DESIGN OF ARRAY SWITCHING CIRCUIT FOR MULTIPLEX NUCLEAR PULSE SIGNAL

by

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Technical paper
https://doi.org/10.2298/NTRP2204321L

Commercial multi-channel energy spectrometers have good performance, they have multiple input signal channels and multi-channel analyzers, which can simultaneously acquire the energy spectrum of multiple nuclear pulse signals. But the input signal channel of this general multi-channel energy spectrometer cannot be switched between the internal multi-channel analyzers, and an input signal channel can only be fixed to the corresponding multi-channel analyzers. Hence, to resolve this issue, this paper designed a nuclear pulse signal array switching circuit. The core of the array switching circuit is a switch array chip with low internal resistance and high bandwidth, which controls the signal connection between the input signal channel with the multi-channel analyzers. Using ^{137}Cs and uranium ore as radioactive sources, the energy spectrum test and spectrum data analysis were carried out using a NaI detector, respectively, when the nuclear pulse signal passed through and did not pass through the array switching circuit. The results showed that the circuit demonstrates little effect on the energy resolution and linearity of the multi-channel analyzers but causes a small drift of the high-energy photopeak, and improve the reliability of the circuit by energy spectrum data accumulation. This circuit can make the application of a multi-channel energy spectrometers more flexible and reliable.

Key words: nuclear pulse signal, switch array chip, energy resolution, linearity

INTRODUCTION

In the field of nuclear radiation detection, nuclear pulse [1, 2] signal measurement and energy spectrum analysis [3, 4] are extremely important analysis methods. It is necessary to use a multi-channel data acquisition system [5] to analyze the multi-channel nuclear pulse signals at the same time when measuring the ray energy spectrum of different places. At present, multi-channel energy spectrometers are designed according to multiple parallel data acquisition cards [6]. The structure is shown in fig. 1. Each acquisition card corresponds to an input channel, and each input channel is independent and corresponds to a multi-channel analyzer (MCA) [7, 8]. This multi-channel energy spectrometer exhibits good versatility and excellent performance and is easy to use. However, the disadvantages of a multi-channel energy spectrometers include the following: the input channel and MCA cannot be switched, only fixed one-to-one correspondence is considered, and its use is not flexible.

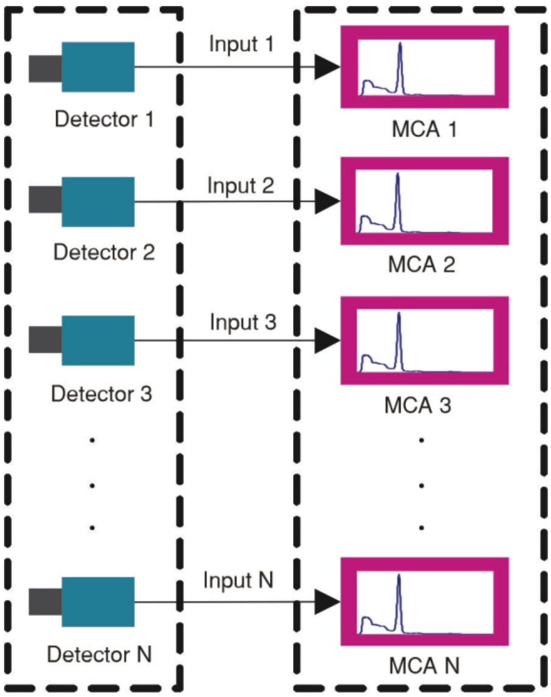

Figure 1. Multi-channel energy spectrum analyzer

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In places with extremely high stability and reliability requirements, redundant design of channels is required when performing online real-time acquisition of multi-channel nuclear pulse signals. In other words, when an abnormality occurs in one channel, it should be quickly switched to other channels to ensure nuclear pulse signals that are real-time, accurate, and reliable. If the general multi-channel acquisition system is used, determining whether the detector or the MCA is faulty is difficult. In such cases, manually checking the fault point is necessary, which not only affects the work of the instrument but also causes radioactive hazards to the human body.

In order to solve the defects, the present study designs a multi-channel nuclear pulse signal array switching circuit that can switch the input multi-channel nuclear pulse signals to the corresponding MCA arbitrarily.

SYSTEM STRUCTURE

During energy spectrum measurement on rays, the amplitude of the pulse signal output by the detector is in the range of 5 V, and the pulse width is in the range of 0.2~5 s. The signal array switching circuit should exhibit the highest possible and the lowest possible bandwidth to reduce the ballistic depletion of the signal and the effects of pulse pile-up [9, 10]. In this paper, the switch array chip was selected to realize the channel array switching function. Figure 2 presents the structural block diagram of a multi-channel energy spectrum measurement system with an array switching circuit. The circuit is mainly composed of a switch array chip, a microcontroller, and an operational amplifier. The input signals 1-8 come from the detector, and the output signals 1-8 are output to 8 MCA.

The switch array chip controls any connection relationship between the input signals 1-8 and the output signals 1-8. Here, the pulse signal is input to the switch array chip through the operational amplifier. Externally, the switching command is sent to the microcontroller through the 485 bus, and the microcontroller sends the control command to the switch array chip through the IIC bus. After the completion of the signal path switching, the parameters of the MCA should also be changed to match the corresponding detector.

ELECTRONIC DESIGN

The array switching circuit includes two parts: a signal input buffer and a switch control. As shown in fig. 3, the signal input buffer part includes the subminiature version A (SMA) connector, impedance matching resistor, and voltage follower. The nuclear pulse signal output from the detector is connected to the SMA connector on the circuit board through a coaxial cable, and the input voltage ranges from –5 V to +5 V. A 49.9 matching resistor is connected to the input end of the detector to realize the impedance matching between the detector input signal and the switch array chip. After passing through the voltage follower, the pulse signal is input to the switch array chip.

The switch control part, *i. e*. the second part of the array switching array, includes the switch array chip of ADG2108 (with low internal resistance and high bandwidth), a 485 communication chip, and a microcontroller. The chip demonstrates a bandwidth of 300 MHz and a maximum connection impedance of 35 . It integrates a switch array of 8 10 channels and supports 5 V signals [11]. The switching of the internal switch array chip is realized by writing to the internal register through the IIC

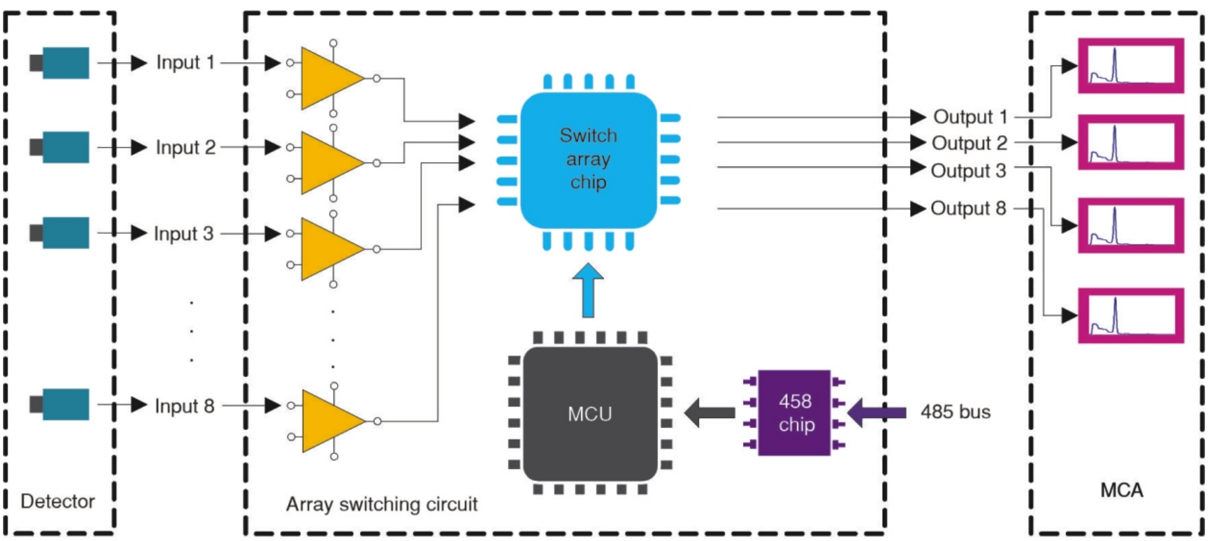

Figure 2. Multi-channel energy spectrum measurement system with the array switching circuit

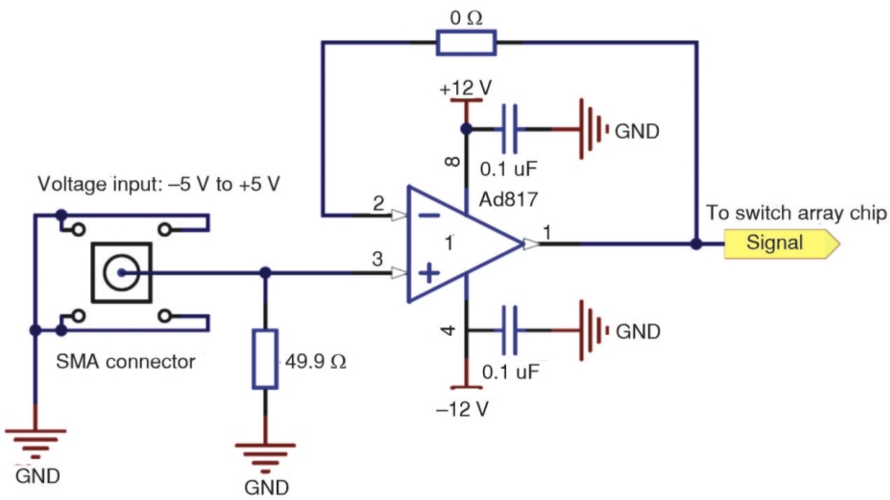

Figure 3. Signal input buffer circuit

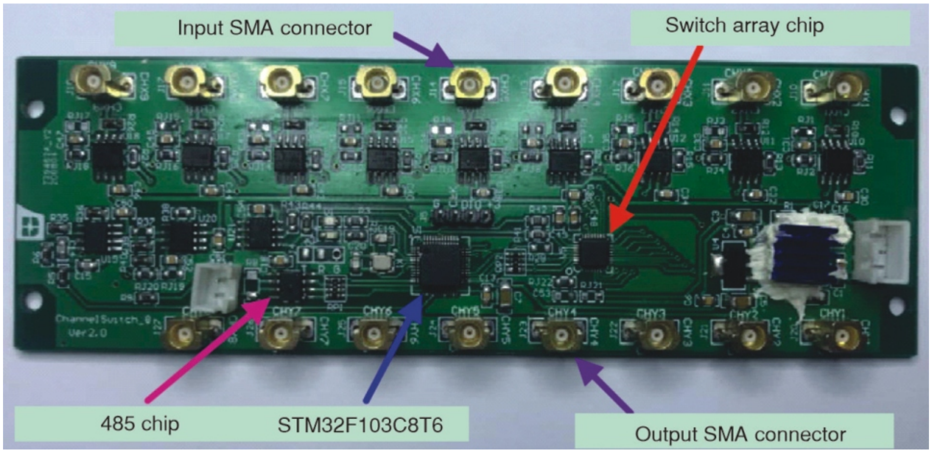

Figure 4. Array switching circuit

bus of the chip. The connection and disconnection between the switch arrays are realized by setting the corresponding register at 1 and then clearing it to 0, respectively. The microcontroller realizes the switch between the input channel and the output channel by writing the corresponding value to the switch chip register through the IIC bus. The microcontroller selects STM32F103C8T6 [12], which realizes the instant switching of a single switch. The microcontroller realizes one-time synchronous switching of all switches by setting the load switch (LDSW) pin of the ADG2108 chip to 0 or 1 as per the requirement. The operation characteristics of the LDSW pin of the switch array chip can ensure that switching a certain channel does not affect the work of other channels. Thus, this ensures that the switching between channels will not affect each other. The pulse signal after switching the chip is output to the MCA through the SMA connector on the circuit board.

The array switching circuit is shown in fig. 4.

TEST AND RESULTS

This circuit uses ^{137}Cs and natural uranium ore to test the performance of the array switching circuit on the MCA. We carried out the energy resolution [13] influence experiment using ^{137}Cs to evaluate the influence of the array switching circuit on the energy resolution. Also, we conducted the energy linearity [14] influence experiment using uranium ore to investigate the influence of the array switching circuit on the energy linearity of the subsequent MCA. The structure of the experimental test system is shown in fig. 5.

During the test, a NaI detector measuring 50 mm × 100 mm × 400 mm was used. The high voltage of the photomultiplier tube was –700 V, and the MCA of 1024 channels was used. The computer controls the array switching circuit and obtains energy spectrum data from the MCA through the 485 transceivers. Next, the test environment is shown in fig. 6.

Energy resolution test

The ^{137}Cs was placed above the detector, and the output signal of the detector was directly input to the MCA without passing through the array switching circuit. The measured spectrum is shown in fig. 7(a). In the same environment, the output signal of the detector is input to input Channel 1 of the array switching circuit

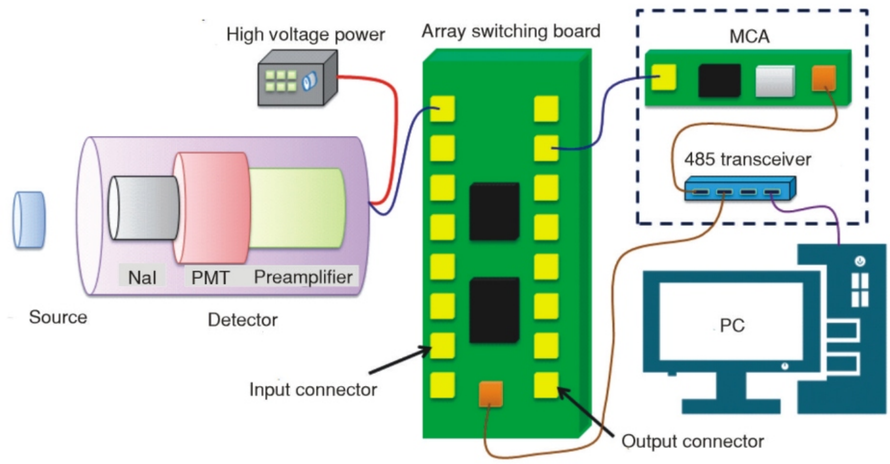

Figure 5. Experimental test system structure

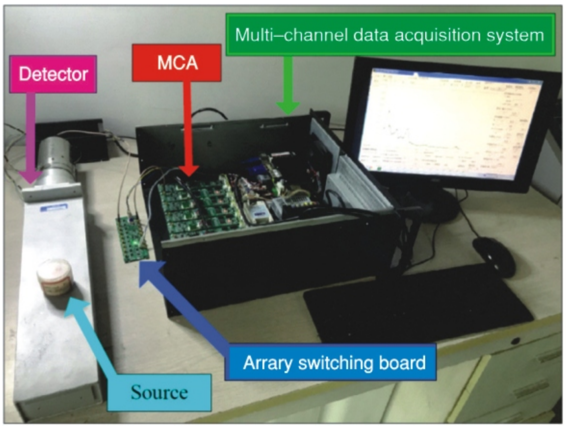

Figure 6. Experimental test system

that switches input 1 to all output channels. The energy spectrum measured by MCA on any output channel is shown in fig. 7(b). The measurement time of the two energy spectrum experiments was 180 seconds.

As shown in fig. 7(a), the 662 keV photopeak of ^{137}Cs is located in channel 203, and the energy resolution is 7.4 %. In fig. 7(b), the 662 keV photopeak of ^{137}Cs is also located in channel 203, and the energy resolution is 7.88 %. For a clearer comparison, the two energy spectra are put in the same graph, as shown in fig. 8.

Figure 8 shows that the distribution of the Compton plateau is consistent. The two photopeaks are almost similar, with similar energy resolution. Therefore, the nuclear pulse signal demonstrates very little influence on the energy resolution of MCA after passing through the array switching circuit.

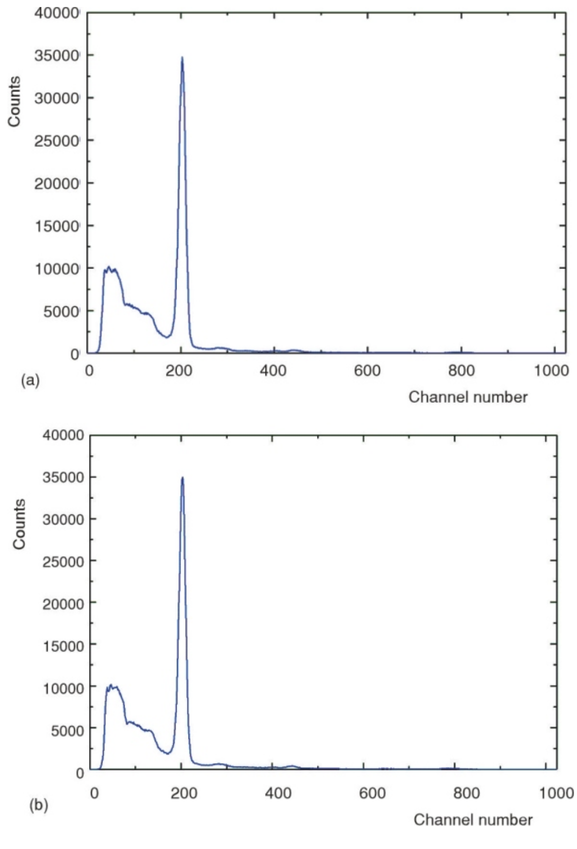

Figure 7. The energy spectrum of ^{137}Cs: (a) energy spectrum obtained without the array switching circuit and (b) energy spectrum obtained with array switching circuit

Linearity test

In nature, ^{238}U, ^{232}Th, and decay products of natural uranium ore emit energy-rich gamma-rays [15], which are good natural radioactive sources for testing the linearity of MCA to gamma-rays with different energies [16]. For the linearity test, the uranium ore was placed above the detector, and the same methodology of the energy resolution test was followed to measure the energy spectrum of the circuit with and without array switching, as shown in fig. 9.

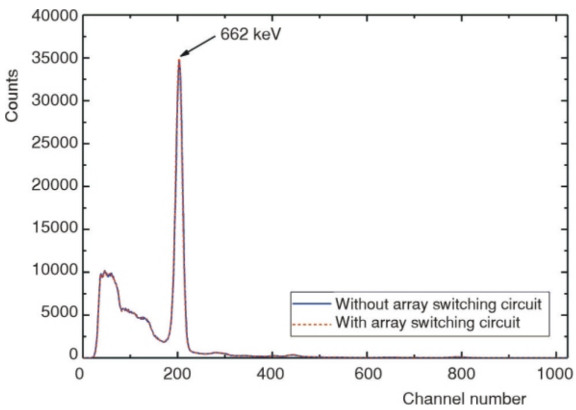

Figure 8. The energy spectrum of ^{137}Cs

Energy calibration was performed by obtaining the channel numbers of 7 photopeak positions of ^{214}Pb, ^{214}Bi, and ^{228}Ac [17] and combining them with the gamma-ray energy released by International Atomic Energy Agency, as shown in fig. 10.

The Pearson correlation coefficient between the number of channels at the photopeak position and the gamma-ray energy is 0.99987in fig. 10(a) and 0.99991 in fig. 10(b).These values of the Pearson coefficient indicate that the MCA with an array switching circuit demonstrates good linearity for gamma-rays of different energies. The circuit will exhibit a certain drift in the position of the photopeak, such as the position of 1764.96 keV in fig. 9. The photopeak position is 528 in the case of no array switching circuit, and it is 520 in the case of an array switching circuit. This shows that the circuit demonstrates a certain influence when the pulse voltage amplitude is high, causing a slight attenuation of the pulse voltage amplitude. However, the circuit demonstrates negligible effect when the pulse voltage amplitude is low.

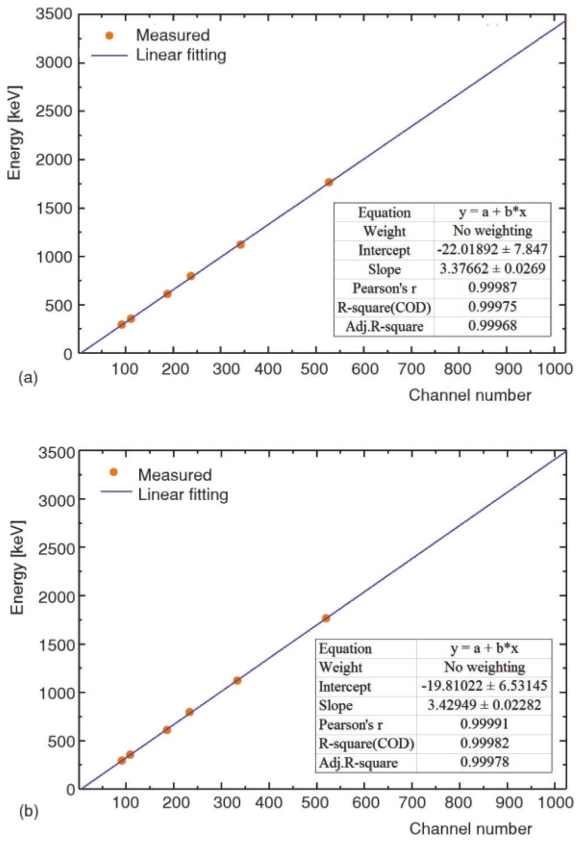

Figure 10. Energy calibration: (a) without array switching circuit and (b) with the array switching circuit

Reliability test

To test the working stability of the designed array switch circuit, used ^{137}Cs and uranium ore to test the energy resolution, linearity, and the photopeak position of ^{214}Bi changes with the number of array switch operations. First, the ^{137}Cs was placed above the detector, operated the array switch every 60 seconds, and

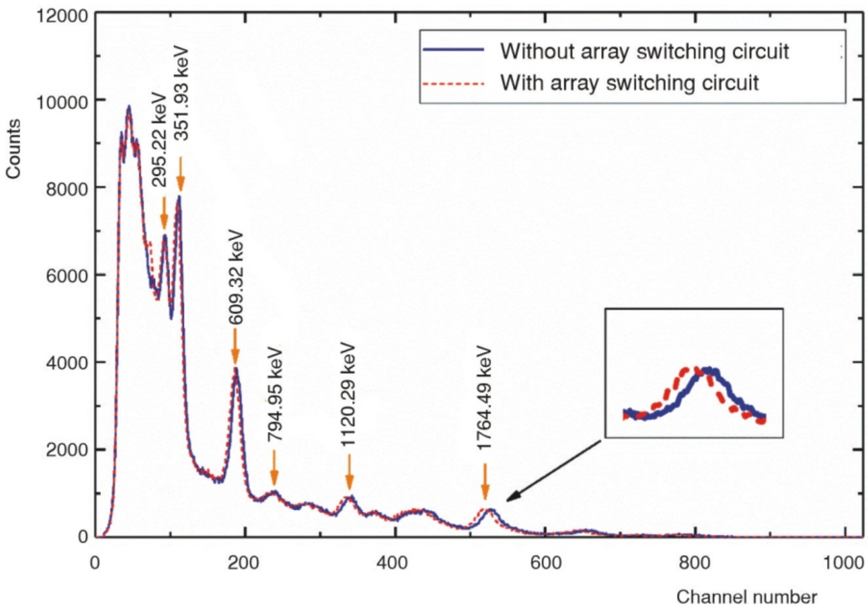

Figure 9. The energy spectrum of uranium ore

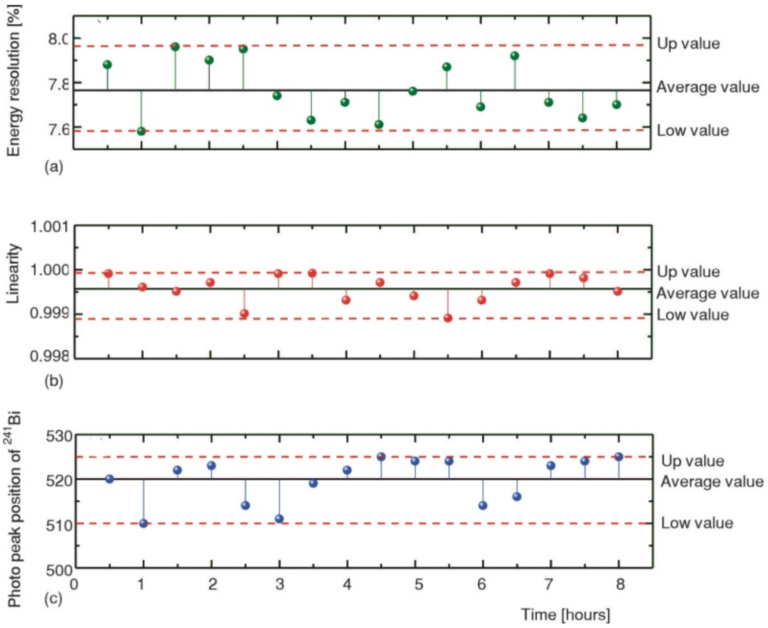

Figure 11. Circuit reliability: (a) energy resolution, (b) linearity, and (c) photopeak position of ^{214}Bi

read the energy spectrum data every 180 seconds. After 8 hours of the test, the data for the change in energy resolution were analyzed. Then, the uranium ore was placed above the detector, used the same method to operate the array switch, and read the energy spectrum data. After 8 hours of the test, the linearity and the photopeak position of ^{214}Bi change data were analyzed. The measured energy resolution is shown in fig. 11(a), the linearity is shown in fig. 11(b), and the photopeak position of ^{214}Bi is shown in fig. 11(c).

In fig. 11(a), the average value of energy resolution is 7.76 %, the up value is 7.96 %, the low value is 7.58 %, and the standard deviation is 0.1284. In fig. 11(b), the average value of linearity is 0.99957, the up value is 0.99992, the low value is 0.99891, and the standard deviation is 0.0003. In fig. 11(c), the average photopeak position of ^{214}Bi is 520, the up value is 525, the low value is 510, and the standard deviation is 4.956. During the 8 hours of the test, the array switch was operated 480 times in total, which had very little impact on the entire multi-channel energy spectrum acquisition system. Because of the use of energy spectrum accumulation, the influence of the array switch on the energy spectrum acquisition data during operation is reduced, and the reliability of the array switch circuit is improved.

CONCLUSION

In this paper, a switch array chip was used to design a nuclear pulse signal array switching circuit, which can realize any connection between the multiple input signals from the detector with the MCA. The results of the experimental test showed that the array switching circuit demonstrates the little effect on the energy resolution and linearity of the MCA, and the circuit has good reliability through energy spectrum accumulation. This circuit makes the real-time acquisition of multi-channel energy spectrum signals more flexible, reliable, and stable. However, its disadvantage includes limited bandwidth. In the case of very high input signal pulse frequency and amplitude, the signal amplitude is attenuated, resulting in the drift of the photopeak. This defect can be further studied by selecting a switch array chip demonstrating a higher bandwidth.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China (No. 12075055), Nuclear Energy Development Foundation (No. 20201192), Open Funds of Engineering Research Center of Nuclear Technology Application of Ministry of Education (No. HJSJYB2020-4), Open Funds of Jiangxi Engineering Laboratory on Radioactive Geoscience and Big Data Technology(No. JELRGBDT202205).

AUTHORS' CONTRIBUTIONS

Qi Liu: methodology, writing – original draft. Hai-Sheng Chen: data curation. Hai-Tao Wang: writing – review and editing. Ren-Bo Wang: discussed the results and revised the manuscript.

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Received on October 29, 2022
Accepted on March 31, 2023

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ПРОЈЕКАТ СЛОЖЕНОГ ПРЕКИДАЧКОГ КОЛА ЗА ВИШЕСТРУКИ НУКЛЕАРНИ ИМПУЛСНИ СИГНАЛ

Комерцијални вишеканални спектрометри енергије имају добре перформансе, више канала улазних сигнала и вишеканалне анализаторе, који могу истовремено да прикажу енергетски спектар вишеструких нуклеарних импулсних сигнала. Међутим, канал улазног сигнала овог општег вишеканалног енергетског спектрометра не може се пребацивати између интерних вишеканалних анализатора, те канал улазног сигнала може бити фиксиран само на одговарајући вишеканални анализатор. Да би се решио овај проблем у раду је пројектовано прекидачко коло за пребацивање низа сигнала нуклеарног импулса. Језгро прекидачког кола низа је чип низа прекидача са малом унутрашњом отпорношћу и великим пропусним опсегом, који контролише везу сигнала између канала улазног сигнала са вишеканалним анализатором. Користећи ^{137}Cs и руду уранијума као радиоактивне изворе, тест енергетског спектра и анализа спектралних података спроведени су помоћу NaI детектора, када сигнал нуклеарног импулса пролази, или не пролази, кроз склоп за пребацивање низа. Резултати су показали да коло показује мали утицај на енергетску резолуцију и линеарност вишеканалног анализатора, али узрокује мали помак фотопика високе енергије. Ово коло може учинити примену вишеканалног енергетског спектрометра флексибилнијом и поузданијом.

Кључне речи: нуклеарни импулсни сигнал, чип низа прекидача, енергетска резолуција, линеарност