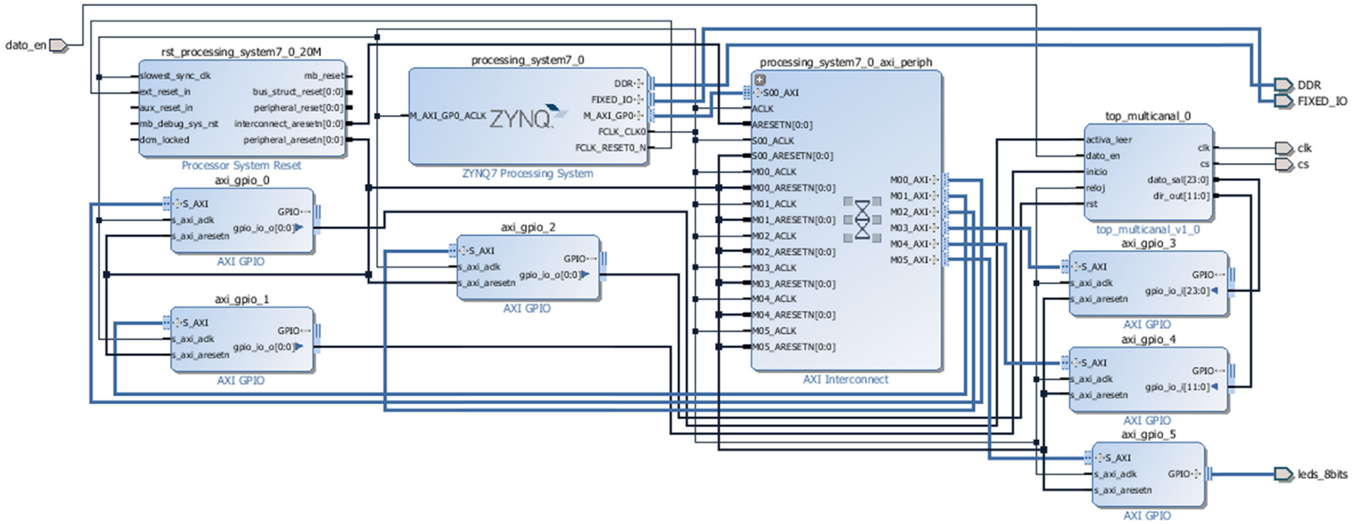


Fig. 2. Block diagram of the multichannel analyzer in Vivado.

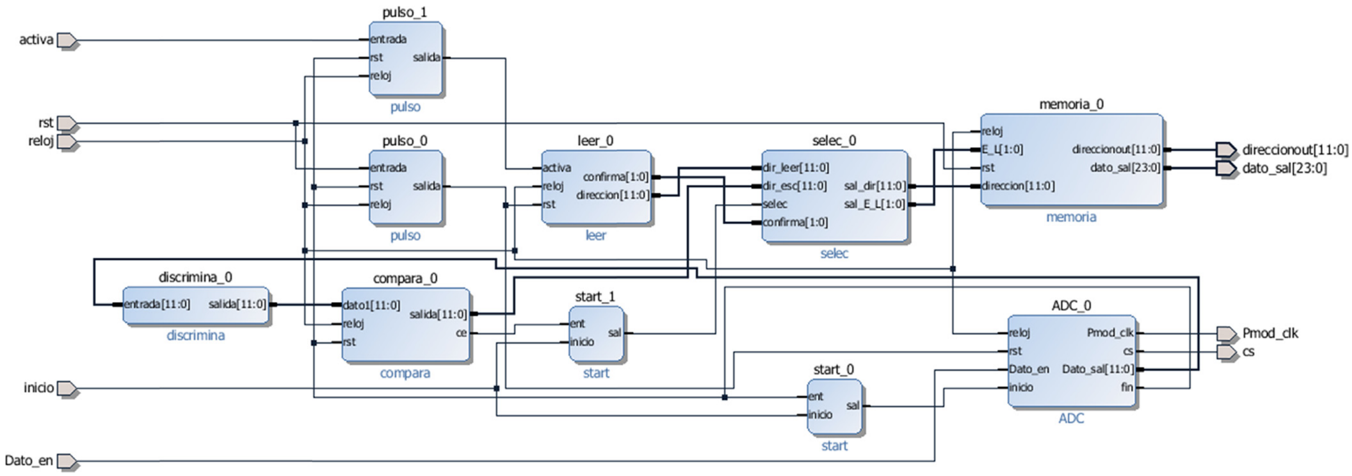


Fig. 3. Block diagram of the architecture of multichannel analyzer.

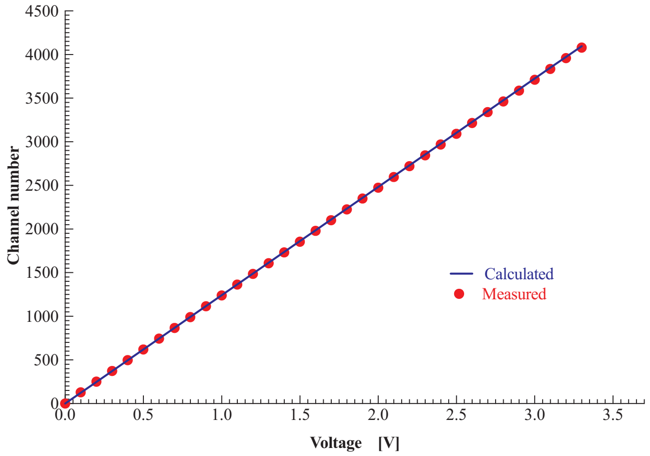


Fig. 4. MCA response to voltage function generator.

3.2.2. *Comparison with multichannel analyzer from Ortec*

The embedded multi-channel analyzer was compared to a gamma-ray spectrometry system; with a 7.62 × 7.62 cm Nal (Tl) scintillation detector, a NIMbin, housing a high voltage power supply, a spectroscopic amplifier, and a personal computer with a multichannel analyzer, all from Ortec. The Ortec MCA was set to 2048 channels. A ^{137}Cs point-like source was allocated to 2 cm above the scintillator and the pulse height spectrum was obtained as is shown in Fig. 5.

The signal from the spectroscopic amplifier was plugin into the embedded MCA and the pulse height was obtained and shown in Fig. 6.

Both spectra show the same features as the 0.662 MeV photopeak and the Compton shoulder. Differences among channel number are due to the embedded MCA scaling, and differences among the counts are due the counting time.

This test was also carried on using a ^{60}Co source. Fig. 7 present the pulse height spectrum of ^{60}Co measured with the Ortec MCA, and Fig. 8 shows the spectrum obtained with the embedded MCA.

In both spectra photopeaks due to 1.17 and 1.33 MeV photons are shown. Both photons are produced almost with the same probability; however the second peak (1.33 MeV) is shorter than de 1.17 MeV peak because the first peak is on the Compton shoulder of the second peak.

3.2.3. *Comparison with multichannel analyzer from Canberra*

The pulse height spectrum of ^{152}Eu point-like source was obtained with a γ-rays spectrometer with a HPGe detector. The NIMbin with the power supply, the amplifier, and the MCA are from Canberra. It was set to 8192 channels. The source was on top the detector and the pulse height spectrum was measured, in Fig. 9 it is shown.

The output from the amplifier was input to the embedded MCA and the pulse height spectrum was measured. This is shown in Fig. 10.

The correlation between the channel number and the ^{152}Eu γ-ray

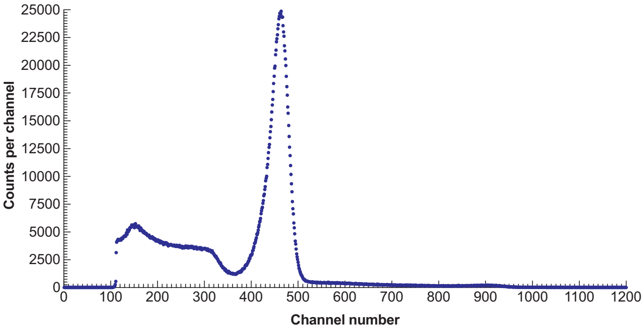


Fig. 5. Pulse height spectrum of ^{137}Cs obtained with the MCA from Ortec.

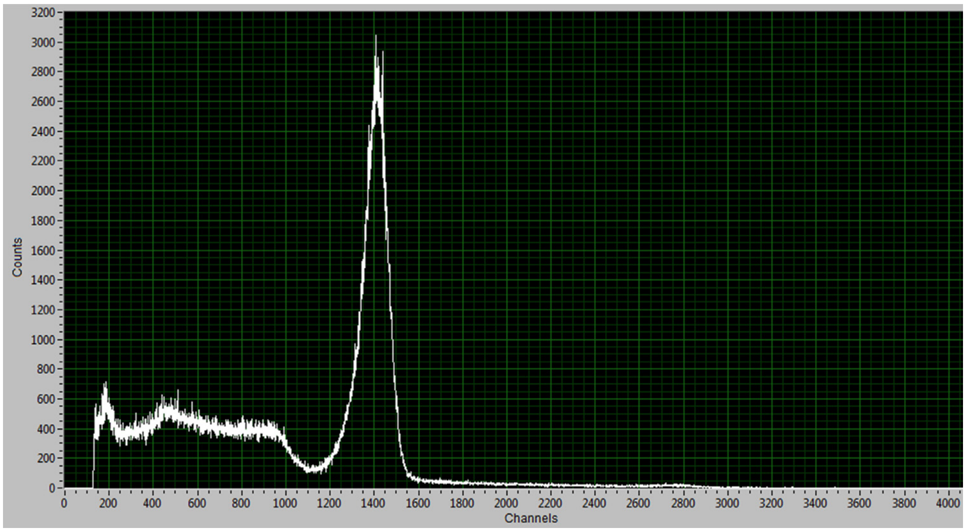


Fig. 6. Pulse height spectrum of ^{137}Cs obtained with the embedded MCA.

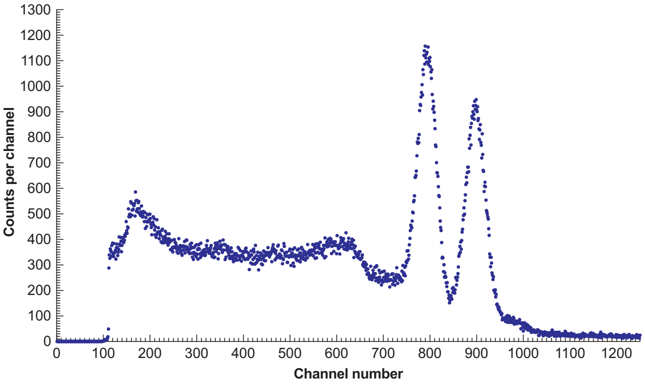


Fig. 7. Pulse height Spectrum of ^{60}Co with the MCA from Ortec.

photopeaks was obtained for the embedded MCA, in Fig. 11 is shown the measured data and the linear fit whose correlation coefficient is 0.9993.

4. Conclusions

An MCA was designed into a FPGA where the input signals are obtained through the analog signal sampling, detecting the maximum pulse heights for memory addressing and thus storing the periodicity of the input events. An application was developed in the C programming language for its execution in an ARM core for the control of the MCA and the data communication with the VI, which was designed for handling the MCA and visualizing the pulse height spectra. The embedded MCA performance was carried by comparing the pulse height spectra of γ-ray sources measured with two commercial MCA.

The embedded MCA has a good linearity for pulses produced by a function generator.

Gamma-ray pulse height spectra obtained with the embedded MCA have the same features as those measured with two commercial MCA.

The embedded MCA has the advantage that it is optimized in terms of the use of hardware related to the programmable logic device in question, therefore only 9% of the hardware available in the FPGA was used, which makes it possible to add other components to improve the MCA or develop a network with several detectors.

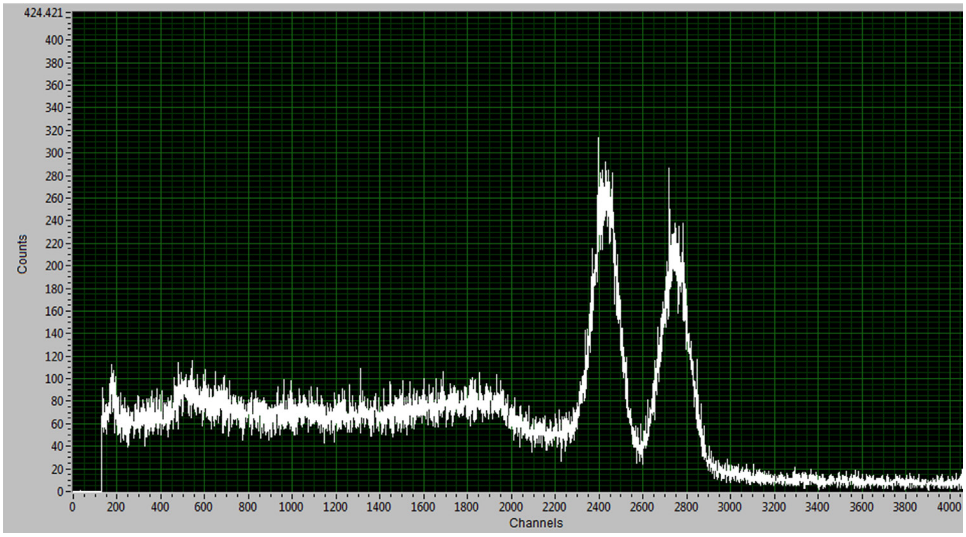


Fig. 8. Pulse height spectrum of ^{60}Co with the embedded MCA.

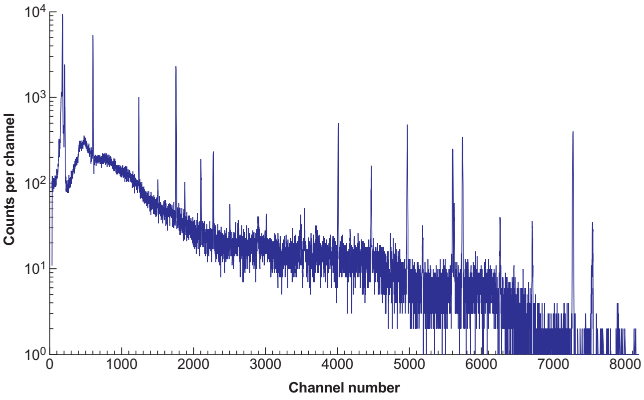


Fig. 9. ^{152}Eu pulse height spectrum obtained with the MCA from Canberra.

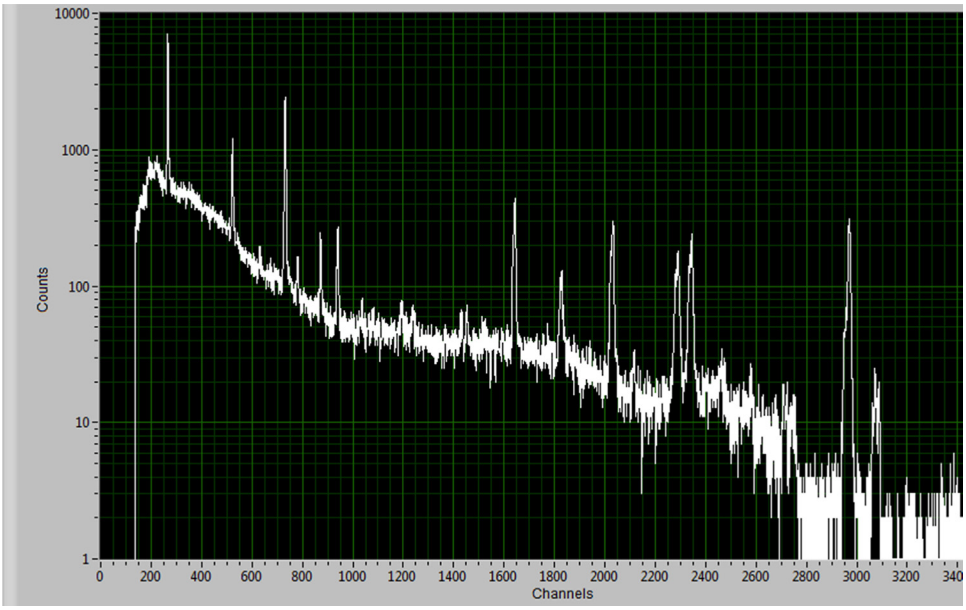


Fig. 10. ^{152}Eu pulse height spectrum obtained with the embedded MCA.

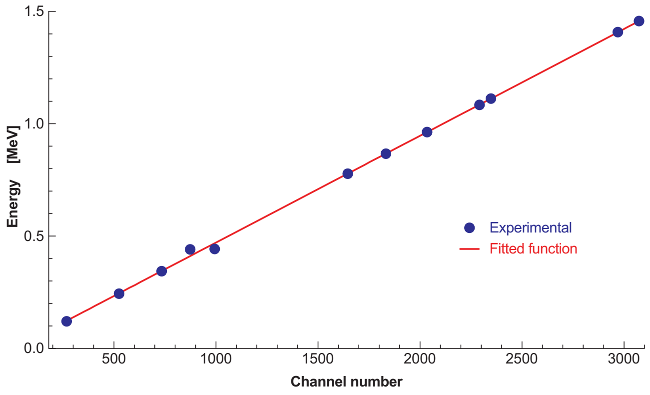


Fig. 11. Calibration of embedded MCA with ^{152}Eu.

The configuration of the MCA architecture has the advantage of being able to implement it in different development platforms that contain FPGA technology, which can be of lower cost and size.

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