ELSEVIER

Nuclear Instruments and Methods in Physics Research A 422 (1999) 400–404

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

A mixed analog-digital pulse spectrometer

João M.R. Cardoso*, J. Basílio Simões, Carlos M.B.A. Correia

Instrumentation Center of the Physics Department, University of Coimbra, P-3020 Coimbra, Portugal

Abstract

This paper presents and discusses some applications and advantages of a hybrid spectrometer system that contains a high performance Pulse-Height Analyzer (PHA) and a Digital Pulse Processor (DPP). This mixed analog-digital system, based on a TMS320C31 Digital Signal Processor (DSP), is implemented in a single board to be hosted in the Personal Computer's ISA bus. Beyond the independent use of the PHA and the DPP units, their integration allow for additional features to be performed without the need of external equipment. Among those features are pileup rejection, pulse shape discrimination, ballistic deficit correction and the capability to measure the experimental noise in order to optimize the pulse shaping parameters or to correct the pulse heights given by the analog PHA. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

Nuclear spectrometry is usually accomplished through the use of analog processing electronics (amplifiers with analog pulse shaping and multichannel analyzers) to perform pulse-height analysis. Although capable of high throughput rates, this approach is not able to perform optimum signal-to-noise ratio pulse shaping and is vulnerable to the physical imperfections of the electronic components as well as to the time and temperature drifts of their values.

On the other hand, the time random nature that is associated with the occurrence of the radiation as well as the physical imperfections of their detection process leads to a number of well-known effects that contribute to the degradation of the measured energy spectrum. There is a range of correcting procedures to fade these and other nasty effects. However, these procedures, like pileup rejection, ballistic deficit and charge trapping correction, base- line restoration and pulse shape discrimination, imply the introduction of additional analog electronic units and, hence, additional error sources.

The alternative digital pulse processing method is based on the full digitization of the preamplifier pulses and their subsequent all-digital treatment. The advantages of this method have been widely recognized. In fact, to obtain the best energy resolutions it should be used with theoretical optimum signal-to-noise filters that can only be implemented through digital methods [1–3]. Besides this, the digital approach allows for the software correction of the above mentioned spectroscopy limiting factors such as pileup, ballistic deficit, charge trapping and recombination [4–6]. Nowadays, however,

* Corresponding author. E-mail: cardoso@nautilus.fis.uc.pt.

PII: S0168-9002(98)00991-7

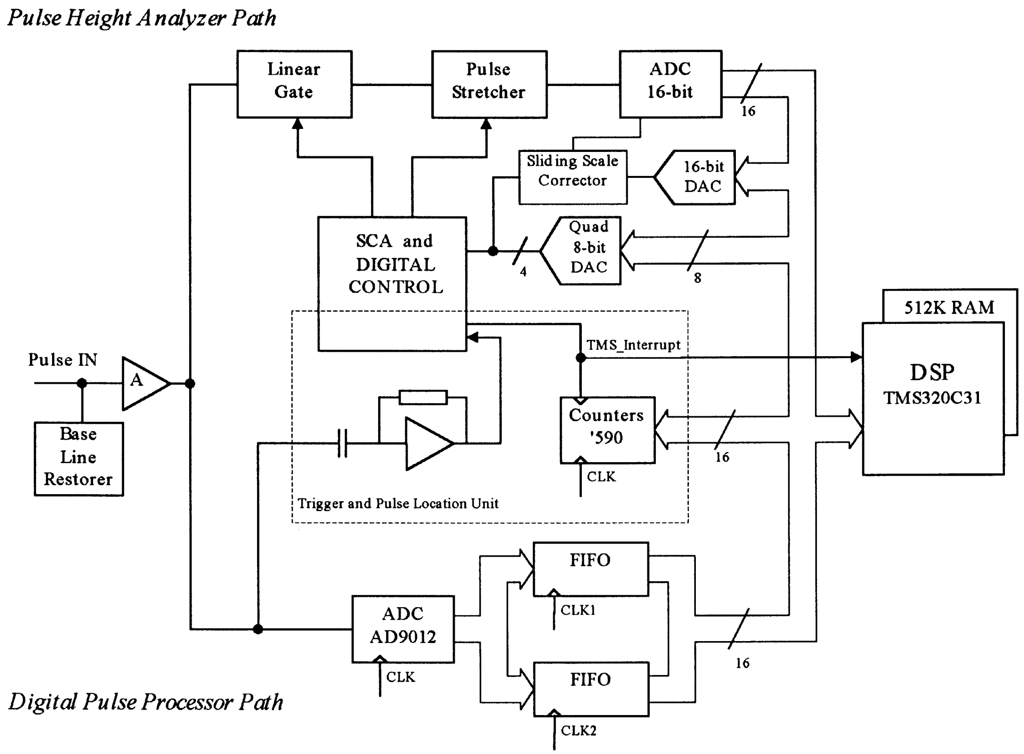

Fig. 1. Overall architecture of the mixed analog-digital pulse spectrometer.

throughput is still the major limiting factor to the generalized use of this processing option [7].

The system here presented includes the implementation of both analog and digital pulse processing methods in the same board (Fig. 1). Section 2 briefly describes the analog Pulse-Height Analyzer (PHA), its performance and specification parameters. Section 3 presents the Digital Pulse Processing (DPP) path along with the associated pulse triggering and location block as well as the implemented data structure and memory management architecture. Finally, in Section 4 some application examples are given showing the advantages of the simultaneously and conjugated use of the analog and digital pulse processing chains.

2. The analog pulse-height analyzer

Fig. 1 depicts a diagram of the major board blocks showing both analog and digital pulse processing chains. The upper side of the figure represents the architecture of the PHA. Its building blocks (linear gate, pulse stretcher, sliding scale corrector and baseline restorer) have been previously described [8–10].

The activity of the PHA is supervised by a Digital Signal Processor (DSP), a Texas Instruments TMS320C31, whose main tasks is to control the sliding scale corrector circuit and to run the pulse-height distribution routine [8].

The incoming pulses are fed into an amplifier with the option of performing baseline restoration. The amplified pulses are then passed, through a DSP controlled linear gate, to the pulse stretcher that interrupts the DSP signaling the presence of a new pulse to process.

The pulse–amplitude is determined using a Burr–Brown ADC700 16-bit successive approximation Analog-to-Digital Converter (ADC) and a Burr–Brown DAC700 16-bit Digital-to-Analog Converter (DAC) in a new implementation of the sliding scale corrector circuit [10].

In order to reduce the dead time of the system, the conversion of a new incoming pulse only starts after its validation by a Single Channel Analyzer (SCA) whose lower and upper levels are software selected using two 8-bit DACs.

This analog PHA is capable of throughput rates up to 50 kHz with very low differential non-linearity (DNL) errors: 2% at 16-bit resolution and less than 0.2% at the usual 12-bit operation (4096 channels).

3. Architecture of the digital pulse processor

The architecture of the DPP was designed to optimize the throughput of the system [11]. Special purpose hardware circuits are used to release the DSP from tasks such as the search for the pulse-position in the long stream of digital data that represent the analog input signal. The software running at the DSP has been written taking into account the random distribution of the pulse's arrival times in order to minimize the system dead time. It is therefore guaranteed that almost all the available computation time of the DSP is used to run the desired pulse processing algorithms.

The main blocks of the DPP are depicted in the lower side of Fig. 1. They are the digitizing block, based on the 100 MSPS, 8-bit flash ADC, AD9012, and two interleaved First-In–First-Out (FIFO) memories, the Trigger and Pulse Location (TPL) unit and the 50 MHz Texas Instruments TMS320C31 floating point DSP.

Each new incoming pulse generates a trigger signal that interrupts the DSP and simultaneously registers in the counters of the TPL unit the pulse's arrival time (and therefore its depth in the FIFO). The counters are then read by the interrupt service routine and the registered value is used to build a lookup table with the positions of the pulses.

This lookup table is used to program the Direct Memory Access (DMA) unit of the DSP to automatically transfer all the digital data relative to each pulse into the next available position on a circular queue that is implemented in the DSP's memory (Fig. 2). Data in the lookup table is also used to build a header that is associated with each pulse. This pulse-header contains useful information like the step position and the number of samples from the previous and to the next pulse.

The main program running at the DSP has the single task of sequentially decoding the information

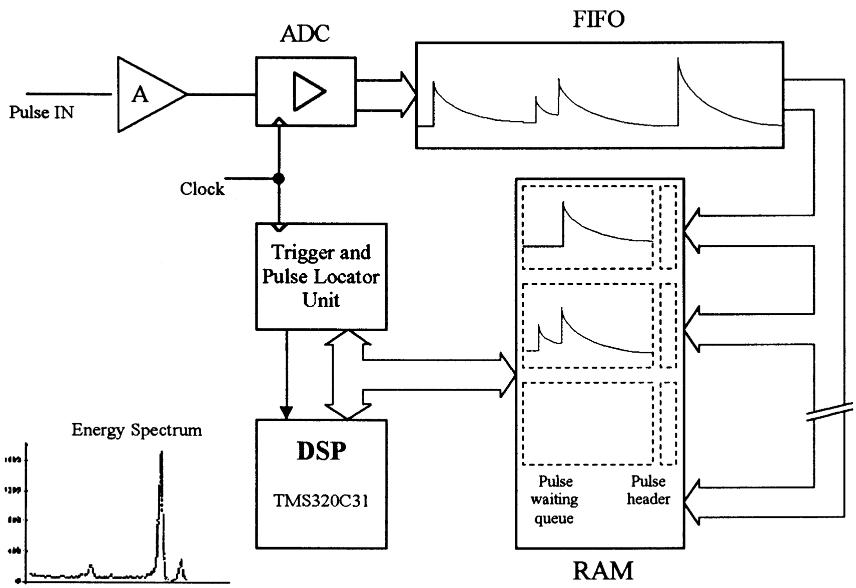

Fig. 2. Digital pulse processing memory management.

from the headers of the queued pulses and performing the programmed digital processing algorithms. In addition to the optimization of the throughput, this architecture containing several stages of pulse buffering, significantly reduces the dead time of the system.

4. Advantages of the mixed analog-digital spectrometer

Beyond the independent use of PHA and DPP units their integration allows for additional features to be performed without the need of external equipment, devising new applications to the system. We divide these features in two categories: the capability to perform multi-parameter pulse-analysis and the enhancement of energy resolution. In both cases the analog PHA determines the pulse height and the DPP unit computes additional pulse parameters or correcting factors.

In the following paragraphs we will discuss these two categories of features, starting with the multi-parameter analysis capability.

(i) *Pulse shape analysis.* Besides amplitude, one pulse is also characterized by its rise time and shape that depends on the specific detector's region where it was formed or in the physical origin of the detected radiation. Hence, the discrimination through shape or rise time criteria allows the acquisition of spectra based on mostly identical events or the construction of 2D-matrix distributions simultaneously representing pulse–amplitude and rise time.

The implementation of pulse shape analysis and discrimination with our analog-digital spectrometer is straightforward. It suffices, in the scheme of the DPP unit described in Section 3, to replace the algorithm that computes pulse–amplitude by the desired pulse shape analysis algorithm. The amplitude information is added to the pulse header (Fig. 2) by the interrupt service routine associated with the PHA unit. As mentioned above the implemented buffered and interrupt-based multitasking pulse processing scheme allows for a very efficient use of the DSP computation time and, unless very complex pulse shape analysis is desired, the throughput of the spectrometer is not affected by this multi-parameter analysis. As an example, an algorithm to compute the pulse-rise time takes about 12 μs (less than the 15 μs conversion time of the 16-bit ADC).

(ii) *Correction of ballistic deficit and charge trapping effects.* The methods of Goulding and Landis [12] to correct for the ballistic deficit, and the method of Simpson et al. [13] to correct for charge trapping effects in Ge detectors can be easily implemented in our spectrometer without any time overhead. The DPP determines the pulse-rise time, as above described, computes the correcting factors and adds them to the pulse height given by the PHA. Other, more complex, corrections to the pulse height can also be done like, for instance, those relating to the incomplete charge collection in CdZnTe detectors [6].

(iii) *Pileup rejection.* By inspecting the lookup table containing the arrival times of the pulses the DSP can verify if the pulse currently being analyzed by the PHA is sufficiently apart in time from the previous one. If it is not, the DSP immediately stops the PHA. This software pileup rejector is implemented in the interrupt service routine of the TPL unit. The associated time overhead is less than 2 μs which means that analysis of good pulses are not delayed by the pileup rejector and bad pulses are discarded very fast, diminishing the system's dead time.

(iv) *Microphonic noise estimation and reduction.* This is implemented through the analysis (using a Fast Fourier Transform) of a stream of digitized data in the absence of pulses. Due to the periodicity characteristic of the microphonic noise, it is possible to estimate its contribution to the pulse height determined by the PHA and hence perform the necessary correction [14].

(v) *Optimization of the pulse shaping time constants.* The time constants of the linear, pulse-shaping amplifier should be set accordingly to the desired goal: make the pulses narrow to avoid pileup; obtain a flat top to minimize ballistic deficit errors; or shape the pulses to optimize the energy resolution. When this last one is the desired criterion, the optimum time constants that should be set on the shaping amplifier in use depend on the experimental noise conditions. Having the possibility to digitize this noise, digital signal processing techniques can be applied to obtain the optimal pulse shaping parameters [15].

Therefore, using the DPP unit, a startup calibration procedure can be run to automatically obtain the best time shaping constants that should be used in order to get the best energy resolution.

5. Conclusions

A versatile mixed analog-digital spectrometer PC board based on a floating-point DSP, TMS320C31, has been presented. This low-cost spectrometry system includes both an analog PHA and a digital pulse-processing unit.

It has been shown how this system can replace complex experimental setups that would be otherwise necessary to perform some multi-parameter analysis like pulse shape discrimination and pileup, ballistic deficit and charge trapping identification and correction. At the same time as the pulse height is being determined by the PHA unit, additional pulse parameters are digitally obtained through the DPP path. Thanks to the architecture of the DPP unit, that makes use of DMA and includes a hardware trigger and pulse location circuit and a multi-buffered pulse-processing scheme; this multi-parameter analysis does not normally imply any compromise in terms of throughput.

Beyond the pulse's multi-parameter analysis, the presented system can also be used to improve the spectral energy resolution by measuring the overall detector and electronic noises that are effectively present in the experimental setup and accordingly optimize the pulse shaping parameters.

References

[1] E. Gatti, M. Sampietro, P.D. Manfredi, Nucl. Instr. and Meth. A 287 (1990) 513.

[2] G. Bertuccio, A. Fazzi, A. Geraci, M. Sampietro, Nucl. Instr. and Meth. A 353 (1994) 257.

[3] J.J. Friel, Richard B. Mott, Adv. Mater. Processes 145 (1994) 35.

[4] Valentin T. Jordanov, Glenn F. Knoll, 1994 IEEE Conf. Record of Nucl. Sci. Symp. and Medical Imaging Conf., 1995, p. 498.

[5] R.E. Chrien, R.J. Sutter, Nucl. Instr. and Meth. A 249 (1986) 421.

[6] R. Hess, P. De Antonis, E.J. Morton, W.B. Gilboy, Nucl. Instr. and Meth. A 353 (1994) 76.

[7] J. Basílio Simões, Carlos M.B.A. Correia, Presented at the 1998 Symp. on Rad. Meas. and Applications, Ann Arbor, Michigan, USA, Nucl. Instr. and Meth. A 422 (1999) 405.

[8] Carlos M.B.A. Correia, José Carlos Martins, Nucl. Instr. and Meth. A 290 (1990) 445.

[9] António Miguel L.S. Morgado, J. Basílio Simões, Carlos M. Correia, IEEE Trans. Nucl. Sci. NS-43 (1996) 1712.

[10] António Miguel L.S. Morgado, J. Basílio Simões, Jorge Landeck, Miguel F. Correia, Pedro Almeida, José Luís Malaquias, Carlos M. Correia, 1996 IEEE Conf. Record of Nucl. Sci. Symp. and Medical Imaging Conf., vol. 1, IEEE Publ., Piscataway, NJ, 1997, p. 490.

[11] J. Basílio Simões, Jorge Landeck, João M.R. Cardoso, Custódio F.M. Loureiro, José Luís Malaquias, Carlos M.B.A. Correia, 1996 IEEE Conf. Record of Nucl. Sci. Symp. and Medical Imaging Conf., vol. 1, IEEE Publ., Piscataway, NJ, 1997, p. 448.

[12] F.S. Goulding, D.A. Landis, IEEE Trans. Nucl. Sci. NS-35 (1988) 119.

[13] M.L. Simpson, T.W. Raudorf, T.J. Paulus, R.C. Trammell, IEEE Trans. Nucl. Sci. NS-36 (1989) 260.

[14] A. Uritani, O. Kubota, Y. Takenata, C. Mori, 1994 IEEE Conf. Record of Nucl. Sci. Symp. and Medical Imaging Conf., 1995, p. 905.

[15] A. Geraci, G. Ripamonti, A. Pullia, Conf. Record of the 1996 IEEE Nucl. Sci. Symp. and Medical Imaging Conf., vol. 1, 1997, p. 478.