Design and construction of gamma – gamma coincidence spectrometer using high sampling rate ADC and DPP technique

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Abstract: The gamma – gamma coincidence spectrometer, which uses analog signal is a complicated system. There are about 15 NIM electronic modules for pulse processing, 2 connectors for data transfer between NIM and computer, a PCI interface card, and corresponding acquisition software. Therefore, the analog gamma – gamma coincidence spectrometer is not portable, and its quality is much affected by physical conditions such as temperature and humidity. The development of high sampling rate ADC and digital pulse processing (DPP) technique makes possible to construct a digital gamma – gamma coincidence spectrometer, which is compact, reliable, and cheaper than the analog one. A digital gamma – gamma coincidence spectrometer, which hardware for pulse processing, data transfer and interface are replaced by software, has developed at Dalat Nuclear Research Institute.

Keywords: *DPP technique, digital gamma spectrometer.*

I. INTRODUCTION

Replacing analogue technology by digital technology is a global tendency, and nuclear instrumentation is not an exception. Digital technology provides various benefits and opportunities in nuclear spectrometry, which were impossible, or very complicated to perform using traditional analogue one. Thank to digital technology, performance and reliability of spectroscopies are improved, instruments have much smaller physical size, use less energy, thus more portable [1]. The core of digital technology in nuclear instruments is Digital pulse processing (DPP), which contains three components: digitizer, digital filter, and acquisition. In the past, digitizer is an important difficulty in building digital spectrometers due to the lack of high frequency sampling ADC. Currently, sample ADCs with frequency up to GHz gradually become popular, therefore, quality of a digital system mainly depends on digital filter component. For energy applications, the role of digital filter is noise reduction, pulse shaping, and ballistic deficit reduction. For timing applications, digital filter is able to determine the coincidence between pulses, which, in analogue systems, must be implemented by a series of electronic blocks including: Fast timing amplifier (TFA), discriminator, and coincidence or time-to-analog converter (TAC). A DPP can be based either on a FPGA or a computer software.

Gamma – gamma coincidence spectrometer is a complex system that simultaneously solves two factors: energy and timing. An analogue gamma – gamma coincidence spectrometer requires at least 15 electronics blocks, including amplifiers, TFAs, discriminators, delays, ADCs, and TAC or coincidence depend on certain configuration. Besides, signal synchronization and parameter selection are also time consuming and problematic, therefore it requires experienced researchers.

In this work, we've built a DPP based gamma – gamma coincidence spectrometer using High-speed A/D converter APX-500-414 and homemade software for control, data acquisition, and interface. This spectrometer can operate in two independent modes: MCA and coincidence. The software is written on C++ and has been continuously testing for more than two weeks without any suspension. Both pulses processing algorithms and testing results with ^{60}Co will be presented below.

II. Manufactures and algorithms

1. High-speed A/D converter APX-500-414

High-speed A/D converter model APX-500-414 is a product of Aval Data Company. This board has a two input channels sampling ADC of frequency up to 400 MHz (2.5 ns sampling time), a DDR2-RAM memory of 2 Gb and connect with computer via PCI express bus. The ADC resolution is 14 bit for input range from ±500 mV to ±4 V. The other detailed specifications can be found on Aval Data product catalogue [2]. Accompanying the board, a free EDK interface provided as a DLL file lets us to control the board without any inhibition.

2. Digital Pulse Processing algorithms

The diagram of our DPP algorithms is given in Figure 1 . From left to right, there is three blocks, called ADC block, Gaussian Pulse-Shaping Filter block and MCA and COINCIDENCE block in succession. The ADC blocks is used to set parameters for sampling ADC and get digitized data from pre-amplifier output. After that, the Gaussian Pulse-Shaping Filter block transforms the digital pulse into Gaussian shape by a series of digital filter in order to reduce noise. Finally, the MCA and COINCIDENCE block checks and rejects pile-up pulses, creating MCA spectrum or searching and acquiring coincidence events according to user selected mode.

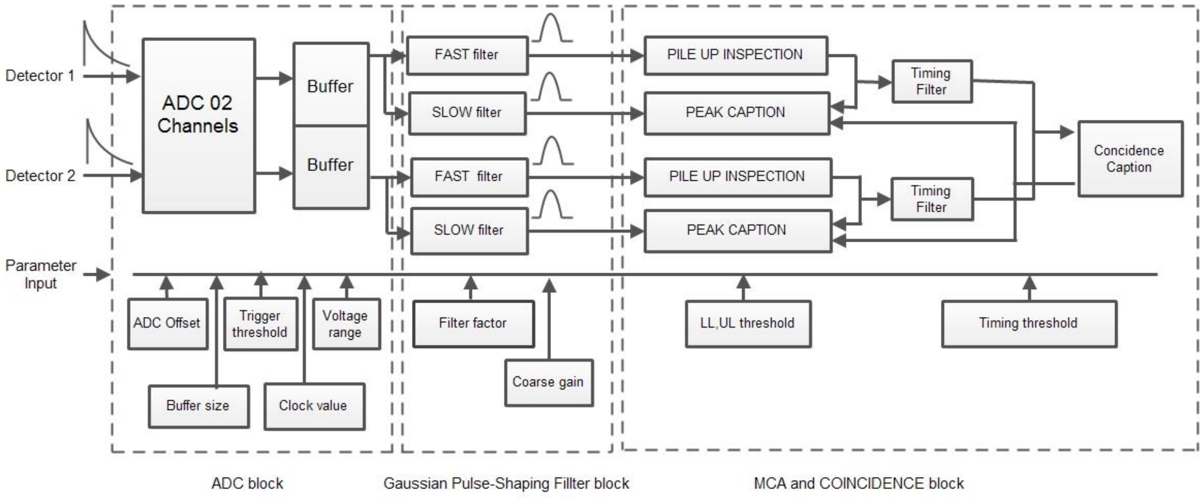


Figure 1. DPP algorithms diagram

ADC block

Analog signals from two semiconductor detectors are converted to discrete digital values by sampling ADC integrated in APX-500-414 board. Thereafter, converted data is saved to Pc's Buffers based on Direct Memory Access method and PCI Express bus. Input parameters consist of Offset ADC, Up and Low level trigger, Voltage range, Buffer size and Clock value.

Gaussian Pulse-Shaping Filter block

This block contains four parallel Gaussian filters with different shaping time. SLOW filters use long shaping time in order to well reduce noise, however the rise time will be long. Therefore, it’s appropriate for measure pulse height. FAST filters use short shaping time in order to keep pulse rise time short enough. This kind of pulse shape is suitable for detecting instant when a pulse starts. Digital pulse from each detector will be input to two independent filters, a SLOW filter and a FAST one. Output of FAST filter will be used to detect if there is a real signal, and if there is a coincidence. Output of SLOW filter will be used to determine amplitude.

The used Gaussian filters is formed by a series of one high-pass filter and two low-pass filters. It looks like the analogue Gaussian filter CR-RC-RC.

MCA and COINCIDENCE block

In MCA mode, this block detects pulses, measures their amplitude and acquires to a frequency histogram. For the purpose of improving energy resolution, an algorithms to detect and reject pileup pulse was applied. Output pulse from FAST filter has short pulse width, therefore, can be used to detect pile-up pulse. An illustration of pile-up pulse detection is given in Figure 2.

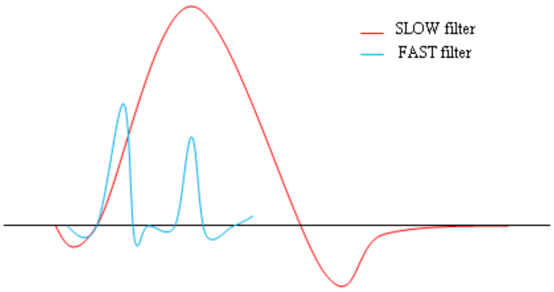


Figure 2. An illustration of pile-up pulses

In Figure 2, the red pulse is output from SLOW filter, and the blue one is output from FAST filter. As we can easily see, the red pulse has only one peak, while the blue one has two peaks. This case is detected as a pile-up pulse and will be rejected. The algorithms is very simple. First, from FAST filter output, we detect if there is a real signal by comparing FAST filter output with a threshold (pulse height higher than the threshold is considered as a peak). When a peak is detected, program will continue to scan in a time interval equal to shaping time of SLOW filter. If program find another peak, this pulse is considered as pile-up pulse, and will not be acquired.

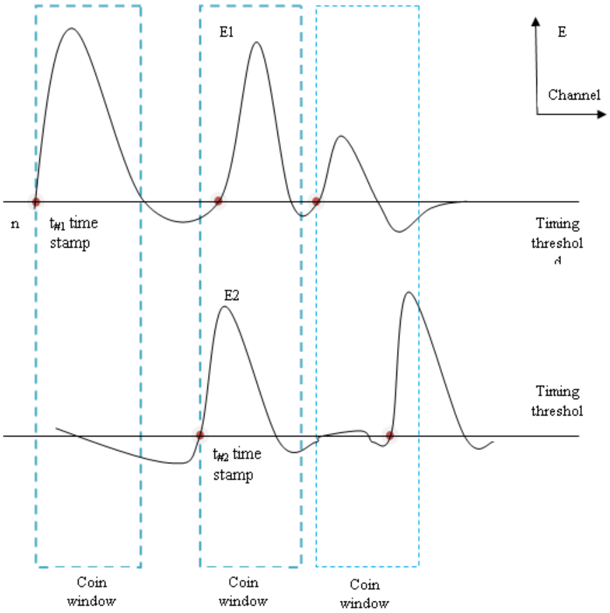


Figure 3. Coincident events detection

In coincidence mode, peak detection, pile-up detection, and pulse height measuring are performed by using the same algorithms as in MCA mode. Besides, it is necessary to add an algorithms to detect coincidence events. The selected method is using a time window, which value can be set by user. First, program searches peak on both channels (from detector 1 and detector 2). If it finds a peak on any channel, it will create a time window, then search peak on the other channel within time window. If a peak is found, program detects as a coincident events.

An instance of coincident events detection is shown in Figure 3. First, program searches peak on both channel, and it finds a peak on 1st channel ($t_{\#1}$ time stamp). A time window is then created, and program searches peak on 2nd channel. However, no peak is found. Therefore, program continues to search peaks on both channel. A peak is detected on 2nd channel ($t_{\#2}$ time stamp). Again, a time window is opened, then peak is searched on 1st channel. This time, a peak is found on 1st channel within time widow. Consequently, the event is considered as a coincident event.

III. Testing with ^{60}Co source

Our program was tested with a system of two semiconductor detectors, ORTEC type GMX35P4-76-A. APX-500-414 board was installed on a computer with processor Intel Core i7 and 8 Gb RAM memory. ^{60}Co gamma source, which has appropriate level scheme to check coincidence feature, was measured.

Input parameters were set as following: Offset ADC 1 = 0; Offset ADC 2 = -45, LL trigger = UL trigger = 0; Voltage range = +4000mV and 16k channel; Buffer Size = 65536 byte; Clock = 200MHz, $\tau_{FAST} = 1/4\ \tau_{SLOW}$; $\tau_{SLOW\text{-}CR} = \sum\tau_{SLOW\text{-}RC}$; Course Gain = 2.718; MCA Low threshold = 100; MCA Up threshold = 8192; Timing threshold = 1.

IV. Result and Discussion

Result

Digitized pulse from pre-amplifier is shown in Figure 4. The sampling time is 0.025 seconds. Thanks to sampling ADC of 400 MHz frequency, pulse shape is well conserved. Pulse shape after SLOW filter and FAST filter are presented in Figure 5.

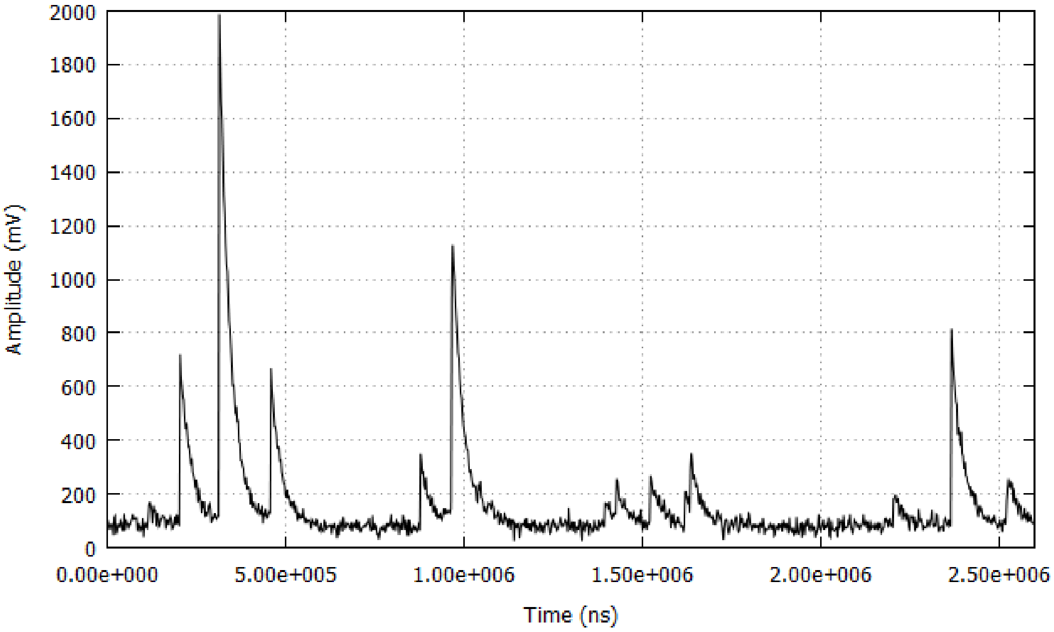


Figure 4. Digitized pulse from pre-amplifier

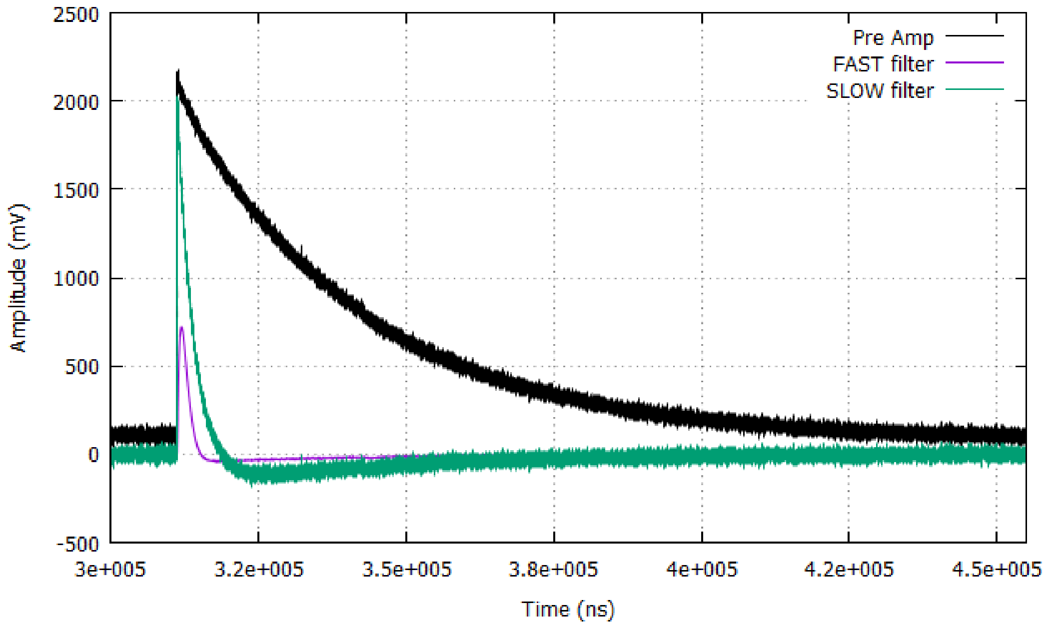


Figure 5. Pulse shape after SLOW filter (red) and FAST filter (blue)

All pile-up pulse, which an example is given in Figure 6, are rejected.

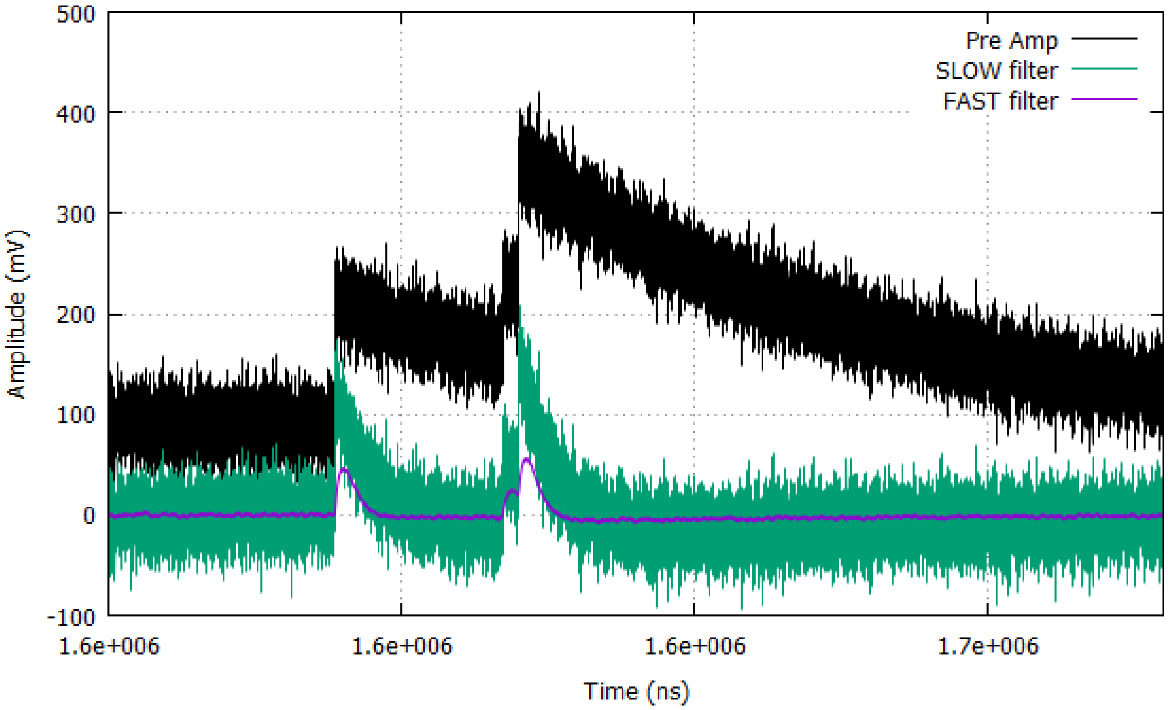


Figure 6. Pile-up pulse

MCA spectrum of ^{60}Co measure with HPGe detector is shown in Figure 7. The energy resolution is achieved 3.5 keV, which is approximately equal to our current analog systems.

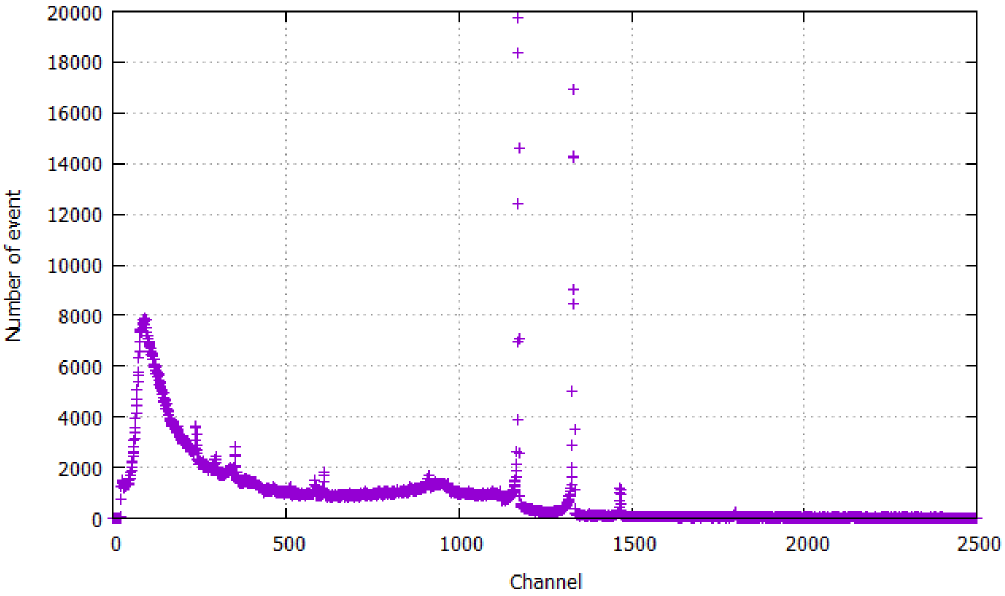


Figure 7. MCA spectrum of ^{60}Co

Timing spectrum, when measure ^{60}Co source in COINCIDENCE mode, is shown in Figure 8. The timing resolution is approximately 30 ns.

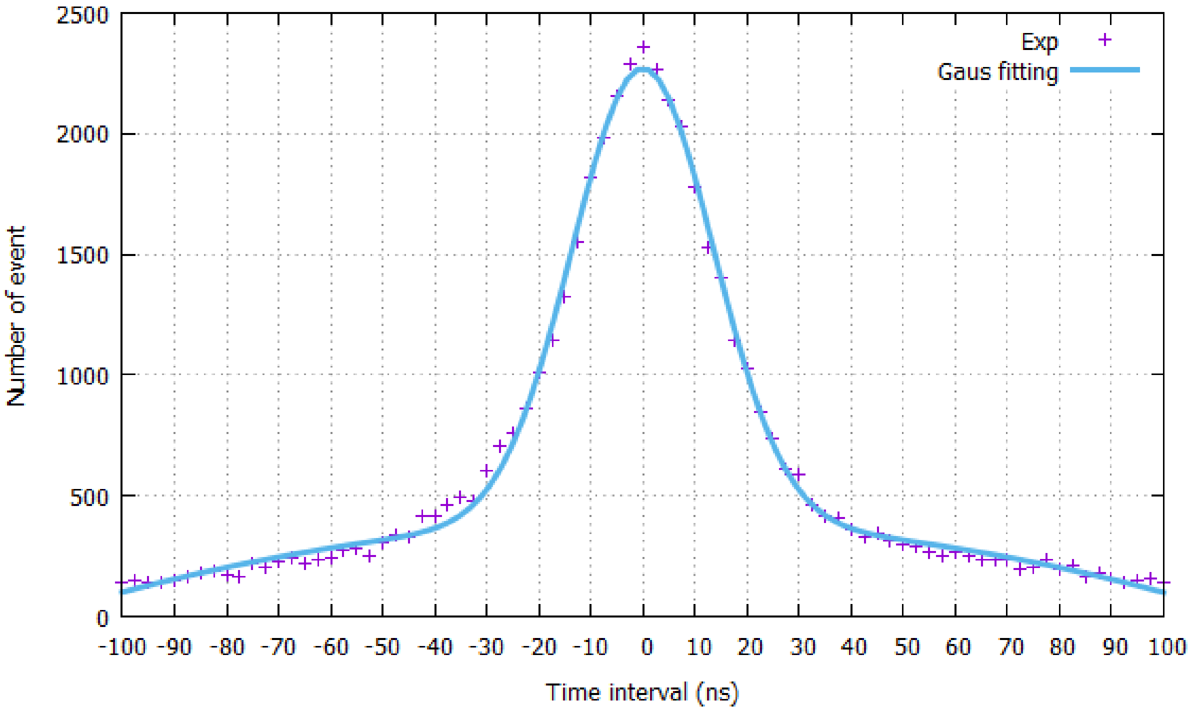


Figure 8. Timing spectrum measured with ^{60}Co source

Spectrum of ^{60}Co in COINCIDENCE mode is shown in Figure 9. Compton background is almost reduced.

Program's interface and parameter setting window are shown in Figure 10. We tested the reliable of program by using it non-stop for 15 days. Any suspension has been detected.

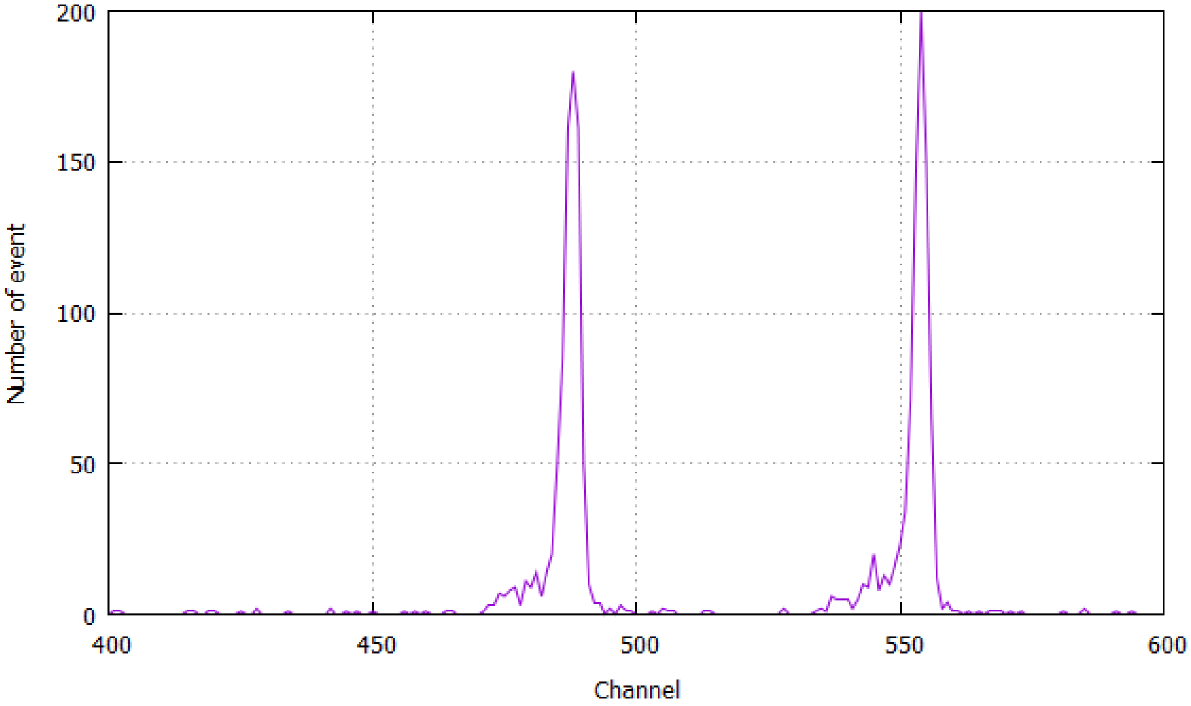
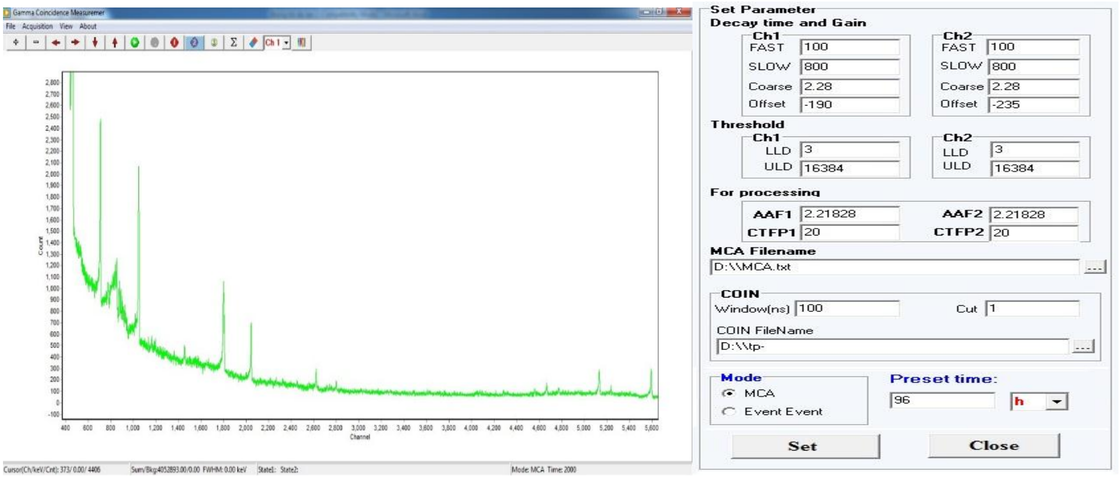


Figure 9. Coincidence spectrum of ^{60}Co



Cursor(Ch/keV/Cnt): 373/ 0.00/ 4406
Sum/Bkg:4052893.00/0.00 FWHM: 0.00 keV
State1: State2:
Mode: MCA Time: 2000

Set Parameter
Decay time and Gain
Ch1
FAST 100
SLOW 800
Coarse 2.28
Offset -190
Ch2
FAST 100
SLOW 800
Coarse 2.28
Offset -235
Threshold
Ch1
LLD 3
ULD 16384
Ch2
LLD 3
ULD 16384
For processing
AAF1 2.21828
CTFP1 20
AAF2 2.21828
CTFP2 20
MCA Filename
D:\\MCA.txt
COIN
Window(ns) 100
Cut 1
COIN FileName
D:\\tp-
Mode
● MCA
○ Event Event
Preset time:
96
h

Figure 10. Program’s interface and parameter setting window

Discussion

In the same counting condition, our new digital spectrometer has energy resolution nearly the same as analogue one (using 572A amplifiers, 7072 ADC). However, the low energy tail is a little bit higher than analogue one. Therefore, we need to improve our pulse height measure algorithms. The timing resolution of ~30 ns, is 3 times more than our current analog one, because sampling rate is only 1 sample per 2.5 ns. The quality of coincidence data is proved in Figure 9, where the Compton background is almost reduced.

Compare to analogue system, the digital system has almost the same quality but much more compact. The using is also simpler, all parameters can be set in software.

Conclusion

Although there is still few disadvantages that need to improve, our digital system is ready to replace the analogue one. This success lets us think about an expansion, in which, we will replace old and low quality analogue radiation detection devices by the digital one, and commercialize new devices according to the needs of the market.

References

[1] IAEA-TECDOC-1706, INSTRUMENTATION FOR DIGITAL, IAEA, 2010.

[2] [Online]. Available: https://www.avaldata.co.jp/english_08/products/analogue/apx500414/apx500414.html.

Thiết kế và chế tạo hệ phổ kế trùng phùng gamma – gamma sử dụng ADC lấy mẫu tần số cao và kỹ thuật DPP

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Tóm tắt: Hệ phổ kế trùng phùng gamma-gamma xử lý tín hiệu tương tự là một hệ thống phức tạp, trong đó 15 mô-đun điện tử chuẩn NIM được sử dụng để xử lý xung, 2 hộp kết nối để chuyển dữ liệu từ NIM tới máy tính, một các giao diện PCI và phần mềm ghi nhận số liệu tương ứng. Do đó, hệ phổ kế trùng phùng gamma-gamma không có tính di động, chất lượng bị ảnh hưởng mạnh bởi các điều kiện vật lý như nhiệt độ và độ ẩm. Sự phát triển của các bộ biến đổi tương tự-số tần số cao (fast ADC) và kỹ thuật xử lý xung số (DPP) cho phép chế tạo hệ phổ kế trùng phùng gamma-gamma nhỏ gọn hơn, tin cậy hơn, và rẻ hơn so với hệ thống tương tự tương đương. Một hệ phổ kế trùng phùng gamma – gamma số, trong đó phần cứng dùng trong xử lý xung, truyền dữ liệu và giao diện đã được thay thế bằng phần mềm, đã được phát triển tại Viện Nghiên cứu hạt nhân.

Từ khóa: *kỹ thuật DPP, phổ kế gamma số.*