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Original Article

Pocket PC-based portable gamma-ray spectrometer

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Abstract

A portable gamma-ray spectrometer based on a Pocket PC has been developed. A 12-bit pipeline analog-to-digital converter (ADC) associated with an implemented pulse height histogram function on field programmable gate array (FPGA) operating at 15 MHz is employed for pulse height analysis from built-in pulse amplifier. The system, which interfaces with the Pocket PC via an enhanced RS-232 serial port under the microcontroller facilitation, is utilized for spectrum acquisition, display and analysis. The pulse height analysis capability of the system was tested and it was found that the ADC integral nonlinearity of ±0.45% was obtained with the throughput rate at 160 kcps. The overall system performance was tested using a PIN photodiode-CsI(Tl) crystal coupled scintillation detector and gamma standard radioactive sources of Cs-137 and Co-60. Low cost and the compact system size as a result of the implemented logical function are also discussed.

Keywords: pocket PC, gamma-ray spectrometer, FPGA, pipeline ADC, pulse height analysis

1. Introduction

A portable gamma-ray spectrometer is a necessary tool for radioisotope identification in radiation safety, security inspection, and environmental surveying (Kaewtubtim and Changkain, 2002), as well as for a variety of other scientific and industrial applications. It collects and analyzes data obtained from a suitable radiation detector. A commercially available gamma-ray spectrometer sometimes contains functions more than actually needed and can be either too costly or difficult to maintain. Therefore, a simple spectrometer with minimal physical dimensions to implement in stand-alone monitoring systems or in field operations, as well as in applications requiring portability and user friendliness, is preferred. The advanced technique of programmable chip and high performance analog-to-digital converter (ADC) products are applied in modern development.

A field programmable gate array (FPGA) has a flexible internal structure, which allows designers to configure and reconfigure the logical function by programming. It represents a very suitable choice in realization of dedicated digital pulse processor in gamma-ray spectroscopy. The FPGA technology was applied in a pulse processor associated with a digital signal processor (DSP) for high counting rate gamma-ray spectroscopy of NaI(Tl) detector by Bolic and Drndarevic (2002). The spectrum can be displayed and stored in a personal computer (PC). Huang *et al.* (2007) presented a low-cost portable radiation spectrometer using a personal digital assistant (PDA) to measure energy spectra of radioisotopes. It was designed in accordance with the Nuclear Instrument Module (NIM) standards. The output signal from an ADC is supplied to a PDA where data analysis is performed and where spectrum and analyzed results are displayed. However, the size of the system is still the major limiting factor for field use.

In this paper, we present the detailed description of a developed portable gamma spectrometer together with relevant performances required for the identification of radioactive materials in field surveys. Section 2 is devoted to the description of system architecture. Various operations performed by analog and digital parts of the system are described together with the control software. Section 3

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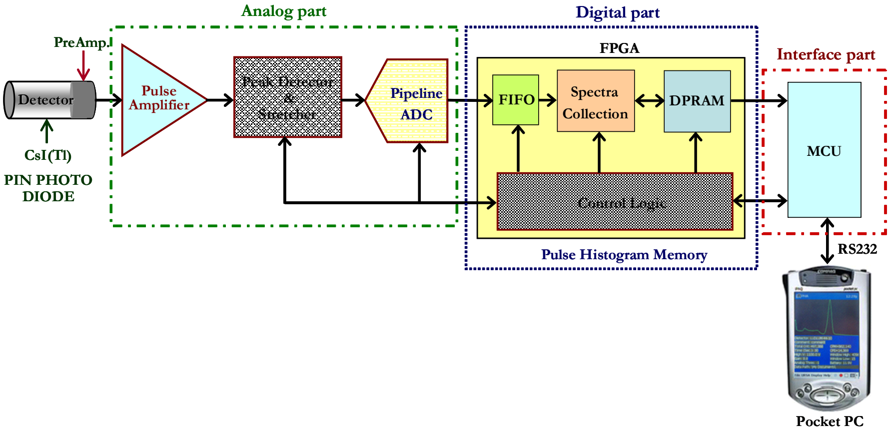


Figure 1. Schematic drawing of the Pocket PC-based portable gamma-ray spectrometer.

presents the results of the developed system performance for gamma spectrometry.

2. System Architecture

The basic structure of the developed Pocket PC-based portable gamma-ray spectrometer system can be divided into three main parts: the analog part, the digital part, and interfacing part as shown in Figure 1. In the analog part, a PIN photodiode and a CsI(Tl) crystal of 10x10x10 mm size coupled as a scintillation detector with a preamplifier is associated to a pulse amplifier and a pulse height ADC, developed from a pipeline ADC chip (Maxim Integrated Products, 2001). As an advantage it has a flash feature and successive approximation ADCs in combination. The digital part (FPGA) is assigned for processing the digitized signal as a pulse height spectrum, and the processed signal is transferred to a Pocket PC via the interface part by software control. The interface part also supports control command communication from the Pocket PC to the digital part.

2.1 Analog part

From analog part shown in Figure 1 the low noise charge preamplifier with a sensitivity of 121 mV/MeV is integrated with a spectroscopy amplifier. Four cascading stages of a high-speed operational amplifier, which is configured for a pulse processing function such as polarity control, pole-zero adjustment, signal amplification, pulse shaping, and baseline restoration that are performed as a spectroscopy amplifier with an overall gain of 100 times. A unipolar pulse output at maximum 10 V linear range based on NIM standards is provided for optional output in support of commercial multichannel analyzer. The 12-bit pipeline ADC, AD9225 of the analog device as shown in the functional diagram in Figure 2, operating at 15 MHz, is employed for pulse height digitizing in amplitude range 0-4 V with a constant conversion time. The data storage cycle of the digitized signal is sequentially controlled by the control logic output of the digital part.

In operation, the incoming pulses from the PIN photodiode-CsI(Tl) coupled scintillation detector are fed into the pulse amplifier and then processed for optimum signal-to-noise ratio pulses. The amplified pulses are then passed through a 2.5 time passive attenuator and a peak detector with stretcher circuit toward the pulse-height digitizing ADC. Each stretched peak pulse is sampled and converted in three clock cycles for fully processed ADC conversion and then interrupts the control logic function for the digitized data storage. New coming pulses will be processed when the memory cycle is completed.

2.2 Digital part

The Altera EP1C12Q240C8 FPGA of the Cyclone family (Altera Corporation, 2008) was chosen because of its advantageous features of the embedded memory within the chip. The core of the digital part is the FPGA with implemented logical function for pulse height histogram acquisition, the logical control signal of data acquisition process,

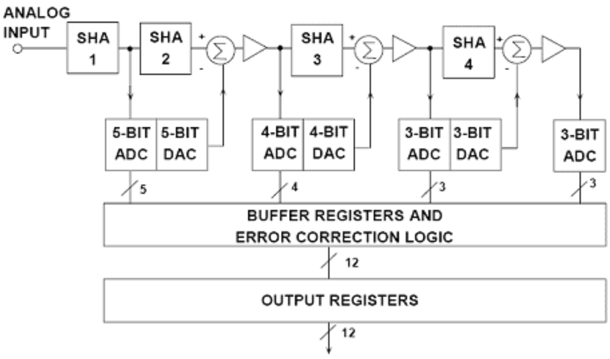


Figure 2. Functional diagram of a 12-bit pipeline analog to digital converter.

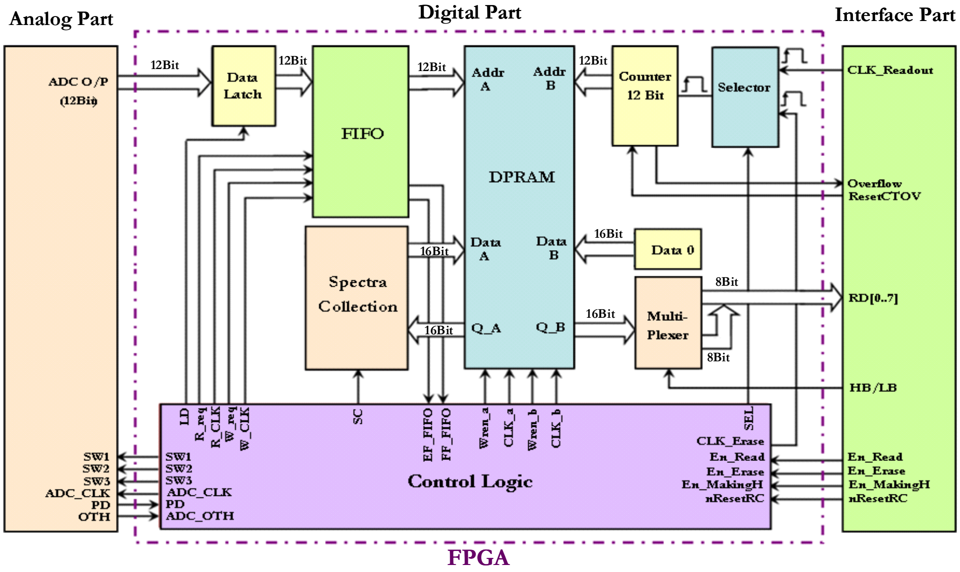


Figure 3. Block diagram of the implemented function on the FPGA in the digital part.

and the data transfer from and to the microcontroller unit (MCU). In an algorithm for high speed signal processing at the 15 MHz pulse rate, subsystems such as the first-in first-out (FIFO) memory, dual port RAM (DPRAM), spectra collection, and control logic functions are utilized in this development. Figure 3 shows a block diagram of the digital part which is implemented in the FPGA.

The function program is written using the schematic diagram in Quartus II. The FIFO memory is engaged for buffering the signal chain of the digitized data from the pipeline ADC, when close consecutive pulses occur by random nature of radioactive decay at high counting rate. The DPRAM has two individual ports, which allow multiple read or write processes to be accessed at the same time. Port A is provided for the increment of the counts in pulse height histogram, while port B is reserved for the communication with the MCU. The pulse height analyzing process (Ploykrachang, 2008; Ploykrachang *et al.*, 2009) will be done continuously during the acquisition time.

2.3 Interface part

The interface part is facilitated by the MCU for data reading from the FPGA to the Pocket PC, and manages user actions of pulse height analysis through the Pocket PC via the enhanced RS-232 serial port. Software control on the Pocket PC is developed using Microsoft eMbedded Visual Basic 3.0 which runs on Windows Mobile 2002. The designed software is capable of controlling spectra collection and displaying functions of the gamma spectrometer by remote command such as acquisition time, start/stop acquisition, cursor channel readout and readout/clear spectrum. In addition, the software includes analyzing function such as region of interest (ROI) selection and spectrum expanding.

3. Performance Tests

A prototype of the portable gamma-ray spectrometer based on a Pocket PC was built as illustrated in Figure 4. With the implemented logical function on the FPGA, the physical dimension of the spectrometer module is 16x16x 4.5 cm with a total weight of 1.3 kg including a Pocket PC. The printed circuit board assembly is illustrated in Figure 5. In the full system operation test, the power consumption was 3.6 W when powered by a 12 V Ni-MH battery pack. At 2,500 mAh battery capacity, it could be operated up to 8 hrs continuously in the field. Test results of the built-in spectroscopy amplifier using a pulser signal reveal a shaped unipolar pulse output in linear range of 0-10V gave pulse shape and base line adequate for pulse height analysis as shown in Figure 6 (b). For the system evaluation, the high pulse rate from a precision function generator was applied. The integral

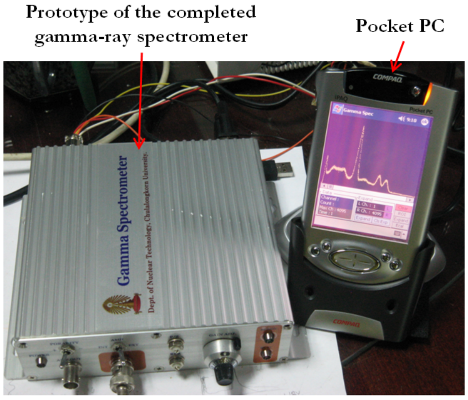


Figure 4. Complete set of the portable gamma-ray spectrometer.

nonlinearity (INL) equation as shown in Figure 7(a) was used for an accuracy test of the ADC. The INL could be found by evaluate a maximum deviation between the reading and ideal channel (Ch -Ch$_L$) divided by the maximum channel number (Ch$_{max}$). It was found that the maximum ADC integral nonlinearity of ±0.45% was obtained and the maximum throughput rate was found to be 160 kcps, as shown in Figure 7(a) and 7(b), respectively. The pulse height analysis performance of the developed portable gamma-ray spectrometer with a 10x10x10 mm CsI(Tl) scintillation detector was tested using standard radioactive sources with different gamma-ray energies. Figure 8 and 9 show the analyzed energy spectrum of Cs-137 and Co-60, respectively. Results of energy resolution and energy calibration linearity are found to be 12.61% at 662 keV of Cs-137 and 0.999 % of a correlation coefficient (R^2), respectively. Since the volume of the CsI(Tl) crystal was small, only 1 cm^3, the high energy spectrum of Co-60 analyzed at 1.17 and 1.33 MeV will give high Compton continuum, resulted in decreasing peak efficiencies.

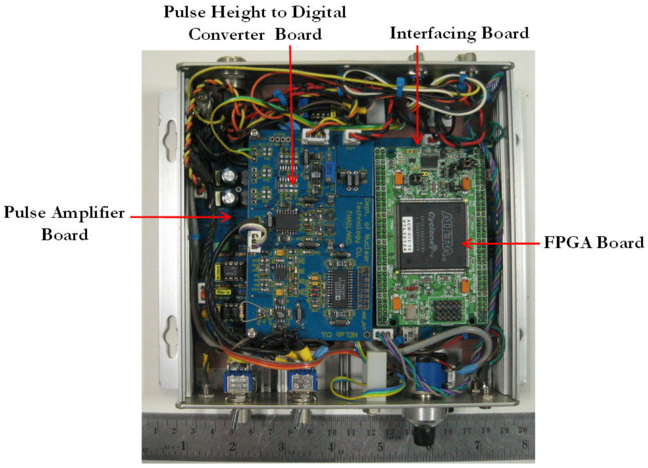
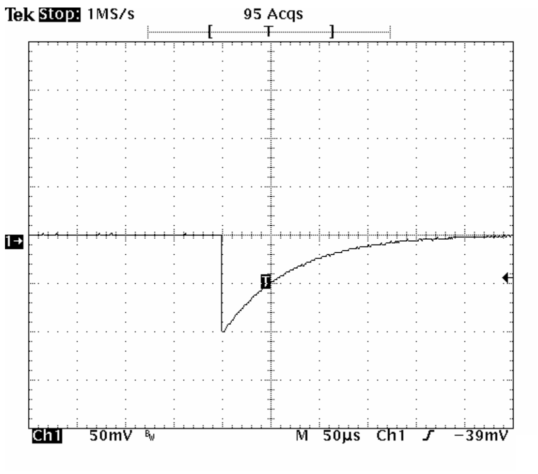
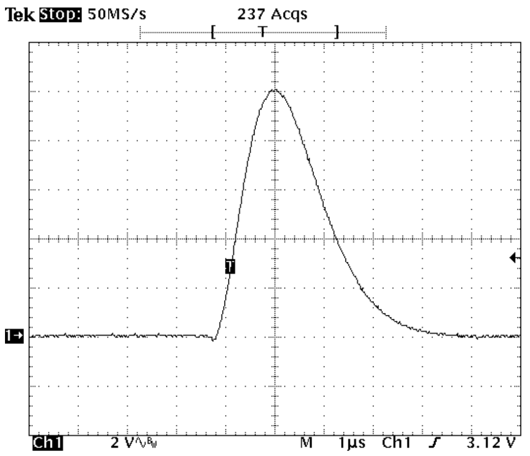


Figure 5. Printed circuit boards assembled in the portable gamma-ray spectrometer.

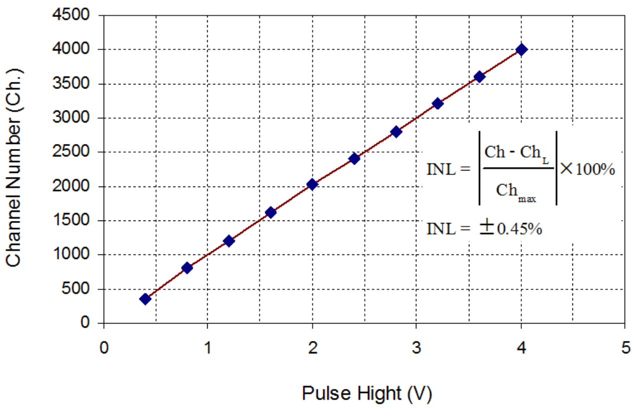


(a) Signal input

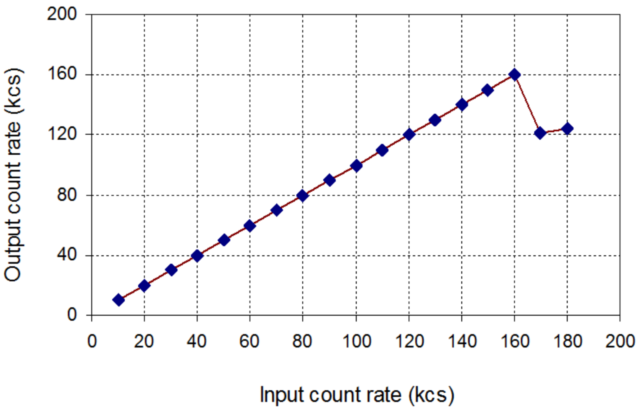


(b) Amplifier output

Figure 6. Test results of the built-in spectroscopy amplifier.

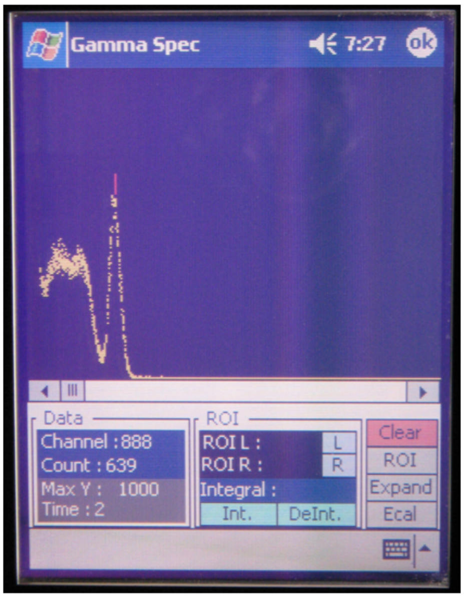


(a) ADC linearity.



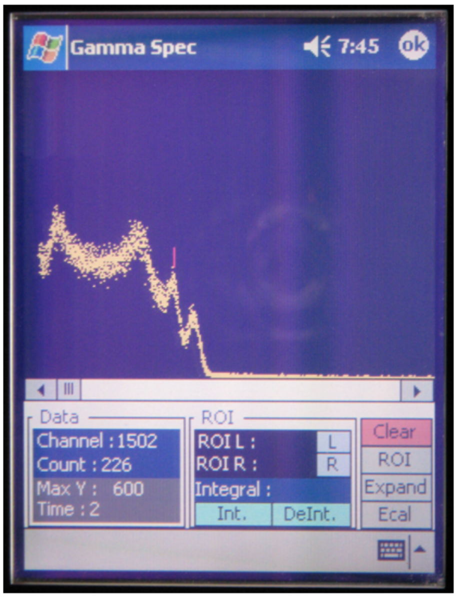
(b) Throughput pulse rate response.

Figure 7. Test results of the pulse height analysis system.



Channel :888
Count :639
Max Y : 1000
Time : 2
ROI L :
ROI R :
Integral :

Figure 8. Energy spectrum of Cs-137.



Channel :1502
Count : 226
Max Y : 600
Time : 2
ROI L :
ROI R :
Integral :

Figure 9. Energy spectrum of Co-60.

4. Conclusions

The portable gamma-ray spectrometer based on a Pocket PC was designed and constructed. The 12-bit pipeline analog-to-digital converter (ADC) associated with an implemented pulse height histogram function on a field programmable gate array (FPGA) operating at 15 MHz is employed in the pulse height analyzer part. The FPGA device with embedded memory is an important part of the system to implement the pulse height analysis logical function and by this it reduces significantly the use of digital hardware components. Besides, the dual port memory feature enhances the system for high throughput rate at 160 kcps response. The Pocket PC functions as a compact display and supporting software for remote system command. As a result of the development, a portable gamma-ray spectrometer with a reasonable performance, low cost, compact size, light weight and user friendliness was obtained. The system performance satisfies the requirements for both field and laboratory radioisotope spectrum measurements in educational applications.

Acknowledgements

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