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STM32F407 microcontroller based multichannel analyzer for spectroscopy

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The multichannel analyzer (MCA) is a crucial device for recording and analyzing radiation energy spectra to ascertain energy and intensity. It can be implemented via FPGA with a fast ADC and digital algorithm or a microcontroller with a peak detector circuit using an analog electrical circuit. MCA is widely applied in field work, nuclear medicine, and accelerator experiments. This work focuses on developing a low-cost alpha and gamma spectrometric system for experimental physics and field work, such as recording radiation and monitoring nuclear facility surroundings. Modern microcircuits, with small size and low power consumption, enable simpler and cheaper analog signal processing circuits that process signals in real-time without digital conversion delays. The spectrometric amplifier (SA) and peak detector (PD) were modeled and prototyped. A Python-based real-time data acquisition program was developed. Signals are recorded on the STM32F407 microcontroller's ADC and transmitted via USB to a PC. An experiment obtaining the Ra226 alpha source spectrum verified the MCA's functionality. It is valuable for environmental radioactivity field work and student teaching.

Key words: Multichannel analyzer, alpha spectroscopy, gamma spectroscopy, nuclear electronics.
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1. Introduction

Modern integrated circuits, which possess small dimensions and low power consumption, open up the possibility of fabricating portable nuclear radiation detection systems. These systems are constructed using an electrical circuit that includes a charge sensitive preamplifier, a spectrometric amplifier (shaper), and a multichannel analyzer (MCA), as reported in references [1, 2, 3]. The MCA is a device that enables the registration and analysis of the energy spectra of diverse types of radiation and can determine their energy and intensity. It can be based on FPGA integrated circuits, which incorporate fast ADCs and digital signal processing algorithms, or on a microcontroller with a peak detector circuit. In the latter case, the signal is processed entirely by an analog electrical circuit, as described in [2, 4, 5, 6]. MCAs find application in various fields, such as nuclear medicine, accelerator experiments, and the detection of radioactive emissions for radiation monitoring over large areas in field conditions, among others, as documented in [7 – 10].

A multichannel analyzer based on the commercially available STM32F407 – Discovery microcontroller series is proposed. This microcontroller is characterized by fast multichannel ADCs with a sampling rate ranging from 2.5 to 5 million samples per second. Such a sampling rate is not sufficient for accurately measuring the signal peak when using digital signal processing methods, in contrast to digitizers where the ADC speed can reach 250 – 500 million samples per second, as noted in [11]. However, by employing an analog peak detector circuit, the signal peak can be preserved prior to being recorded by the ADC, thereby allowing any ADC and microcontroller to be utilized, as indicated in [9, 12].

The objective of the article was to develop a low-cost and portable system dedicated to alpha and gamma spectrometry. This system is designed to be applicable in experimental physics and fieldwork scenarios, particularly for detecting radioactive background levels during the monitoring of areas in the vicinity of nuclear facilities. To achieve this, suitable microchips were carefully chosen, and an analog signal processing circuit was devised. The simulation of the analog signal processing circuits was carried out with the utilization of NI MultiSim 14 software, as detailed in references [13 – 15].

2. Methodology

Figure 1 presents the overall operational framework of the alpha spectrometry system. The detector is furnished with a bias voltage via the Bias block. Signals originating from the surface barrier detector (manufactured by Ortec) that has a thickness of 300 microns are amplified by a charge-sensitive preamplifier (CSA, Ortec 142B). Subsequently, the signal is transformed into a semi-Gaussian shape by the spectrometric amplifier (SA). A single-channel analyzer (Discr) functions as a comparator. It compares the signal emerging from the amplifier block with a predetermined threshold and generates a TTL signal. The TTL signal from the single-channel analyzer prompts the microcontroller's ADC to commence recording the signal from the output of the peak detector (PD). Thereafter, the microcontroller gathers the data and transmits it to a PC. On the PC, the data is processed by a program developed in Python.

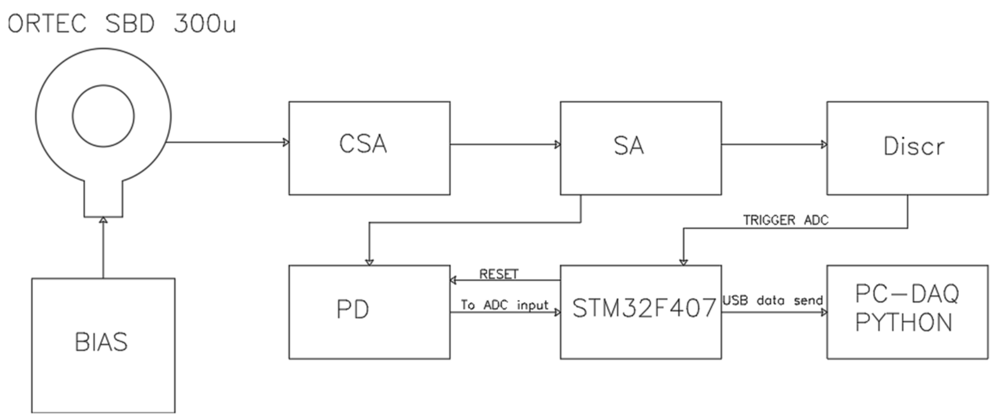

Figure 1 – Block Diagram of the MCA

The analog signal processing circuit is composed of several essential components. Firstly, the **SA**, which is the Spectrometric amplifier, is responsible for shaping the incoming signal to a more suitable form for further analysis. Secondly, the **Discr**, or discriminator, also known as the single-channel analyzer, functions by comparing the signal to a preset threshold. This comparison is crucial in determining certain characteristics of the signal. Lastly, the **PD**, or peak detector, plays a vital role in holding the peak value of the signal, which is then made available for subsequent processing. These components are all constructed using operational amplifiers.

The operational amplifiers (OAs) are the key determinants of the speed and resolution of the MCA. Specifically, they must possess specific characteristics. A high slew rate of at least 10 volts per microsecond is required to ensure rapid signal processing. Additionally, a low noise level at the nanovolt per hertz level is essential to maintain the integrity of the signal. Moreover, a wide bandwidth of no less than 20 MHz is necessary for handling a broad range of signal frequencies. Based on these requirements, the OPA354 and AD8616 operational amplifiers were selected as they meet these criteria.

For the discriminator (Discr), the TLV3201 and LM339N comparators were chosen. This selection is due to the fact that the pulse width of the signal from the SA output is 2 microseconds. In such a scenario, the speed of the comparator becomes a critical factor for the proper and efficient operation of the entire circuit. It ensures that the signal is accurately and promptly processed and analyzed within the required time frame.

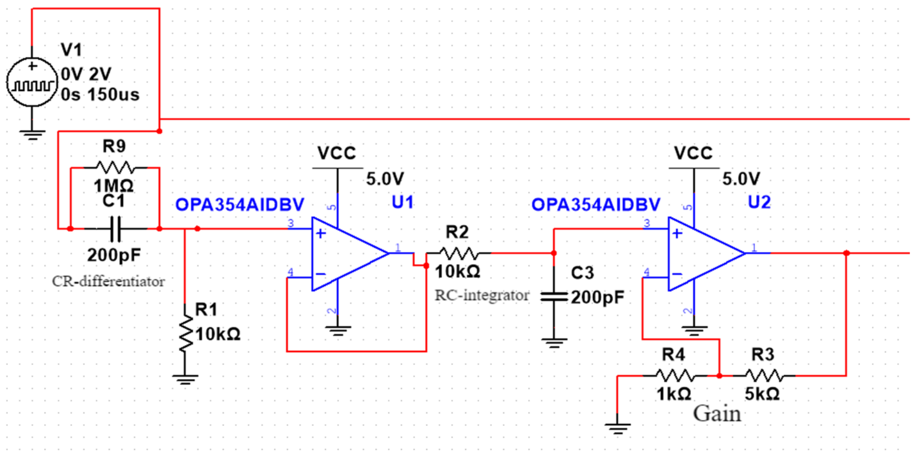

Figure 2 – Schematic diagram of the **SA** spectrometric amplifier

SA is designed using two operational amplifiers, OPA354AIDVDR. The circuit is a CR-RC chain of discriminator and integrator circuits. C1C3 – 200 pF and R1R2 – 10k, converts a long signal from the preamplifier 100–150 microseconds long into a Gaussian signal 10 microseconds long. By changing the values of the resistor and capacitor CR-RC, you can achieve a change in the signal width, as well as its height. In Figure 3, the signal from the preamplifier is shown in turquoise, and the signal from the SA output is shown by yellow line. In the first case, C1C3 – 200 pF and R1R2 – 10k; in the second, C1C3 – 400 pF and R1R2 – 10k.

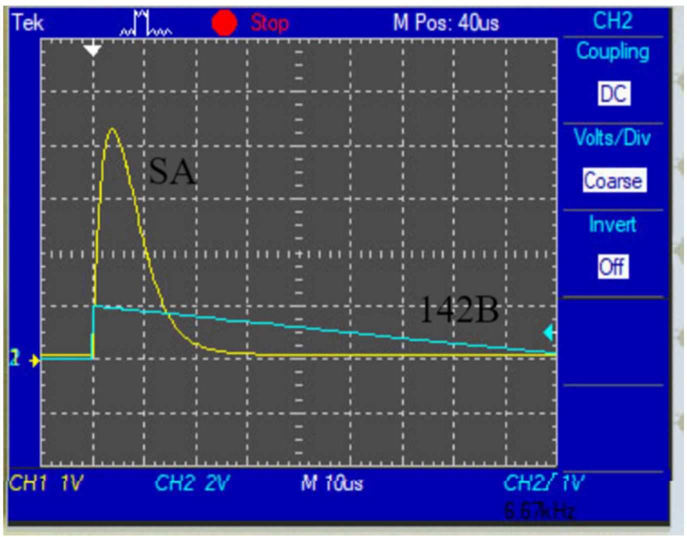

Figure 3 – Signal from preamplifier and **SA**

Figure 4 shows the **Discr** discriminator circuit and the output TTL signal of the comparator with a width equal to the signal from the **SA**. The signal from the comparator starts the operation of the ADC of the microcontroller and allows reading the number of events from the detector.

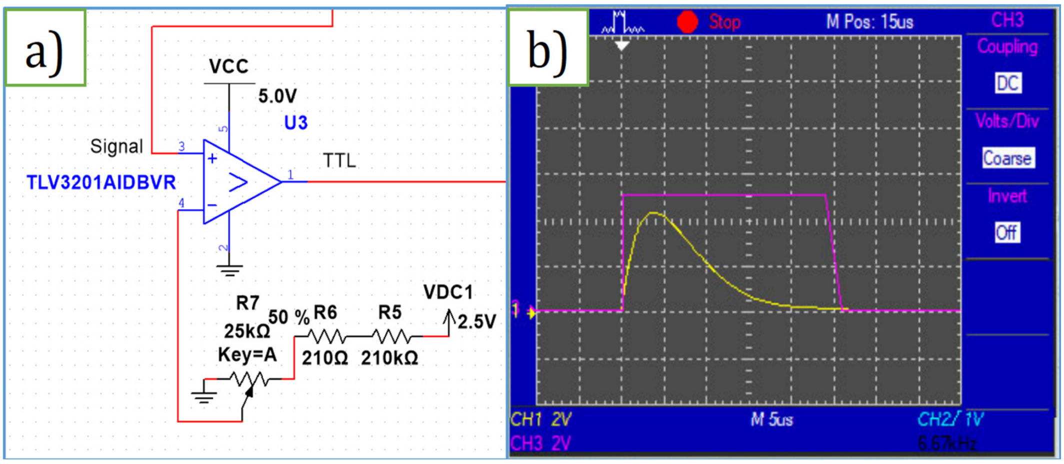

Figure 4 – a) **Discr** discriminator circuit and b) **Discr** output signal

Figure 5 presents the circuit diagram of the peak detector that is based on the operational amplifier AD8616. This particular circuit diagram of the peak detector is sourced from [16]. A basic circuit diagram of a peak detector typically comprises diodes and a capacitor. The signal, when passing through the diodes, charges the capacitor to the value of the signal peak. In the event that the capacitor is not grounded, the signal gets stored in the capacitor for a duration equal to the product of the capacitor capacitance and the resistor resistance. The ADG701 analog CMOS switch discharges the capacitor C5 subsequent to recording the signal from the ADC. In this scenario, the signal from the comparator arrives with a 10-microsecond delay and then discharges the capacitor. As a result, the peak detector is then primed and prepared to handle the next signal that emanates from the detector.

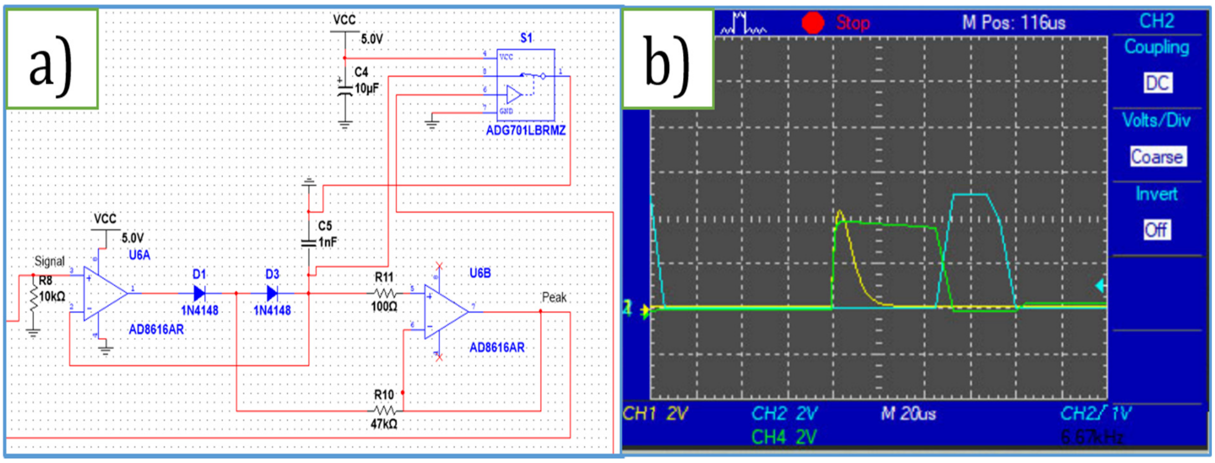

Figure 5 – a) Peak detector circuit and b) signals from the oscilloscope

3. Results and discussion

After modeling and simulating the electrical circuits in the NI MultiSim program, prototypes of **SA**, **Discr**, **PD** were created. The created circuits were tested in real conditions on an Ortec 300 micron thick surface barrier silicon detector and an Ortec 142B preamplifier [17-19]. In Figure 6a, you can see the telescope with the detector installed inside and the Ra^{226} alpha source [20-22].

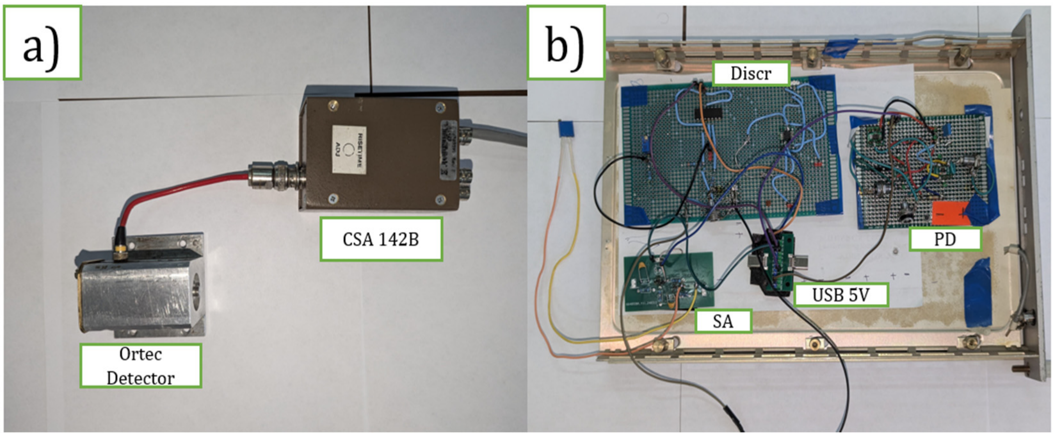

Figure 6 – a) Detector in the telescope connected to the preamplifier and b) prototype of analog frontend of MCA

Figure 6b shows the designed prototype of analog frontend consisting of SA, PD and Discr. PD and Discr were developed on double sided solder boards. The prototype of SA was designed in the EasyEda environment and manufactured as a two-layer board.

In Figure 7 you can see the signals from the preamplifier and the converted signal by the SA. The amplitude of the converted signal corresponds to the amplitude of the signal from the preamplifier linearly.

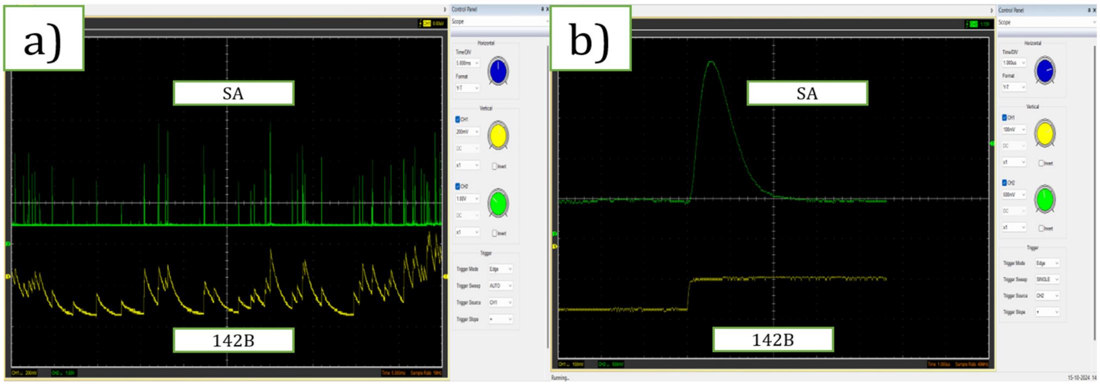

Figure 7 – a) series of signal from the preamplifier and **SA** b) scaled signals

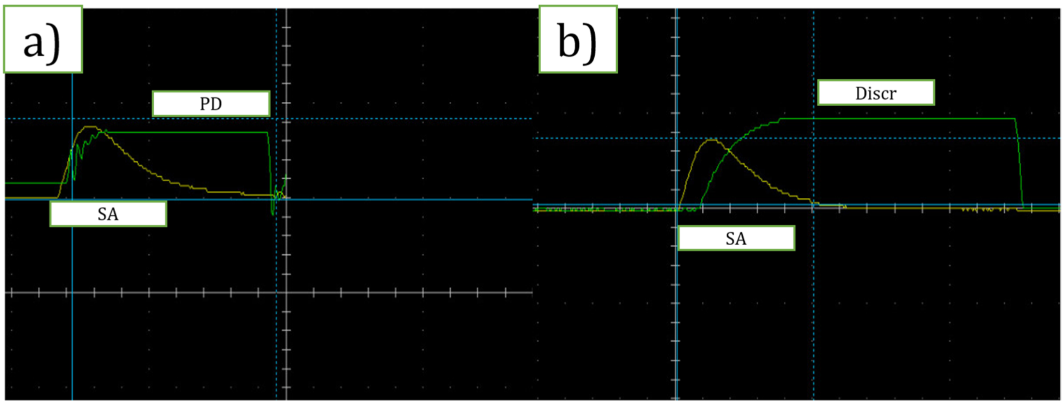

Figure 8 – a) Peak detector signal b) Discr signal

Figure 8 illustrates the signals originating from the peak detector (8a) and the discriminator (8b), which are employed to activate the microcontroller's ADC. The Discr prototype was implemented by utilizing the LM339N comparator, which exhibits a latency of approximately 1.3 microseconds.

The peak detector signal is fed to the input of the microcontroller's ADC, which is configured for 1024 channels and operates in ADC Direct Memory Access (ADC_DMA) mode [23]. This mode allows the ADC to start quickly and store values in the microcontroller's RAM. The ADC is triggered by an external signal from the discriminator. After signal from PD detected and stored microcontroller sends TTL signal to ADG701 switch and resets PD.

Data transfer occurs via USB at a speed of 12 Mbps. On the PC side, a Python-based PC-DAQ program was created for real-time data processing and storage. The program uses the Matplotlib library [24] for visualization and processes the data, saving it in CSV format.

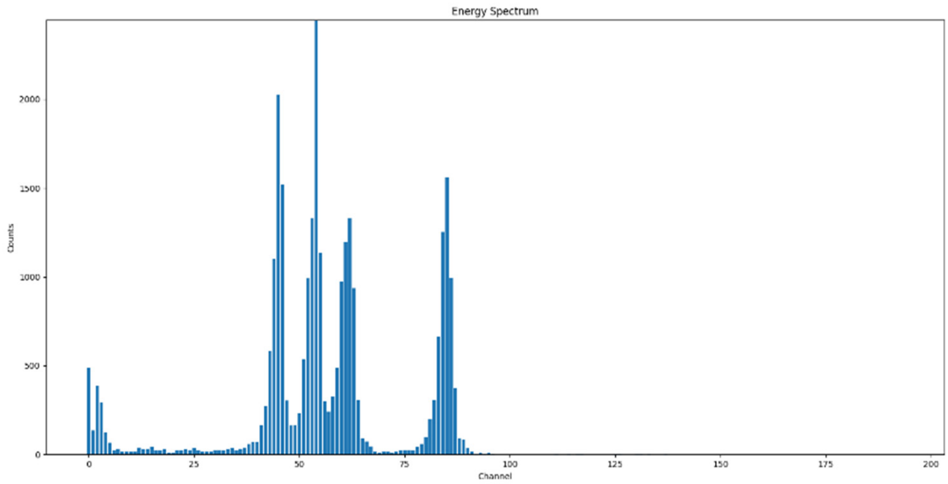

Figure 9 – Python DAQ Program

Figure 10 shows the spectrum from an alpha source [25]. The native resolution of the Ortec detector with a thickness of 300 microns is 15-20 KeV when measuring the energy of alpha particles in a vacuum. In this case, the measurement was performed in air. Despite this, it is possible to reliably identify 4 peaks of the Ra^{226} alpha source, which corresponds to an energy resolution of 200-250 KeV and is comparable to the energy resolution of NaI and CsI scintillation crystals [26].

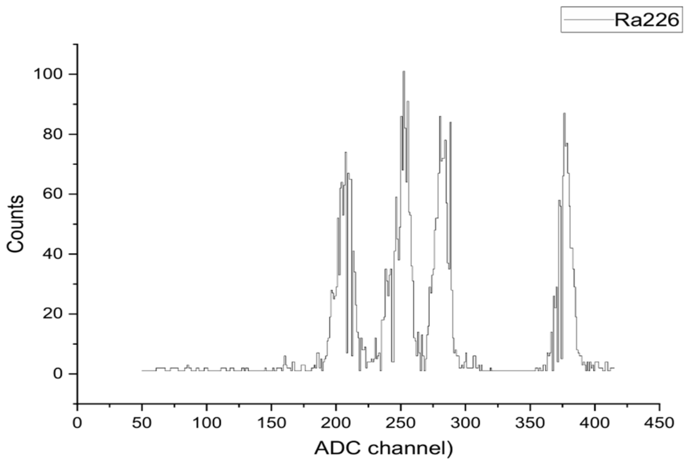

Figure 10 – Spectrum of the alpha source of radium 226 collected from the MCA

4. Conclusions

In this academic paper, a novel methodology for fabricating electronic units dedicated to nuclear spectroscopy, leveraging contemporary microcircuits, was put forward. This innovative approach is anticipated to curtail the size and cost of such units while concurrently retaining all essential characteristics. At the present developmental stage, electrical circuits for the SA spectrometric amplifier were successfully devised. Additionally, a multichannel analyzer, founded on the STM32F407 microcontroller in combination with the PD peak detector circuit, was meticulously designed. A program was authored in the Python programming language, endowing the system with the capacity to amass data in real-time and archive the data array in CSV format. The Ra226 alpha source was measured using a surface barrier detector, thereby validating the functionality and viability of the proposed data collection system.

Looking ahead, efforts will be directed towards constructing a system for gauging charged particles, predicated on these advancements and employing the EdE method. In this envisioned setup, a two- or three-detector system will be deployed to accurately ascertain the type of particle engendered as a byproduct of nuclear reactions during the operation of the U-150M accelerator.

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