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Digital coincidence acquisition applied to portable β liquid scintillation counting device Postprint

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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 3H sample, the results show that the detection efficiency is (58.5\$±0.1)±\$0.7) cpm. Meanwhile, 3H β spectrum is obtained.

Full Text

Preamble

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Digital Coincidence Acquisition Applied to Portable β Liquid Scintillation Counting Device

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Abstract

A digital coincidence acquisition system for a portable liquid scintillation counting device has been developed. The system simplifies device design through its three main components: an Agilent U1066A DC438 digitizer card, a discriminator, and a host computer. The anode analog pulses from two photomultiplier tubes are captured using sequence acquisition storage mode. By applying proper thresholds to each channel, setting a coincidence time window of $±$30 ns, and comparing pulse amplitudes between the two channels, the portable scintillation counting device enables effective β particle detection. For an unquenched standard ^{3}H sample, the system achieves a detection efficiency of (58.5$±0.1)±$0.7) cpm, while simultaneously obtaining the ^{3}H β spectrum.

Key words: Digitizer, Liquid scintillation, Coincidence

Introduction

Liquid scintillation counting is widely employed for measuring radioisotope activity. A typical conventional liquid scintillation counting system is illustrated in Fig.1. In such systems, anode analog pulses from two photomultiplier tubes (PMTs) are amplified by preamplifiers and fed into a coincidence gate that controls a linear gate. Simultaneously, the PMT anode pulses are summed into a single pulse and transmitted to a spectrum analyzer via an amplifier and linear gate. Through appropriate high-speed discrimination circuits, detection efficiency is maintained while tube noise is reduced for cocktails with short lifetimes. However, conventional circuits require numerous adjustable parameters—including pulse-shape discrimination, thresholds, and resolving time windows—for different radioisotopes, leading to increasingly complex electronics for generating counting pulses.

As digital pulse processing technology advances, it is playing an increasingly important role in many research fields [1,2]. In recent years, both online digital counting platforms [3] and FPGA (Field Programmable Gate Array) acquisition systems for TDCR (Triple to Double Coincidence Ratio) counting [4] have been developed. FPGA-based digitizers function as general A/D transient recorders with several hundred million samples per second sampling rates and up to 12-bit resolution, providing an input pulse dynamic range exceeding 1000. Digitizers enable acquisition systems to record pulse-shape information along with time stamps, simplifying data acquisition procedures while enhancing subsequent data analysis. For liquid scintillation counting devices, coincidence events can be readily acquired through recorded pulse time stamps. Although liquid scintillation counting devices are widely used and studied, most existing systems are massive and bulky.

This paper presents the development of a portable liquid scintillation counting device employing a digital coincidence acquisition system. The developed detection system was tested through β particle detection, successfully obtaining both β energy spectra and coincidence data. To the best of our knowledge, previous systems of this type could only provide β counting rather than energy spectra.

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2 Experimental Section

Although conventional liquid scintillation counting devices exhibit excellent performance for detecting low-energy β particles, their substantial weight makes them more suitable for laboratory use than field applications. This limitation motivated the development of a portable liquid scintillation counting device. To improve detection efficiency and reduce background, the portable system incorporates several kilograms of lead shielding, two Hamamatsu CR135 PMTs, and positive high voltage.

The negative analog output pulses from each PMT anode are amplified by preamplifiers developed using AD8065 FastFET amplifiers as two-stage amplification units. Rather than employing dedicated analog electronic modules for energy spectrum analysis, coincidence counting, and summation circuits, the output pulses from both preamplifiers are acquired by a digital coincidence acquisition system. This system comprises an Agilent U1066A DC438 digitizer card, a custom-built discriminator, and a host computer. The DC438 features two input channels with 4 MSamples memory per channel and one external trigger channel. It includes a 12-bit digitizer with $±$5 V maximum full scale and sampling rates up to 200 MSamples/s, providing 2.4414 mV vertical resolution and 5-ns time stamping resolution. All DC438 parameters can be set via the host computer [5]. To eliminate unnecessary noise and non-coincident events, an external trigger from the discriminator is utilized. The discriminator is designed to discriminate pulses through leading-edge triggering, with its output standard TTL logic pulses serving as acquisition triggers.

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

Acquisition and analysis software was developed using VC++ 2008 and ROOT release 5.32. To maximize utilization of the 4 MSamples memory per channel, sequence acquisition storage mode is employed. In this mode, acquisition is triggered only by TTL logic pulses from the discriminator, after which 410 sample points from both channel 1 and channel 2 fill an acquisition segment at 200 MSamples/s (providing 2.1 µs acquisition time per segment). Once 8000 segments are filled, data are transferred to the host computer via high-speed Direct Memory Access (DMA) for analysis and storage. Through cyclic acquisition, the desired statistical accuracy can be achieved. Data files are stored in binary format to optimize space requirements.

In sequence acquisition storage mode, a "dead time" interval exists between segments during which signals cannot be acquired or stored. The DC438 can time-stamp intervals between segments. Dead time was measured using periodic 100 MHz pulses, revealing a 1.12 µs dead time between segments.

3 Analysis and Results

An unquenched standard ^{3}H sample with activity of 2.043$×10^{5}$ dpm was used to test the system. Pulse shape characteristics were first studied, with preamplifier results shown in Fig.3. The rise time is approximately 50 ns and decay time less than 150 ns, confirming that 410 sample points per acquisition with 500 ns pre-trigger delay are sufficient.

During offline analysis, time stamps of pulses from channel 1 and channel 2 are compared. Pulses falling within a 100 ns coincidence time window are retained; this broad window was initially chosen for data filtering. The energy spectra for each channel are shown in Fig.4. For the preamplifier output pulses recorded by digitizer DC438 (with a one-volt shift applied to channel 1 to discriminate between the two channels), the trigger reaches the digitizer after channel 2 pulses due to discriminator delay. Additionally, a time delay exists between coincidence pulses from the two channels. If the channel 1 pulse arrives earlier than channel 2, it may not be completely recorded. To prevent this, a pre-trigger delay of 500 ns is implemented, causing acquisition of both analog input channels to begin 500 ns before the trigger.

When pulses are present in both channels, their amplitudes and leading-edge timing stamps are obtained. If both pulses fall within the coincidence time window, a count is registered and their amplitudes and time stamps are recorded for further analysis. The amplitudes can be simply summed to represent the energy of a detected β particle. For conventional liquid scintillation counting devices, peak-holding circuits would be required to sum the two channel pulse amplitudes, increasing system complexity.

For improved signal-to-background ratio, thresholds should be set at the left valleys of CH1 and CH2. The time delay of leading-edge timing between coincidence pulses from channel 1 and channel 2 is shown in Fig.5. Positive time delay indicates pulses reaching channel 1 earlier than channel 2, and vice versa. As shown in Fig.5, the time distribution for background is much broader than for the ^{3}H sample, with smaller coincidence time windows yielding better signal-to-background ratios. In this work, a coincidence time window of $±$30 ns is sufficient to record the majority of coincidence events while maintaining low background. As mentioned in Ref.[4], a significant advantage of post-analysis measurement approaches is that coincidence time windows can be optimized to reduce accidental coincidence effects.

Photons produced in the scintillation cocktail and reaching the two PMTs are similar, so the ratio of pulse amplitudes between the two channels varies around a value of one. Background photons produced in the PMTs or other locations cause significant variation, so pulse amplitude comparison can improve signal-to-background ratio [6]. For analog coincidence circuits, obtaining pulse amplitude ratios from two channels is much more complicated. In this work, the ratio of channel 1 pulse amplitude over the sum of pulse amplitudes from both channels is obtained, clustering around 0.5. Results are shown in Fig.6, where most events lie between 0.15 and 0.85. Therefore, selecting only events with ratios between 0.15 and 0.85 for further analysis causes minimal event loss while substantially improving signal-to-background ratio. Reducing the dynamic range of the ratio can also reduce accidental coincidence.

Using the adopted thresholds for each channel, a coincidence time window of $±$30 ns, and pulse amplitude comparison, the final ^{3}H spectrum is obtained and shown in Fig.7. The detection efficiency for the unquenched standard ^{3}H sample is (58.5$±0.1)±$0.7) cpm.

4 Conclusion

A digitizing coincidence acquisition system for a portable liquid scintillation counting device has been developed using a digitizer, discriminator, and custom software. The system demonstrates promising results for detecting unquenched standard ^{3}H samples. Through analysis of each channel's spectrum and the coincidence time distribution of leading-edge timing, thresholds for each channel and the coincidence time window were determined. Meanwhile, pulse amplitude ratio technology was employed to achieve better results. All parameters were obtained from single acquisitions for ^{3}H source and background separately, and the energy spectrum of ^{3}H β particles was successfully obtained.

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