A novel acquisition method for nuclear spectra based on pulse area analysis *

LI Dong-Cang(李东仓)[1;1)] REN Zhong-Guo(任忠国)[1,2] YANG Lei(杨磊)[1] QI Zhong(祁中)[1] MENG Xiang-Ting(孟祥厅)[1] HU Bi-Tao(胡碧涛)[1]

[1] School of Nuclear Science and Technology, Lanzhou University, Lanzhou 730000, China
[2] China Academy of Engineering Physics, Mianyang 621907, China

Abstract: A novel simple method based on pulse area analysis (PAA) is presented for acquisition of nuclear spectra by a digitizer. The PAA method can be used as a substitute for the traditional method of pulse height analysis (PHA). In the PAA method a commercial digitizer was employed to sample and sum in the pulse, and the area of the pulse is proportional to the energy of the detected radiation. The results of simulation and experiment indicate the great advantages of the PAA method, especially as the count rate is high and the shaping time constant is small. When the shaping time constant is 0.5 μs, the energy resolution of PAA is about 66% better than that of PHA.

Key words: pulse height analysis, pulse area analysis, digitizer, nuclear spectrum

PACS: 29.85.Ca **DOI:** 10.1088/1674-1137/39/4/046201

1 Introduction

Pulse height analysis (PHA) is a traditional method of nuclear spectrum acquisition, in which a pulse from a detector is transformed, amplified, shaped and filtered by the preamplifier and the pulse amplifier. The suitable pulses enter the acquisition system and the spectrum of pulse height distribution can be obtained in this way. The general ADC (analog to digital converter) cannot directly be used in PHA because of its poor differential nonlinearity (DNL). To decrease the disadvantage the DNL of ADC should be reduced by some special way, such as the slide scales [1].

Recently, great progress has been made in the digital processing technique. Faster digital signal processors, microprocessors and ADCs are developed and also applied in nuclear instruments [2, 3]. Sampling and recording the pulse waveform is becoming much easier and affordable. The advantages of using digital techniques in nuclear spectrum acquisition have widely been proved. These digitization techniques provide more possibilities than traditional analog techniques, such as enhancing signal-noise ratio, pile-up pulse correction and baseline correction. To get the nuclear spectrum from these digital waveform data, many methods to improve the nuclear spectrum have been developed [4, 5]. For example，one of them is to pick up the maximum value close to the peak position by simple comparison or polynomial fitting [6]. The main idea of these methods is to get the particle energy by the pulse height analysis and the accuracy of these methods is subject to the noise. But all these methods need much more computation than traditional PHA.

In the traditional analog signal processing, pulse integration was used, such as the charge preamplifier, which is just the charge integration circuits [7], and the shaping circuit of semi-Gauss which is also the multiple integrals net. By these methods, high frequency noise can be eliminated or reduced effectively. In the present paper, a method of pulse area analysis (PAA) after the amplifier based on digital pulse waveform is studied that is used, by our knowledge, for the first time.

In the method, to get the area of the pulse after amplifier digitized by high speed ADC, which is proportional to its amplitude, all the samples of each pulse are summed up. The main advantages of PAA are that it efficiently decreases the effect of the high frequency noise by averaging, thus can be used with a high accuracy at a higher counting rate.

Section 2 describes the principle and theory of the PAA method, Section 3 describes the experiment realization and results of nuclear spectrum acquisition based on the digitizer and the traditional multi channel analyzer (MCA). The conclusion is in the final Section.

2 Method and simulation of PAA

The output signal of the pulse amplifier is usually

Received 30 May 2014
* Supported by National Natural Science Foundation of China (11375077, 11027508)
1) E-mail: pelab@lzu.edu.cn

shaped to the quasi-Gauss waveform whose maximum amplitude represents the energy of the particle into the detector [8]. When the pulse shaper is CR-(RC)^2, the output waveform of the amplifier, shown in Fig. 1, can be expressed as

$$v_0(t)=At^2\mathrm{e}^{-t/t}, t\geqslant 0, \tag{1}$$

where A is the constant about amplitude and waveform, τ is the time constant. Its peak value (PH) is proportional to the energy of the detected radiation and can be given as

$$PH=V_{\mathrm{om}}=\frac{4A\tau^2}{e^2}, t_{\mathrm{m}}=2\tau, \tag{2}$$

where V_{om} is the amplitude of the pulse, and t_{m} represents the time reaching the highest point. Taking into account the noise, the real PH is given by (3).

$$PH=V_{\mathrm{om}}+v_{\mathrm{n}}(2\tau). \tag{3}$$

The PHA method is to obtain PH by ADC with the pulse peak holder. Fig. 2 is the reconstruction waveform sampling by the digitizer (U1066A-DC438, Agilent). When the details section of the sampling waveform are focused (the small figure in Fig. 2), it is found that the relative fluctuation of data, which comes from the high frequency noise, at the top of the pulse is closed to 1%. It severely restricts the resolution of PHA.

The pulse area (PA) is obtained by full integral to waveform as shown by Eq. (4).

$$PA=\int_0^\infty v_0(t)\mathrm{d}t=2A\tau^3. \tag{4}$$

It is obvious that PA is proportional to the PH and the energy of the detected radiation. If the noise is taken into account, PA can be expressed as Eq. (5).

$$PA=\int_0^\infty v_0(t)\mathrm{d}t+\int_0^\infty v_{\mathrm{n}}(t)\mathrm{d}t, \tag{5}$$

where $v_{\mathrm{n}}(t)$ is noise. After digitizing by ADC, Formula (5) is converted to Eq. (6).

$$PA=\sum_{i=0}^{m}v_0(i)+\sum_{i=0}^{m}v_{\mathrm{n}}(i), \tag{6}$$

where m is the sampling points of the waveform and PA is the addition of all the samples of the pulse. When m is

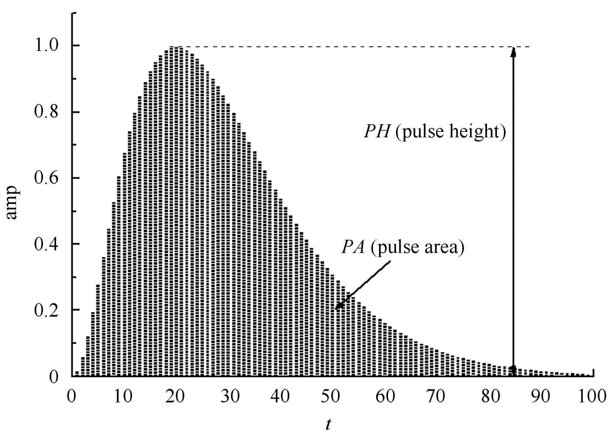

Fig. 1. The semi-Gauss pulse waveform.

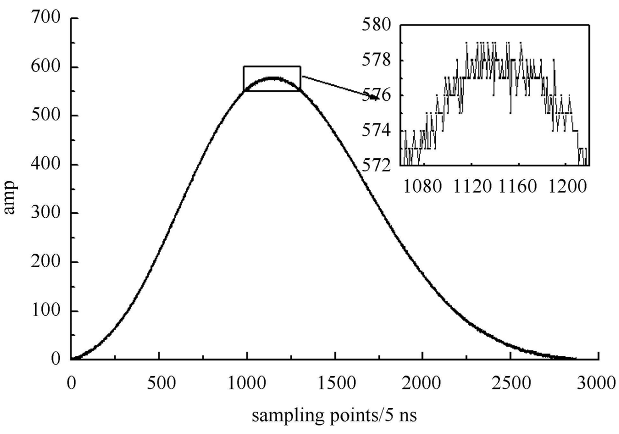

Fig. 2. The pulse waveform sampled by the digitizer (U1066A-DC438, Agilent).

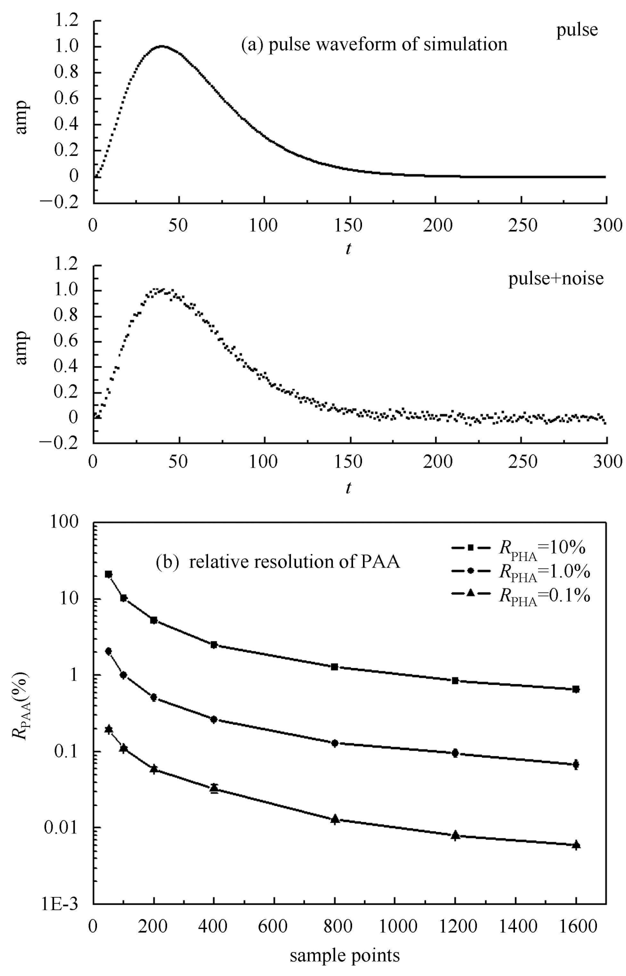

Fig. 3. Simulation results of PAA.

much larger than one, we have

$$\sum_{i=0}^{m} v_n(i) \to 0, \tag{7}$$

and then

$$PA \approx \sum_{i=0}^{m} v_0(i). \tag{8}$$

By this simple sum, the noise of the fluctuation is dropped and more precise results can be obtained.

Based on the above reasoning, the process of simulation is implemented by MatLab 7.0. The quasi-Gauss pulse without noise (pulse) and appending the noise (pulse+noise) are shown in Fig. 3(a). To get more accurate results, 20000 pulses are generated for each process. The statistical distribution of PAA was obtained and fitted on different relative resolutions of PHA and different sampling numbers. The results of the simulation are shown in Fig. 3(b). There are three relative resolutions of pulse height that were set R_{PHA}=10%, 1% and 0.1%. When sampling points are more than 1000 for each pulse, the relative resolution of PAA improves upon 1% from 10%, 0.1% from 1% and 0.01% from 0.1%. The noise is compressed and the resolution is improved for the signal with high frequency noise. The simulation shows that the resolution will be improved efficiently by this simple way.

3 Realization and experimental results

For verification of PAA, the digital acquisition system is built composed of a digitizer and a PC, with which the user can set the DPP (digital pulse process) parameters, choose the working mode and display the results by a VC program developed by our group (Control and Display software). In contrast, traditional PHA is also tested with the same conditions.

The detector is high pure Germanium of ORTEC. To digitize the output pulses from the amplifier, a commercial digitizer (U1066A-DC438, Agilent) [9], with two high speed ADCs (12 bits and 200 MS/s)and each channel with a 4 M samples buffer memory, is employed. The data stream from each ADC is written in buffer memories and transported via NI PXI-8360 to PC. The MCA8000 (Amptek Inc.) based on PHA is employed too. The digital pulse processing and spectrum acquiring is carried out by the host computer.

In order to test the characteristics and feasibility of PAA, three isotope sources of ^{133}Ba, ^{137}Cs and ^{60}Co were used. Energy range of γ ray is from 10 keV to 10^3 keV. Fig. 4 and Fig. 5 are the obtained spectrum of these isotopes with MCA 8000 and digitizer separately.

Since the ADC of the digitizer is only 12 bits, the spectrum of PHA has only 4096 channels. Nevertheless, as shown in Fig. 6, the channel of the spectrum based on PAA can be extended up to 32768 or higher by changing weighted coefficients. This method allows us to acquire

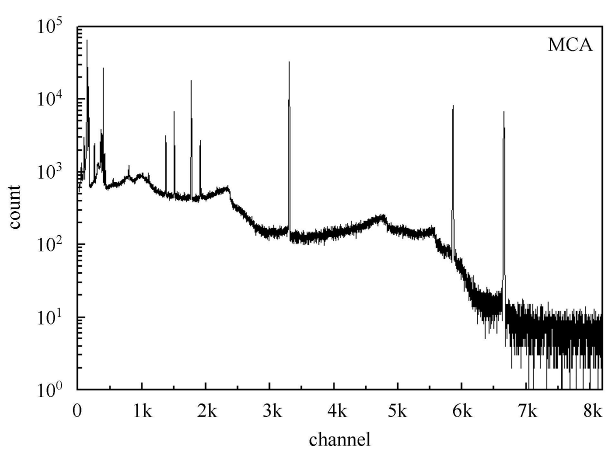

Fig. 4. The spectrum of MCA8000.

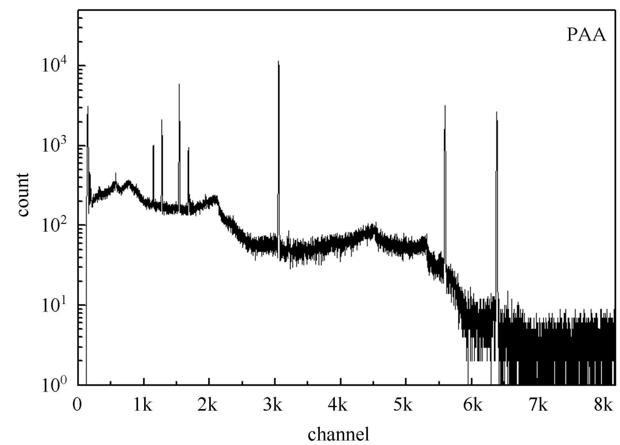

Fig. 5. The digitizer spectrum.

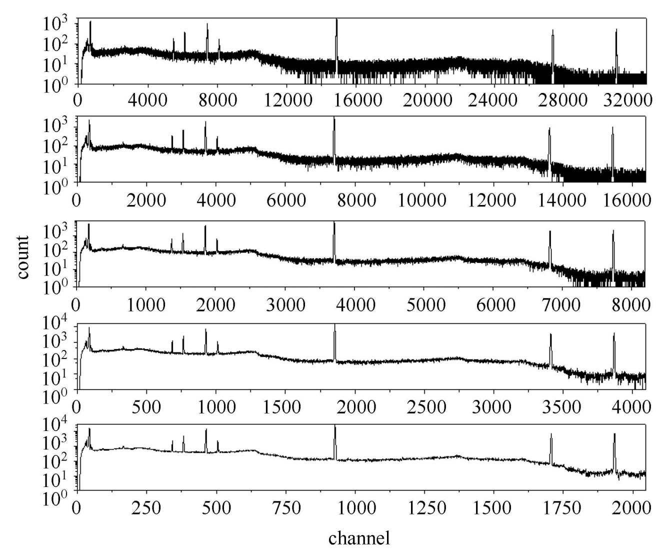

Fig. 6. The spectrum of PAA with different maximum channels.

Table 1. Energy resolution of a digitizer spectrometer (DIG-PAA) and a classical spectrometer (MCA-PHA) in different time constant (T.C.) of shaping.

energy/keV	0.5 μs $FWHM_E$/keV		1.0 μs $FWHM_E$/keV		2.0 μs $FWHM_E$/keV	
	MCA-PHA	DIG-PAA	MCA-PHA	DIG-PAA	MCA-PHA	DIG-PAA
80.999	1.944	1.559	1.351	1.132	0.979	0.980
356.014	3.197	1.900	1.805	1.603	1.311	1.550
661.661	5.014	2.602	2.247	1.784	1.600	1.651
1173.24	8.340	4.927	3.162	2.149	2.067	2.035
1332.51	9.168	5.861	3.498	2.216	2.249	2.160

Table 2. Relative resolutions of PHA and PAA for ^{133}Ba in different T.C. of shaping.

T.C.	0.5 μs		1.0 μs		2.0 μs	
energy/	MCA-PHA	DIG-PAA	MCA-PHA	DIG-PAA	MCA-PHA	DIG-PAA
keV	η_1(%)	η_2(%)	η_1(%)	η_2(%)	η_1(%)	η_2(%)
276.404	0.977	0.600	0.565	0.471	0.412	0.435
302.858	0.923	0.559	0.531	0.423	0.391	0.389
356.014	0.867	0.529	0.466	0.372	0.353	0.334
383.859	0.831	0.477	0.424	0.351	0.318	0.301
$\bar{\eta}$	0.900%	0.541%	0.497%	0.404%	0.369%	0.365%

high channel number spectrum using a low bits ADC which is cheaper and faster than a high bits one.

With the shaping time constant changing from 0.5 μs to 2 μs and other conditions unchanged, we acquired the spectra by both a digitizer and MCA8000 and calculated FWHMs of 5 chosen typical peaks. The results are shown in Table 1. When the time constant is 0.5 μs and 1.0 μs, the resolution of PAA is better than that of PHA. As the time constant is 2.0 μs, the resolution of PAA and PHA does not show significant differences. As we all know, the time constant is a compromise between high count rate and high resolution. Through the simple PAA, the better resolution will be achieved with the small time constant and this method is applicable to high count rate.

For our further study of the resolutions obtained with PAA and PHA, we chose ^{133}Ba as γ source, since it has four characteristic γ rays with close energy as shown in Table 2. It can be seen that the FWHMs and relative resolutions are much better for PAA than for PHA at the smaller shaping time constant. By increasing the shaping time constant, the resolution of PHA becomes close to that of PAA. The mean relative resolutions were also calculated and shown in Table 2. It is very clear that when T.C. is 0.5 μs, the resolution of PAA is about 66% better than that of PHA, but when T.C. is 2.0 μs, both resolutions do not have a significant difference.

4 Conclusions

A new simple method of acquiring nuclear spectra based on PAA proposed in this paper was proved, tested and evaluated with the HPGe detector. It turns out that the method can effectively reduce the effect of the noise to improve the energy resolution. The obtained results show that when the shaping time constant is 0.5 μs, the energy resolution of PAA can be 66% better than that of PHA. For a high count rate, the proposed method is a promising way to improve the energy resolution.

References

1 Jordanov V T, Knoll G F. IEEE Transactions on Nuclear Science, 1995, **42**(4): 683–687

2 Simoes J B P S, Simoes P C P S, Correia C M B A. IEEE Transactions on Nuclear Science, 1995, **42**(4): 700–704

3 DinhSyHien, Toshihiko Senzaki. Nuclear Instruments and Methods in Physics Research A, 2001, **457**: 356–360

4 Kihm T, Bobrakov V F, Klapdor-Kleingrothaus H V. Nuclear Instruments and Methods in Physics Research A, 2003, **498**: 334–339

5 Byun S H, Chin K, Prestwich W V et al. Nuclear Instruments and Methods in Physics Research B, 2007, **263**: 116–118

6 Paulo C P S. Simoes, Jose C. Martins, Carlos M B A. Correia. IEEE Transactions on Nuclear Science, 1996, **43**(3): 1804–1809

7 Connelly J A, Pierce J F. Nuclear Instruments and Methods, 1968, **64**(1): 7–12

8 Sansen W, Chang Z Y. IEEE Trans. Circuits Syst., 1990, **37**(11): 1375–1382

9 Agilent U1066A, Acqiris High-Speed cPCI Digitizers. Printed in USA, October 31, 2008