A Reconfigurable Ethernet-Based DAQP System for Particle Physics Experiments

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1.Introduction

Nuclear science and particle physics is an important subject in physics, and it is important to launch particle physics experiments in university to train students. The typical characteristic of particle physics experiments is that the detector's output signal is directly fed to the front-end electronics (FEE) of the testing system and after digitization and some preprocessing, the data is buffered and recorded. Various detectors are selected for different experiments, bringing different testing schemes and different data formats, as is shown in Fig. 1. So traditional data acquisition system for particle physics experiments usually consists of discrete devices with simple functions and complex circuits having low processing speed. Besides, the reliability of the acquisition system is not that high and it is difficult to debug or to upgrade the system.

To deal with such situations, we design a data acquisition and processing (DAQP) system for particle physics experiments in university. By employing digitalization and reconfiguration techniques in our design, we can achieve various instrument functions within only one DAQP board. A variety of detectors can be connected to the DAQP system, and the task of recording and processing the experiment data can be completed easily. The DAQP system converts the enhancement of the functionality and performance into the development of virtual instruments by using reconfiguration features, making the system retain both the flexibility of software design and high speed of hardware circuit.

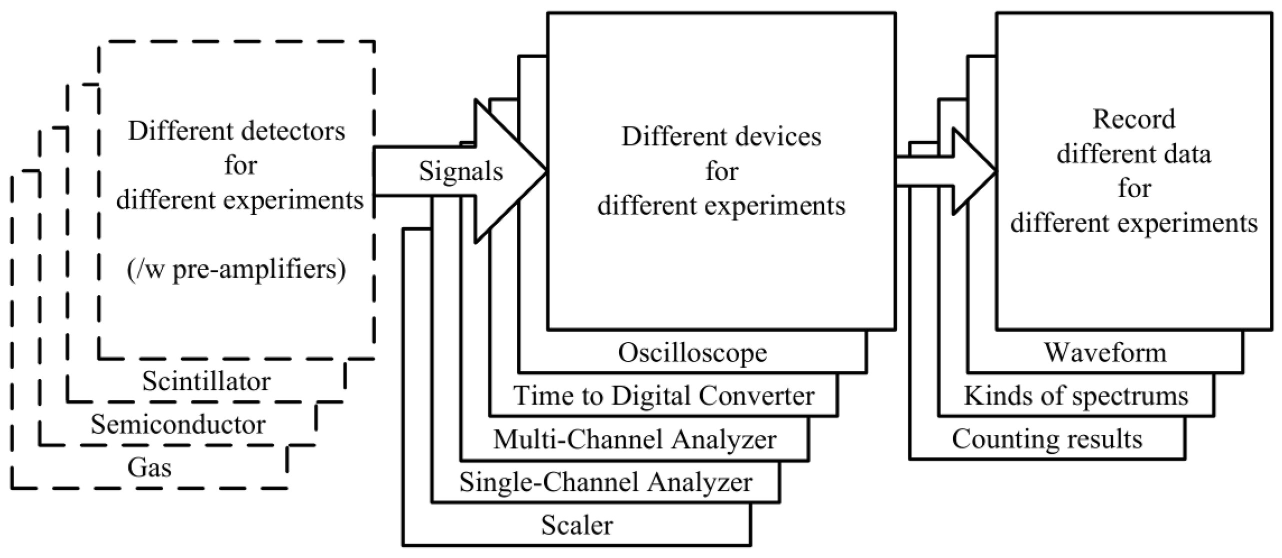

Fig.1. Classic schemes for particle physics experiments

2.System Design

Through analyzing the system requirements, characteristics and feasibility of particle physics experiments, this paper describes the architecture of the DAQP system: various kinds of small customizable FEE boards to accommodate with different detector outputs; multichannel analog-to-digital converter (ADC) for multichannel signal processing; field programmable gate array (FPGA) for data buffering, digital signal processing, command parsing as well as system control; Ethernet chip (iMCU W7100A) for network connection and FPGA reconfiguration.

The schematic structure of the DAQP system is shown in Fig. 2. The core of the system is one Cyclone III FPGA, which can be configured via JTAG for debugging, and it can also be configured in passive serial configuration mode by W7100A. The detector signals in various types are fed to small FEE boards that have different signal conditioning functions, like filter and pulse shaping, leading edge discrimination, charge sensitive amplification and so on. And some of FEE boards' outputs are sent into FPGA for direct processing and measurement, while the others are sent to ADC for continuous digitization. The digitized outputs of the ADC are then processed and integrated in corresponding digital processing IP cores for different experiment purposes. W7100A is respond for establishing Ethernet data communication between PC and the DAQP system. The readout and control software on PC is developed using National Instruments LabVIEW.

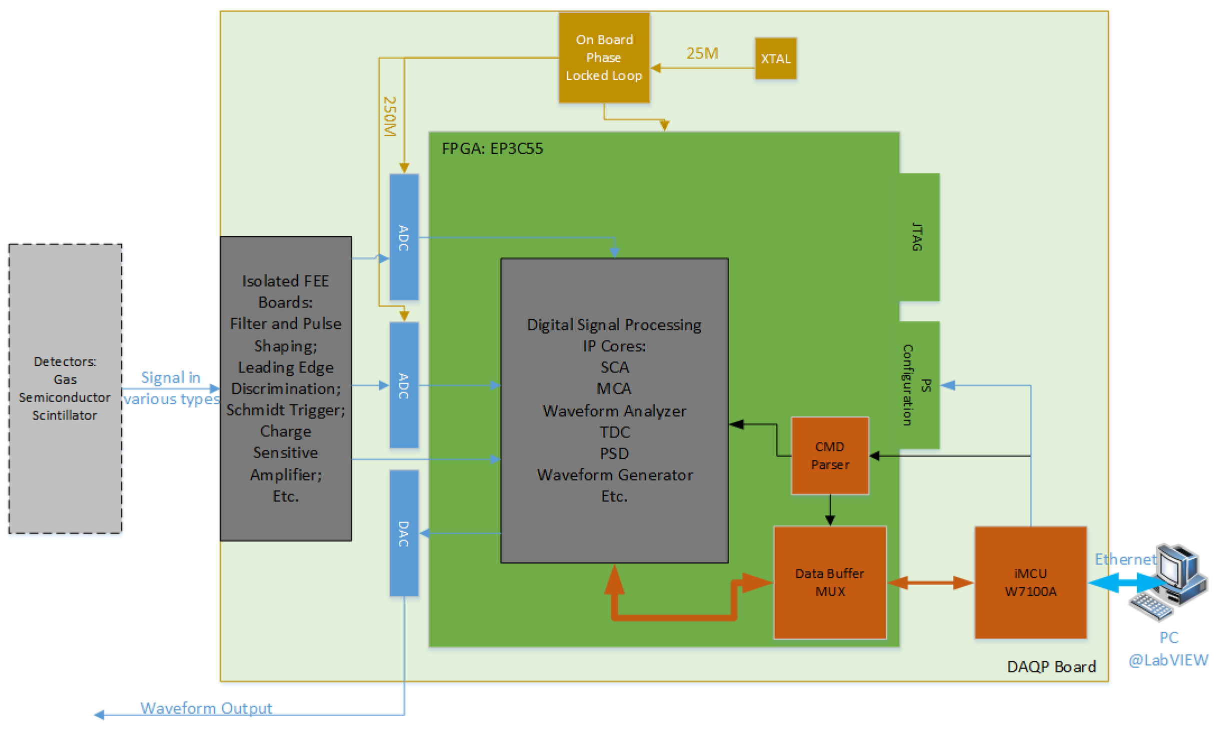

Fig.2. Schematic Block diagram of the DAQP System

The DAQP system mainly consists of four parts: FEE Boards, DAQP module, Reconfiguration module and PC Software. In a specified experiment, appropriate FEE Board will be plugged into the socket on DAQP Board, and Reconfiguration module along with PC Software will decide which digital processing IP core to use. The four parts work together to realize remote data acquisition and real-time data processing for various experiment applications.

All the FEE Boards we design have uniform package style, making it convenient to change front-end signal conditioning circuit aiming at different experiments. One FEE Board has 8 pins for signal connection as well as mechanical fixation to match with the socket on DAQP Board, as is shown in Fig. 3.

The core of DAQP module is one Cyclone III FPGA which implements the function of data storage and digital processing. We can pack a variety of digital function algorithms into independent IP cores, like single-channel analyzer (SCA), multi-channel analyzer (MCA), waveform analyzer, pulse shape discrimination (PSD), time-to-digital converter (TDC) based on tapped delay line and so forth. Fig. 4 illustrates block division of FPGA internal logic. Logic modules needed in most experiments will be assigned to stationary part, including the phase-locked loop, ADC data storage, CMD parser and data buffer control. The rest logic modules are basically developed for specific instrument functions, consisting of SCA, MCA, TDC, oscilloscope and scaler. These specific instrument functions can be easily reconfigured for different experiment purposes through transformations of different logic.

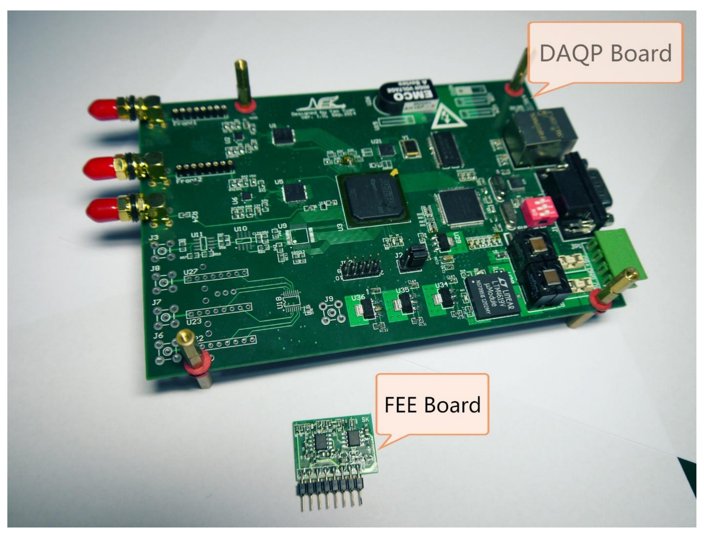

Fig.3. Prototype PCB of the DAQP Board and FEE Board

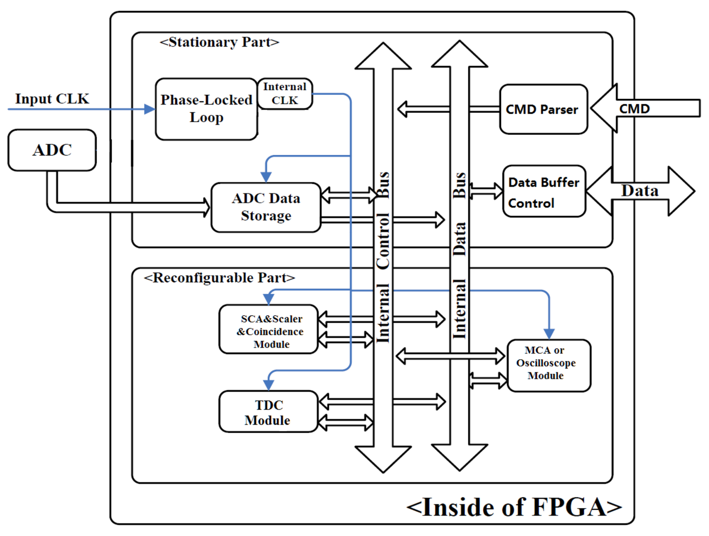

Fig. 4. FPGA internal logic block diagram

Passive Serial (PS) configuration can be performed on Cyclone III FPGA with an external intelligent host. As to our case, W7100A can receive configuration data from PC in form of .rbf file and then repack the data for PS configuration. The specific configuration data can be assigned in the PC software according to different experiments. In this way, online reconfiguration of the DAQP system can be realized.

3.Application Examples

The first implementation is virtual oscilloscope, which can complete the functions of signal reading and acquisition as well as waveform display and storage. We use ADS6149 for waveform digitization which is one 14-bit ADC with sampling rates up to 250MSPS. First a function generator is used to produce a sine wave with voltage amplitude at 125mV (peak to peak) and frequency at 2MHz. And then the wave signal is fed to the DAQP system. We can clearly see the waveform and its corresponding parameters on the oscilloscope panel, as is shown in Fig. 5.

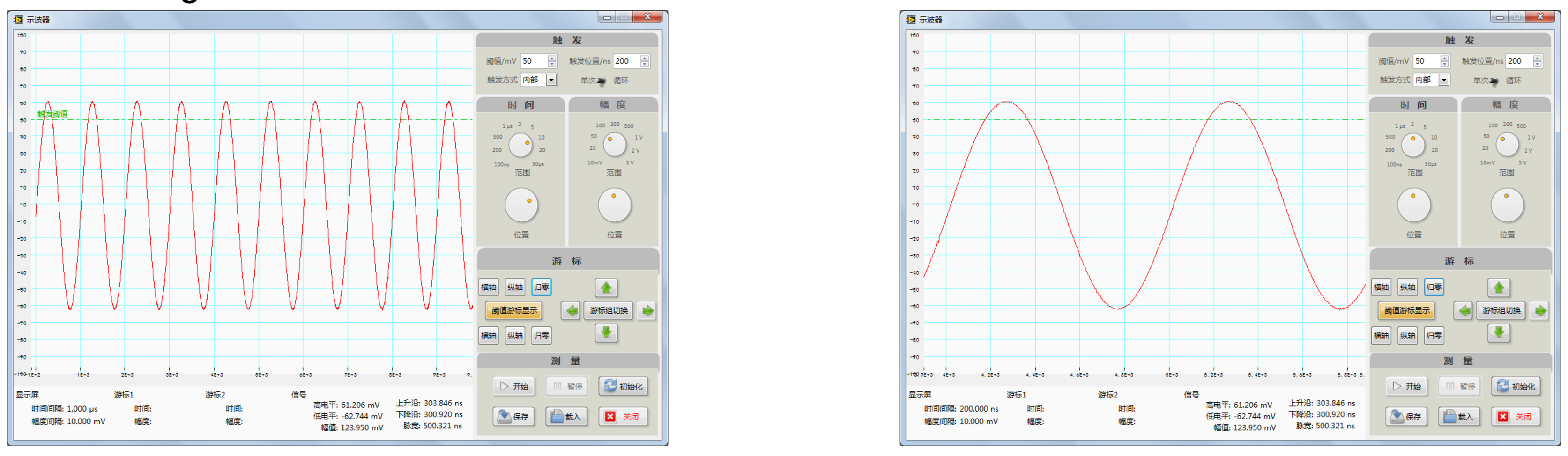

Fig. 5. Oscilloscope Panel

The second implementation is MCA based on FPGA and hi-speed ADC (ADS6149). As to our case, the MCA works in pulse height analysis mode and it is used to measure a complete energy spectrum of radioactive sources.

Fig. 6 displays alpha energy spectrum of ^{241}Am: the full energy peak site is channel 5018.57 and the FWHM is 144.00, thus the energy resolution is 2.87%.

Fig. 7 displays alpha energy spectrum of ^{239}Pu: the full energy peak site is channel 4622.76 and the FWHM is 247.00, thus the energy resolution is 5.34%.

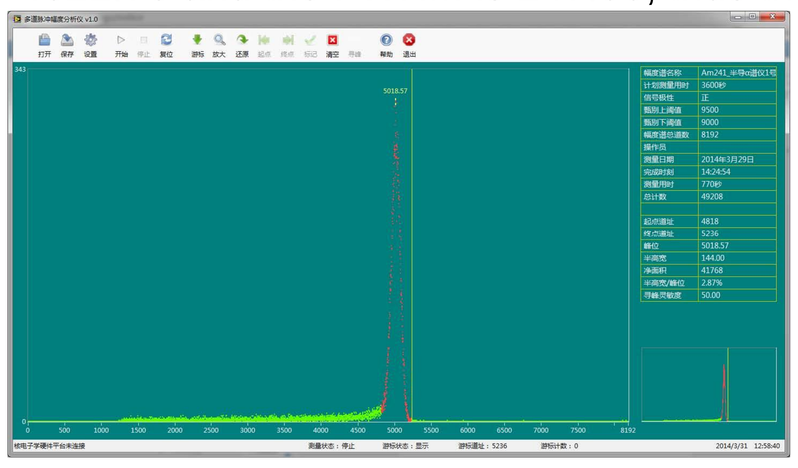

Fig. 6 Alpha energy spectrum of ^{241}Am

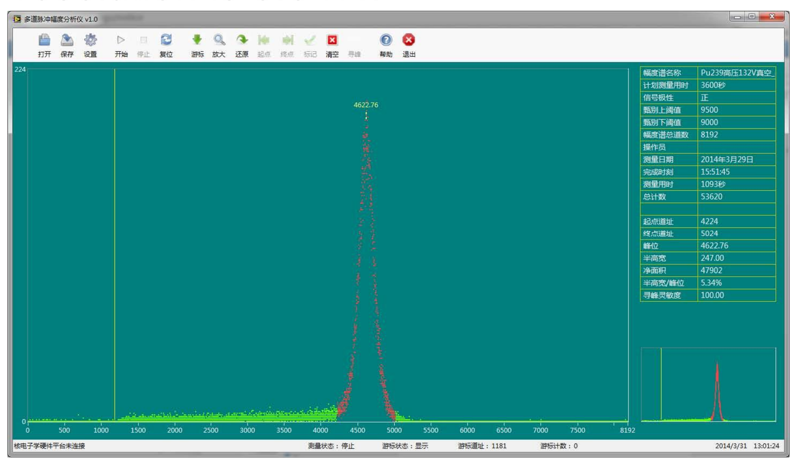

Fig. 7 Alpha energy spectrum of ^{239}Pu

4.Conclusions

This paper proposes a reconfigurable DAQP system for particle physics experiments in university. The novel aspect of the design is bringing the system into small size, reduced cost, scalability, reconfiguration and real-time processing. That is an enormous improvement over the existing experiment system. Furthermore, the system can be easily upgraded because of uniform virtual instrument user interfaces and FPGA based hardware design.

References

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