Digital coincidence acquisition applied to portable β liquid scintillation counting device

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Abstract A digital coincidence acquisition system applied to a portable liquid scintillation counting device is developed. The system which simplifies the device design consists of a digitizer card of Agilent U1066A DC438, a discriminator and a host computer. The anode analog pulses from two photomultiplier tubes are captured by the system, which adopts the sequence acquisition storage mode. By choosing proper threshold for each channel, coincidence time window of ±30 ns, and comparing the pulse amplitudes from two channels, the portable scintillation counting device can be used to detect β particles. For the unquenched standard ^{3}H sample, the results show that the detection efficiency is (58.5±0.1)% and the background is (86.7±0.7) cpm. Meanwhile, ^{3}H β spectrum is obtained.

Key words Digitizer, Liquid scintillation, Coincidence

1 Introduction

Liquid scintillation counting is widely used to measure the radioactivity of the radioisotopes. A typical conventional liquid scintillation counting schematic diagram is shown in Fig.1. The anode analog pulses from two photomultiplier tubes (PMTs) are amplified by preamplifiers and fed into coincidence gate which is used as a control of the linear gate. At the same time, the anode pulses from PMTs are summed as one pulse and sent into the spectrum analyzer through the amplifier and the linear gate. By means of appropriate resolving time discrimination circuits, the high detection efficiency is maintained and the tube noise is reduced for cocktails with short lifetimes. To improve the performance, in the conventional circuits, lots of parameters such as pulse-shape discrimination, thresholds and resolving time window are necessary and adjustable for different radioisotopes, which leads to increasingly complex electronics to generate the counting pulses.

As the digital pulse processing technology's developing, it is playing an increasingly important role in many research fields[1,2]. On-line digital counting platform[3] and FPGA (Field Programmable Gate Array) acquisition system for TDCR (Triple to Double Coincidence Ratio) counting[4] were developed in the past few years. The digitizer based on FPGA as a general A/D transient recorder has several hundred million sampling rate and the resolution up to 12-bit that means the input pulse dynamic range is up to 1000 and more. By using a digitizer, the acquisition system enables record pulse-shape information along with time-stamp, which not only simplifies the data acquisition procedure but also improves the further data analysis. For liquid scintillation counting device, the coincidence events can easily be acquired through time-stamps of recorded pulses. Although the liquid scintillation counting device is widely used and studied, most of them are massive and have large size. In this paper, a portable liquid scintillation counting device is developed, and, a digital coincidence acquisition system is adopted for it. The developed detection system is tested by detecting β particles. The β energy spectrum and coincidence are obtained. To the best of our knowledge, previous such kind of detection system could only provide the β counting rather than the energy spectrum.

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2 Experimental section

Though conventional liquid scintillation counting devices have excellent performance for detecting low energy β particles, they all are so heavy that they are more suitable to be used in laboratory rather than in the field. That is why the portable liquid scintillation counting device is developed. To improve the device's efficiency and reduce the background, several kilograms Pb as shielding materials, two Hamamatsu CR135 PMTs and positive high voltage are deployed. The negative analog output pulses from each anode of two PMTs are amplified by preamplifiers, which are developed by using AD8065 FastFET amp as the two-stage amplification unit.

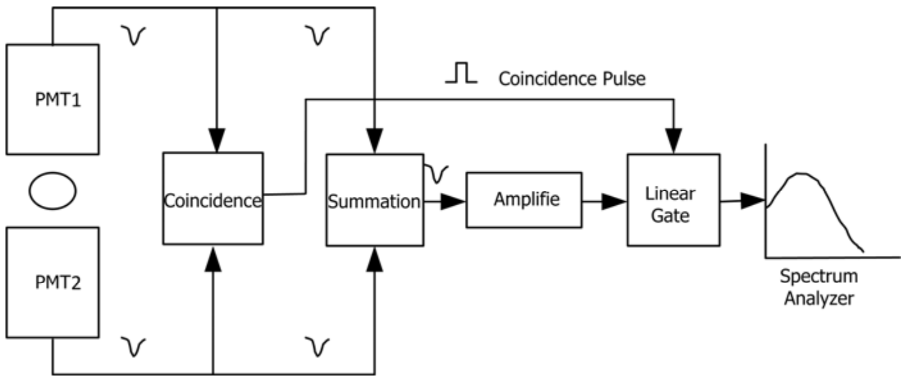

Fig.1 Block diagram of conventional liquid scintillation.

The output pulses from both preamplifiers are acquired by the digitizing coincidence acquisition system, instead of dedicated analogue electronic modules of energy spectrum, coincidence counting, and summation circuits. The system consists of one digitizer card of Agilent U1066A DC438, a developed discriminator and a host computer. DC438 has two input channels with 4 M Samples memory/channel, one external trigger channel. And it has a 12 bits, ±5 V of the max full scale and sampling rate up to 200 M Samples/s digitizer that means the vertical resolution is 2.4414 mV and time stamping with 5-ns resolution. All the parameters of DC438 can be set by host computer[5]. To eliminate the unnecessary noise and un-coincidence, the external trigger from the discriminator is used. The discriminator is designed to discriminate pulses through cutting-edge trigger and its output standard TTL logic pulses are the triggers of the acquisition.

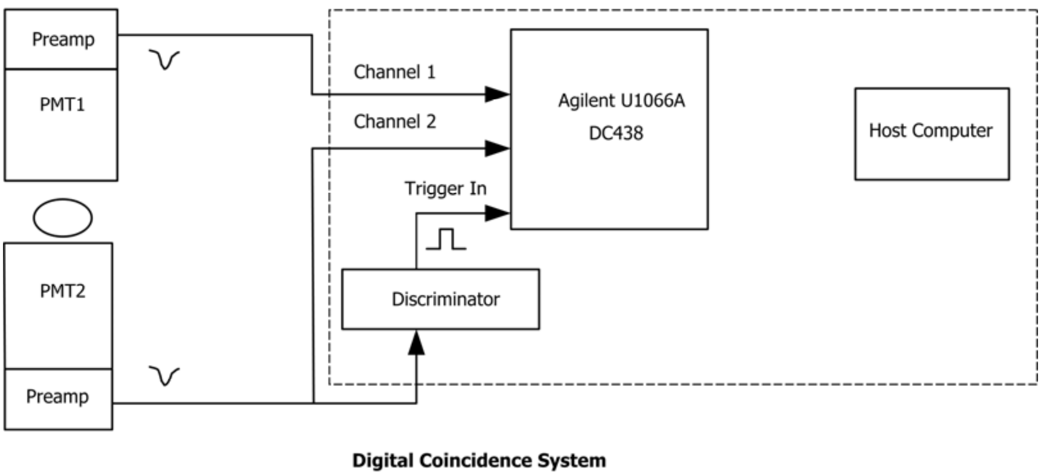

Fig.2 Block diagram of portable liquid scintillation counter device.

In the digital coincidence system, output pulses from PMT1 are sent to input channel 1 of DC438, and output pulses from PMT2 are split into two: one is to the input channel 2 of DC438, and the other to the discriminator. Its threshold is set to –40 mV. Its block diagram is shown in Fig.2.

The acquisition and analysis software has been developed using VC++ 2008 and ROOT release 5.32. In order to maximize the use of the 4 M Samples memory/channel, the sequence acquisition storage mode is adopted. In this mode, the acquisition is triggered only by the TTL logic pulse from the discriminator, and then, 410 sample points from channel 1 and channel 2 fill a segment of the acquisition with the rate of 200 M Samples/s (that means 2.1 μs acquisition time per segment). Once 8000 segments filled, the data were transferred to the host computer through high speed Direct Memory Access (DMA) communication ways for analysis and storage. Through cycles' acquisition, the expected accuracy can be reached. The data files are stored using a binary file format to optimize the space requirement of the measurement.

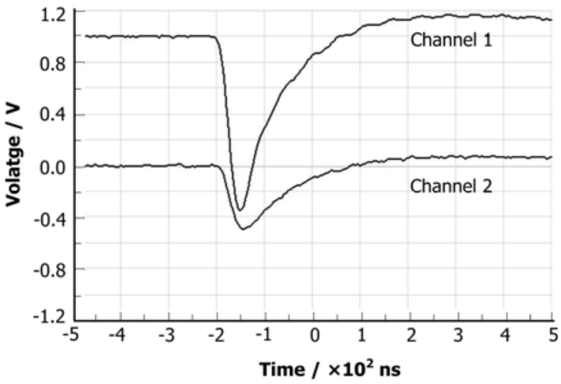

Fig.3 Channel 1 and channel 2 output pulses of the preamplifiers, recorded by digitizer DC438, (to discriminate two channel pulse, there's one volt shift for channel 1).

The trigger happens after channel 2 pulse reaches the digitizer because of the discriminator's delay. And there's also a time delay between two coincidence pulses of two channels. If the pulse of channel 1 is earlier than that of the channel 2, it wouldn't be recorded completely. To avoid that, the per-trigger delay is deployed and set to 500 ns to make the acquisition of two analog input channels begin 500 ns earlier than the trigger.

If both channels have pulses, the pulse amplitudes and time-stamps of lead edge timing are obtained. If both pulses are in coincidence time window, there will be an output count, and their amplitudes and time-stamps will be recorded for further analysis. The amplitudes can be simply summed up to present the energy of a detected β particle. For conventional liquid scintillation counting devices, the peak holding circuits are needed to add up the two channel pulse amplitudes, which increases the complexity of the system.

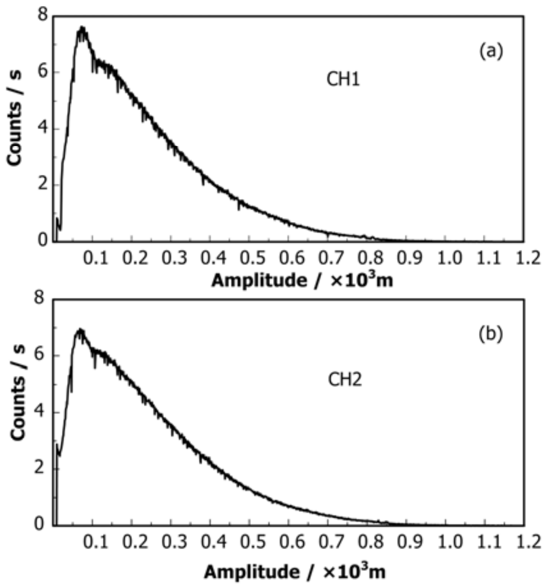

Fig.4 Energy spectrum of channel 1 (CH1) (a) and energy spectrum of channel 2 (CH2) (b).

In sequence acquisition storage mode, there's a time interval called "dead time" in which the signals between the two segments of a sequence acquisition can't be acquired and stored. DC438 can time stamping time interval between segments. A test has been performed through period pulses of 100 MHz to get the dead time, and it shows that the dead time is 1.12 μs between segments.

3 Analysis and results

The unquenched standard ^3H sample with activity 2.043×10^5 dpm is used to test the system. The pulse shape is studied firstly and the obtained results from the preamplifiers are shown in Fig.3. It is clearly shown that the rise time is about 50 ns and the decay time is less than 150 ns, which means 410 sample points acquisition per trigger and the 500 ns pre-trigger delay are enough.

During the offline analysis, the time stamps of the pulses from channel 1 and channel 2 are checked and compared. If they are in 100 ns coincidence time window, they will be restored. 100 ns coincidence time window is roughly chosen to filter the data. The energy spectra of each channel are shown in Fig.4. For better signal-to-background ratio, the thresholds should be set at the left valleys of CH1 and CH2.

The time delay of lead edge timing between coincidence pulses from channel 1 and channel 2 is shown in Fig.5. Positive time delay represents that pulse reaches channel 1 earlier than channel 2, and vice versa. As can be seen in Fig.5, the time distribution for background is much broader than that for ^{3}H sample, and the smaller coincidence time window means better signal to background ratio. In the present work, the coincidence time window of ±30 ns is enough to record the majority of coincidence events and keep lower background. As mentioned in Ref.[4], the significant advantage of the post analysis approach to measurement is that the coincidence time window can be optimized to reduce the effect of accidental coincidence.

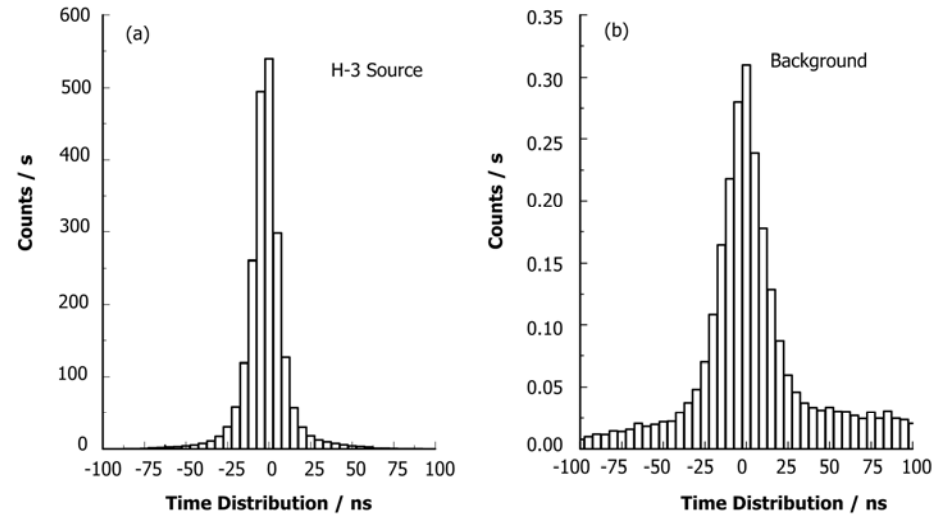

Fig.5 Time delay of lead edge timing between coincidence pulses from channel 1 and channel 2. (a) unquenched standard ^{3}H sample; (b) background.

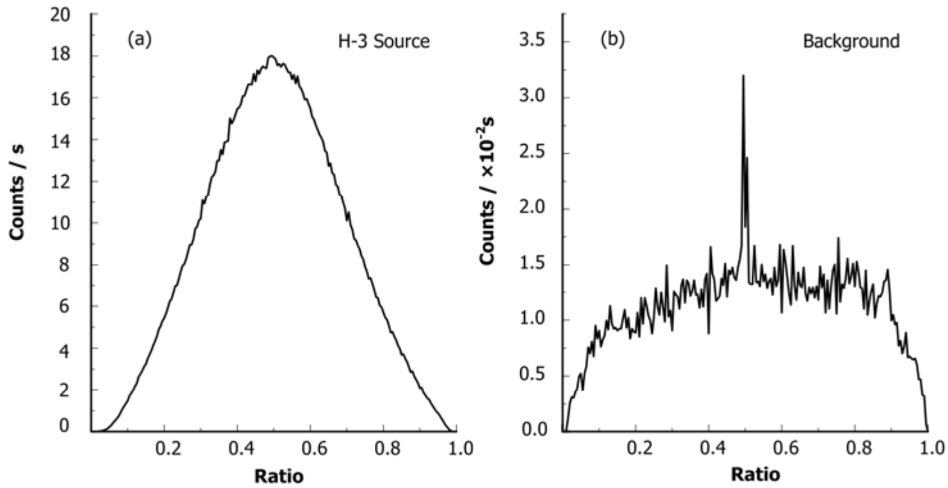

Fig.6 Ratio of channel 1 pulse amplitudes over the summation of coincidence pulse amplitudes of channel 1 and channel 2, unquenched standard ^{3}H sample (a) and background (b).

Photos produced in the cocktail and reaching the two PMTs are similar, thus the ratio of pulse amplitudes of the two channels varies around a value of one. Background photos produced in the PMTs or other places will lead to significant variation, so through pulse amplitude comparison way can improve signal to background ratio[6]. For traditional coincidence circuits, it is much more complicated to obtain the ratio of pulse amplitudes from the two channels. In the present work, the ratio of pulse amplitude of channel 1 over the sum of pulse amplitudes of two channels is obtained and around 0.5. The results are shown in Fig.6. It can be seen that most of events are located between 0.15 and 0.85. Therefore, if only the events with ratios between 0.15 and 0.85 are chosen for the further data analysis, it doesn't cause much event loss and can largely improve signal-to-background ratio. Surely, reducing the dynamic range of the ratio can also reduce the accidental coincidence.

By using the threshold adopted for each channel pulse, coincidence time window of ±30 ns and pulse amplitude comparison way, the final ^{3}H spectrum is obtained and shown in Fig.7. The detection efficiency for unquenched standard ^{3}H sample is (58.5±0.1)%, and the background is (86.7±0.7) cpm.

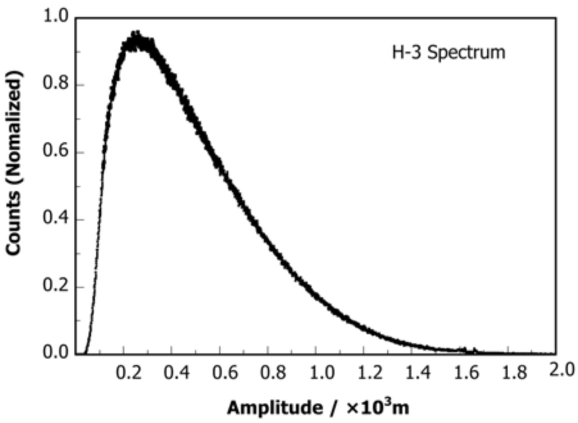

Fig.7 Energy spectrum of tritium β particles.

4 Conclusion

A digitizing coincidence acquisition system for portable liquid scintillation counting device is developed. By using commercial digitizer, discriminator and developed software for the system, it has shown promising results for detecting unquenched standard ^{3}H sample.

Through the spectrum of each channel and the coincidence time distribution of lead edge timing, the threshold for each channel and the coincidence time window are determined. Meanwhile, the pulse amplitude ratio technology is used for better results. All of the parameters are gotten by just one single acquisition for ^{3}H source and background separately. And the energy spectrum of ^{3}H β particles is obtained.

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