Parallel readout of two-element CdZnTe detectors with real-time digital signal processing*

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Abstract: Readout electronics, especially digital electronics, for two-element CdZnTe (CZT) detectors in parallel are developed. The preliminary results show the detection efficiency of the two-element CZT detectors in parallel with analog electronics is as many as 1.8 and 2.1 times the single ones, and the energy resolution (FWHM) is limited by that of the single one by the means of analog electronics. However, the digital method for signal processing will be sufficiently better by contrast with an analog method especially in energy resolution. The energy resolution by the means of digital electronics can be improved by about 26.67%, compared to that only with analog electronics, while their detection efficiency is almost the same. The cause for this difference is also discussed.

Key words: CdZnTe detectors; detectors in parallel; digital method; radiation measurement
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1. Introduction

CZT is the new generation of compound material for room temperature semiconductor radiation detectors due to its wide bandgap and high atomic number[1, 2]. However, with current growth CZT technology, it is still difficult to get low-cost and large volume crystal ingots. But it is possible to combine several small area single-element detectors into a large area detector, that is to say, multi-element detectors in parallel[3]. The CZT detectors are an important application in hand-held radiation dosimeters, which can not only measure the radiation dose but also determine the radioisotope, so the resolution becomes the crucial issue by multi-element detectors in parallel which can increase the effective detection area and overcome low detection efficiency, long time-measurement of a small area detector[4, 5].

One of the keys to fabricating multi-element detectors in parallel is the design and manufacture of the read-out circuit[6]. The differencein crystal quality or detector fabrication for CZT detectors results in a mismatch between the performances of single-element CZT detectors, which will lead to a reduction of spectrum for the multi-element detectors constituted by these single-element CZT detectors[7]. So, the results are unsatisfactory for its considerable hole tailing in spectra and discarding a fraction of the charge, although the circuits summing the analog signals from detectors before the preamplifier are extraordinarily simple[8]. Therefore, how to design a compensation circuit in the signal processing system is the crucial key to improving the spectrum characteristic of multi-element CZT detectors[5, 9]. The available readout circuitry is all based on the analog method, which is very complicated and degrades the energy resolution[3]. However, digital processing electronics are particularly effective because of their high performance, flexibility, and ease of interfacing with a computer control system[6, 10].

In this paper, we will develop readout electronics for two-element CZT detectors in parallel, including an analog method and a digital method, and compare the spectrum characteristics of the digital method with those of the analog method.

2. Circuit design

The amplitude of the signal pulse from the CZT detector is proportional to the energy deposited by the incident radiation. The pulse height spectrum measurement system is based on recording not only the number of pulses but also their distribution in amplitude. A differential pulse height spectrum is a continuous curve that plots the differential number of pulses observed within an increment of pulse height against the value of the pulse height. So a great diversity of the signal pulses formed by different detectors will degrade the energy resolution. An analog and a digital circuit are designed to make the amplitude of the signal pulse from detectors almost the same. Then the spectrum of the two detectors can be equal to that of a signal one with large active volume detector.

A block diagram of the analogy electronics for two-element CZT detectors in parallel is shown in Fig. 1(a). The output signals from the two single detectors are passed through an independent preamplifier and a main amplifier circuit, and then summed before being sent into a multi-channel spectrometer. The main amplifier includes an adjustable parameters filter circuit, a fine-tuning circuit and a baseline restoration circuit. The details of the fabrication and experimental test results for the readout circuit are described in our previous work[11]. The electronics are implemented using standard printed circuit board

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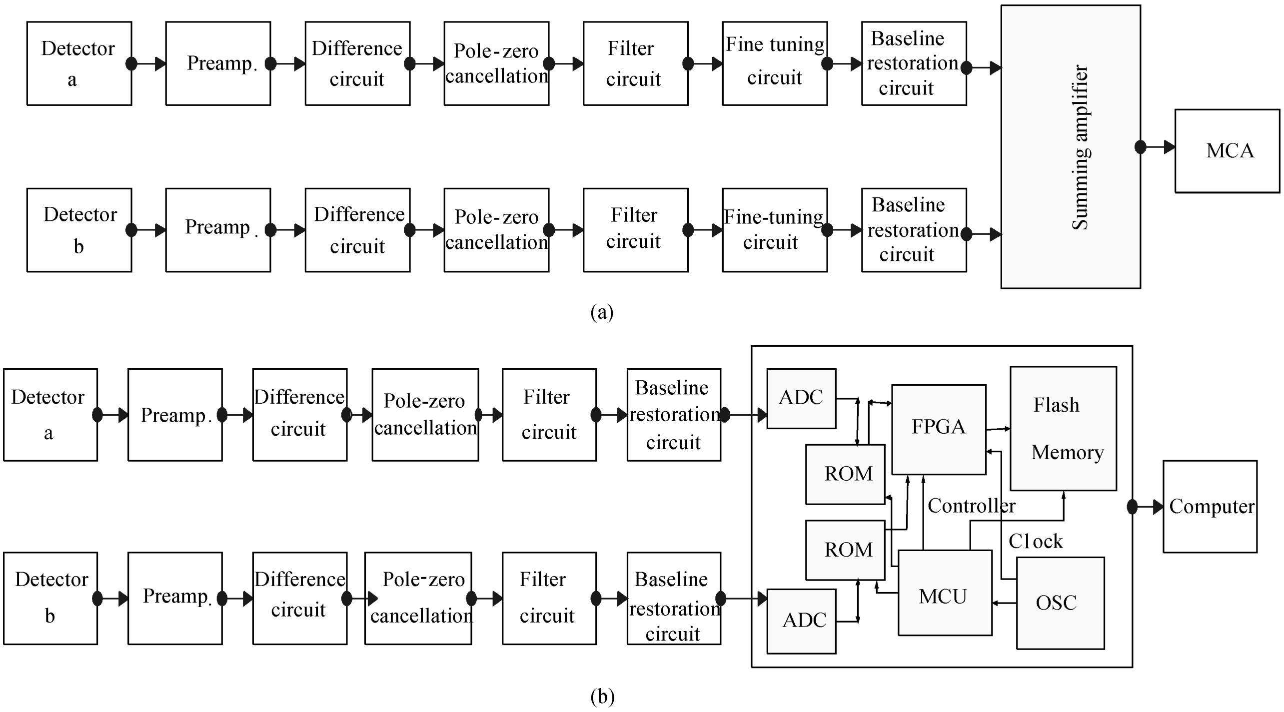

Fig. 1. Block diagram for two single CZT detectors in parallel. (a) For analog electronics. (b) For digital electronics.

(PCB) technology. Low power consumption is achieved for all stages in the circuit. A ±5 V power supply is used in this design for all electronics, which is much lower than those used in commercially available hybrid front-end electronics (say, a +12 V supply). The refined analog electronics are much more compact compared with others[3], which include lots of complicated functional modules. The fine-turning circuit, which is the scaling circuit, comprising an op-amplifier, can modify the pulse signal from two different detectors to be the same, but the precision is not very good and it is hard to control.

A block diagram of the digital electronics for two single CZT detectors in parallel is shown in Fig. 1(b). There are three PCB boards in this system: the preamplifier board, which is the same one used in the analog electronics, and the main amplifier board, which is used to amplify and shape the signal[12]. There are four digital-processing components on the controller board, that is, read-only memory (ROM), analog-to-digital converters (ADCs), microcomputer (MCU) and field programmable gate arrays (FPGA). Signals from two channels are read out by the preamplifier and then amplified and shaped in the main amplifier circuit. The amplitude is separately digitized with a 12-bit ADC, and the resulting digital data are stored in a ROM. Once the MCU is informed, it will instruct the FPGA to acquire the datum from two ROMs, to combine them by a program, and then to send the results into another ROM. So the data are processed and the spectra are formed in the computer. Therefore, all the digitized information is collected by the controller board and sent to a computer by an I/O controller. It should be noted that the FPGA could accurately track the photo-peak position by the digital data that represent the amplitude. However, the noise reduction and filtering have not been restrained strongly, which will depress the energy resolution. Further work focused on reducing the noise by circuit design, sensor structure and software compensation is being carried out.

3. Experiment

Several 5 × 5 × 10 mm^3 n-type In-doped CZT wafers with resistivity of about 10^{10} Ω·cm were used to fabricate radiation detectors with a capacitive Frisch grid structure. The unique features of this configuration are its simplicity and outstanding spectral performance[13]. The evaporated aluminum layers were used as the anode and cathode. An oxide insulator layer was made by two-step passivation processing[14]. A Teflon film was used for the insulation, too.

The pulse height distribution spectra from radiation sources ^{137}Cs (662 keV) for two parallel aligned single CZT detectors with analog electronics or with digital electronics (shown in Fig. 1) were obtained at the temperature of 23 °C by using an ORTEC TRUMP-PCI multitude channel analyzer (MCA) and MAESTRO-32 MCA emulation software. The detector was biased at –1250 V, the distance between the source and detector was about 100 cm, and the source was aligned along the anode of the detector. The two single CZT detectors packaged in aluminum were mounted, respectively, in metal shielding boxes to construct the two parallel detectors, and placed parallel with the charge-sensitive preamplifier. The details of fabrication for two CZT detectors in parallel will be discussed in another paper. Signals are extracted from data lines connected to the external circuit. The power supply for the entire test system is ± 5 V, and the currents are both 0.01 A. In order to make the detecting characteristics clear, the detecting system diagrams for detector a, detector b and parallel aligned detector c (a and b) are given in Fig. 2.

4. Results and discussion

The spectra obtained from the radiation sources ^{137}Cs (662 keV) for two CZT detectors in parallel, together with the two

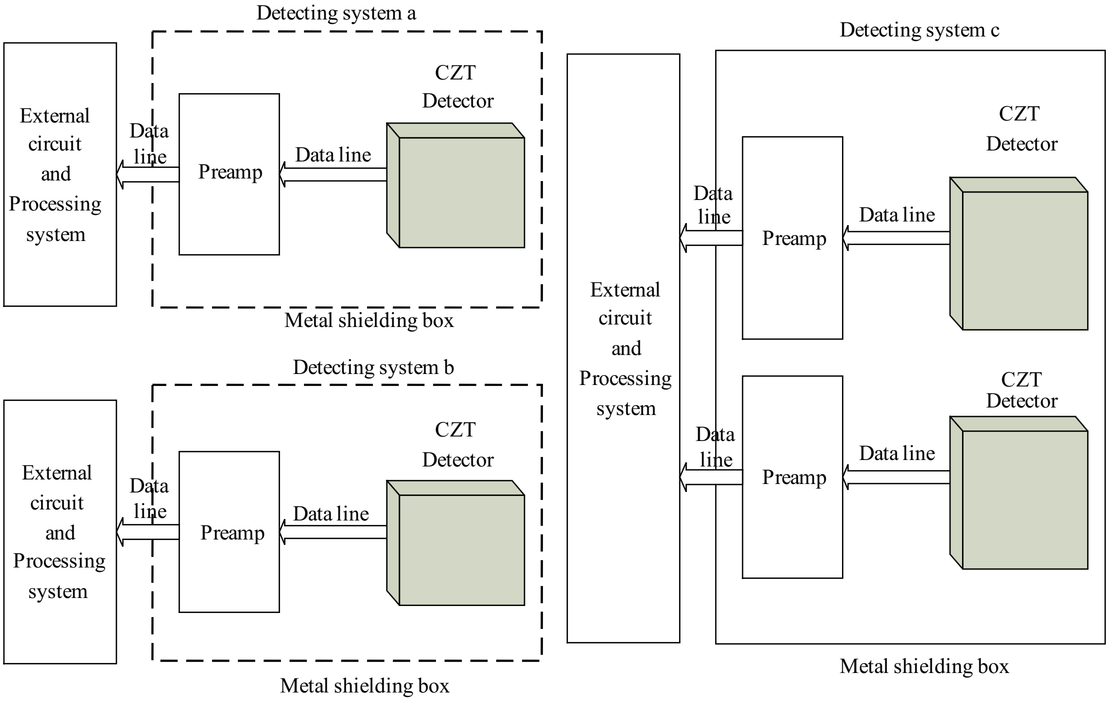

Fig. 2. Detecting system diagram of detecting systems a, b, c, which represent detector a, detector b, and parallel aligned detectors a and b, respectively

single detectors, with an analog electronics signal processing system, are shown in Fig. 3, in which curves *a* and *b* represent the spectra for the single detectors a and b, respectively, and the curve *c* for the spectra of the two parallel detectors. From the area of the spectrum curves in Fig. 3, it can be found that the detection efficiency of the two parallel CZT detectors with this analog signal processing system is much larger than the single ones a or b. The efficiency is herein defined as the number of counts in the spectrum divided by the actual number of 662 keV photons that strike the detector[15]. It was estimated that the detection efficiency of the two parallel CZT detectors c could increase by as many as 1.8 and 2.1 times the single detectors a and b, respectively. However, as seen from Fig. 3, the energy resolution for the two CZT detectors in parallel, c, at 662 keV is 40.01 keV (FWHM), slightly lower than those for single detector a (38.25 keV), or b (18.66 keV). Therefore, the energy resolution for two CZT detectors in parallel with the analog electronics is relatively low, which is limited by that of the single one with the poor resolution, whereas a fine-turning circuit in this analog circuit was used. This might be attributed to the fact that the position of the photo-peak cannot be tracked accurately with analog electronics. This might be caused by the mismatch between the properties of two single CZT detectors, in particular the mismatch between the two photo-peak positions. However, these problems could be solved by using digital electronics, discussed as follows.

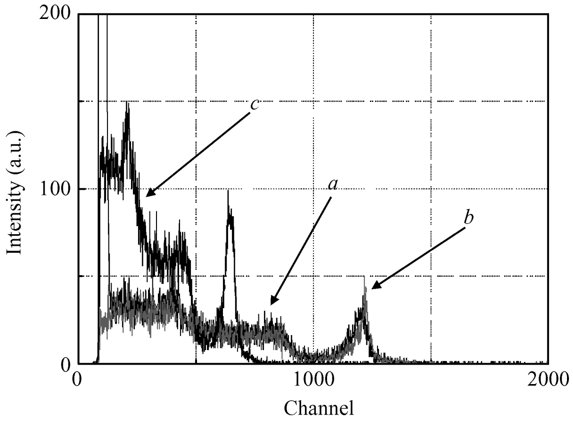

Fig. 3. Pulse height distribution spectra from the radiation source ^{137}Cs (662 keV) with analog electronics. (*a*) For the single detector a. (*b*) For the single detector b. (*c*) For the two detectors in parallel c.

The spectra from the radiation sources ^{137}Cs (662 keV) for two CZT detectors in parallel, together with the two single detectors, with a digital electronics signal processing system, are shown in Fig. 4, in which the curves *a* and *b* represent the spectra for the single detector a and b, respectively, and the curve *c* for the spectrum for the two CZT detectors in parallel. It can be found from Fig. 4 that the energy resolution for the two CZT detectors in parallel c is about 29.40 keV, which is improved by about 26.67%, compared to that with analog electronics, and the detecting efficiency is similar to that in Fig. 3. Comparing the curves in Fig. 4 with those in Fig. 3, it is noted that the position of the photo-peak for the two CZT detectors in parallel *c* obtained with digital electronics is almost the same as that with analog electronics. In digital electronics, the position of the photo-peak can be tracked more accurately by using dedicated firmware, and therefore the photo-peak from the two single detectors can be combined more correctly. It can also be easily understood that if the position of the photo-peaks for the two single detectors is identical, their counts will both contribute to the photo-peak for the two CZT detectors in parallel, without degradation of the energy resolution. Because of the module structure, more CdZnTe detectors can easily be added

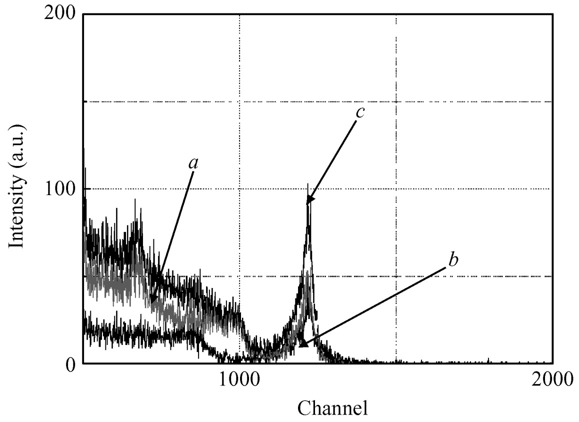

Fig. 4. Pulse height distribution spectra from the radiation source ^{137}Cs (662 keV) with digital electronics. (*a*) For the single detector a. (*b*) For the single detector b. (*c*) For the two CZT detectors in parallel c.

if we need greater efficiency without degrading the resolution.

5. Conclusion

In this paper, the development of readout electronics with digital and analog methods for two CZT detectors in parallel is released, especially the digital signal processing circuit.

The preliminary results show that for the ^{137}Cs source, the detection efficiency of two CZT detectors in parallel with an analogy circuit signal processing system is as many 1.8 and 2.1 times as the single ones, respectively, and its energy resolution (FWHM) is relatively low, limited by that of the single one with poor resolution. However, the energy resolution with digital electronics can be improved by about 26.67%, compared to that with analog electronics, while their detecting efficiency is almost the same.

The above result indicates that the combination of smaller detectors is helpful to achieve high detection efficiency and good energy resolution, which will be important for application in a hand-held radiation dosimeter for measuring the radiation dose and determining the radioisotope.

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