A digital multi-channel spectroscopy system with 100 MHz flash ADC module for the GENIUS-TF and GENIUS projects.

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Abstract

In this paper we will present the first results of applying a digital processing technology in low-level gamma spectroscopy with HPGE detectors. An experimental gamma spectrometer using Flash ADC module is built and tested. The test system is now under development and shows major advantages over the traditional analog technologies. It will be installed for the GENIUS-TF and GENIUS projects in Gran-Sasso in early 2003.

1 Introduction

The GENIUS-TF project [1] and GENIUS project [2] - the latter being under construction in the Gran Sasso Underground Laboratory - require a new modular, multi-channel data acquisition system and electronics, capable of taking data from up to 300 and more detectors simultaneously. Since last year a new range of Flash ADC modules with high sampling rates of 100 MHz and resolution of 11-12 bits are available on the market. With these devices it is now possible to develop a multi-channel system for gamma-spectroscopy if the count range is in moderate range. Using this approach it is possible to capture the detailed shape of the preamplifier signal with high speed ADC, and
then perform digitally all essential data processing functions, including precise
energy measurement over a range of 3 keV-3 MeV, rise time analysis, ballistic
deficit correction and pulse shape analysis. Thus we can obtain both the en-
ergy and the pulse shape information from one detector using one channel of
the Flash ADC module.

2 Test detector and 8-channel electronics

To test the digital processing approach for gamma spectroscopy the following
setup has been used:

An ORTEC germanium detector with a built-in low noise preamplifier was
connected to two 4-channel low noise amplifiers developed by MPI für Kern-
physik in Heidelberg. The amplifier/filter has a variable gain ranging from 10
to 100, a variable offset with a maximum of 4 V, a variable differential filter, a
pole zero cancellation circuit and two integral filters. Currently we do not use
any analog shaping at this stage, these amplifiers provide only the necessary
gain and DC offset. The signal outputs from these amplifiers were directly
connected to the Flash ADC module developed by SIS (model 3300, 100 MHz
sampling frequency, 12 bit, 8 channels, dual buffer). A VME CPU with Intel
P3/850 MHz CPU, running Linux as operating system, reads out the Flash
ADC. Fig.1 shows a schematic diagram of the used test system.

In the current test system the VME CPU waits for at least 10 events (2000
samples for every event) sampled in the dual buffer memory. The trigger for
each event is produced by the flash ADC, which has a trapezoid FIR filter
and a digital threshold circuit [4] for each of the 8 channels. After the 10
events have been triggered the memory banks of the FADC are switched and
the CPU reads out the non-active memory bank. Due to this double buffer
feature of the FADC we can achieve nearly zero dead time (less than 10 µsec
for 10 events) as long as the buffers of the FADC are not overrun. After the
read out which is currently available with 4 Mbytes/sec the test system applies
digital filters to the sampled data to compute the energy, the rise time, and
the timing of the input pulse.

3 Digital signal processing for gamma spectroscopy

Each analog stage in a conventional spectrometer introduces irreversible signal
distortion that cannot be removed by further processing stages. If the input
signal is digitized at early stage, we can eliminate this problem and obtain
the best result using a digital processing. In our test system each pulse from
the Ge detector is digitized at 100 MHz and stored as 2000 16-bit words in the CPU memory (see Fig. 2). The first 400 words are used for base line calculation. After subtracting the base line, we compress the 2000 samples to 250 by summing every 8 samples (see Fig. 3), before applying a digital filter.

As a first stage of digital filtering we use a differential filter with P/Z compensation:

$$y[n] = a_0 x[n] + a_1 x[n-1] + b_1 y[n-1] + px[n-1].$$

(1)

A simple recursive filter is used as one stage of n-pole integral filter:

$$y[n] = a_0 x[n] + b_1 y[n-1].$$

(2)

Repeating these calculations n times we obtain the n-pole integral filter. The coefficients are found from these simple equations [3].

Differential filter:

$$a_0 = (1 + x)/2$$

$$a_1 = -(1 + x)/2$$

$$b_1 = x$$

Integral filter:

$$a_0 = (1 - x)$$

$$b_1 = x$$

The value for $x$ can be found from the desired time constant $d$ of the filter:

$$x = e^{xp(-1/d)}$$

The coefficient $p$ in formula (1) is intended for pole/zero compensation of the preamplifier RC time constant. The optimal value for $p$ can be found experimentally for every particular preamplifier/detector combination.

The energy value for a given event is calculated as a peak value of the filtered pulse sample (see Fig.4). The energy value is used for an energy spectrum histogram filling.
4 Experimental results.

The system was extensively tested for a 3 months period. After optimization of the parameters we have found that the best energy resolution was obtained for the 8-pole digital filter with a time constant of 1.6 $\mu$sec. With this filter the measured resolution of the ORTEC germanium detector was 1.9 keV (FWHM) for the 1332 keV $^{60}$Co line, and 1.3 keV for 59.5 keV $^{241}$Am line.

The resulting energy spectrum of the $^{60}$Co test source is presented in Fig. 5.

The energy resolution has nearly reproduced the FWHM measured with a peak sensing ADC (1.8 keV).

Fig. 6 shows the low-energy part of the $^{241}$Am spectrum. We have found that the low-energy threshold of the test system is about 3 keV for the given detector. It will be lower for a detector with a better energy resolution. In any case it is already a satisfactory value for the GENIUS-TF facility [1]. The measured integral non-linearity of the test system is less than 0.01%, which is corresponding to the integral non-linearity of the used ADC. The measured differential non-linearity is less than 1%. To determine the long time stability, we tested our system for a three weeks period with a $^{60}$Co source. The air temperature in the laboratory was $21\pm1^0$C. At this condition the maximum peak shift was less than 0.5 channels (0.007%). The maximum count rate of the test system is 4000 events per second.

5 Conclusion

A digital spectroscopy system has been developed for the GENIUS-TF and GENIUS projects. Using a digital signal processing instead of analog reveals better accuracy and stability limited only by ADC quality. Our tests have proved, that this system shows an ultimate performance making it the best choice for low-level gamma spectroscopy. The system will be installed in the Gran-Sasso underground lab in the beginning of the year 2003.

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References

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ORTEC Ge−Detector with preamplifier  

Low noise Amplifier  

Flash ADC  
12 bit  
100 MHz  
dual buffer  

VME CPU  
P3/850  
LINUX  

Low noise amplifier

Fig. 1. Schematic diagram of the 8-channel test system. An output of the single Ge detector is split and connected to eight inputs of the spectrometer for test purpose.

Fig. 2. Typical Ge detector pulse recorded by Flash ADC.
Fig. 3. Compressed input pulse. A base line is subtracted.

Fig. 4. The shape of input pulse after applying a differential filter with P/Z compensation and 8-pole integral filter.
Fig. 5. Spectrum measured with $^{60}$Co source.

Fig. 6. Low-energy part of the spectrum measured with an $^{241}$Am source.