Application note: comparison between two CAEN MCAs and two CAEN digitizers

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Introduction

The most recent arrays for nuclear γ-ray spectroscopy are mainly composed of high-purity Germanium (HPGe) detectors, since they have proved to be the best detectors in terms of energy resolution, thus allowing to distinguish also nuclear levels that differ in energy for just few keVs. Resolution is not only affected by the particular detector and the specific experimental conditions but also by the electronics employed for signal read-out. In recent years more and more facilities have started to employ digital electronics, due to the large number of potential benefits it can provide with respect to the analog one. FPGA can indeed simulate the behaviour of a complex electronic chain (amplifier, discriminator, ADC, etc.) by means of dedicated algorithms for the signal processing: this of course reduces the number of electronic modules needed to perform the measurement, thus simplifying the integration of the acquisition system. Moreover the use of digital electronics can facilitate the synchronisation of more acquisition channels, therefore it is particularly suitable when working with segmented detectors (see for example Ref. [1]), and allows to operate at higher counting rates with respect to analog electronics.

CAEN has developed different spectroscopy solutions in very compact desktop digital pulse processing devices for gamma and X-ray spectroscopy. In collaboration with the INFN Laboratori Nazionali of Legnaro (LNL), one of the four Italian national laboratories, the performances in terms of energy resolution of two Multi-Channel Analyzers (MCA) and two digitizers have been compared.

CAEN Multi-Channel Analyzers are mainly conceived as devices for high-resolution energy measurements: they are provided with 14-bit resolution ADCs with adjustable dynamic ranges, low sampling rate and high impedance (1 kΩ). Digitizers on the other hand still have 14-bit ADCs, and higher sampling rate and lower impedance (50 Ω).

Experimental setup

We start by briefly reporting some other specifications of the devices used in this comparison (additional information can be found in Ref. [2]):

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- **DT5780**: MCA integrating 2 independent 16k-channels digital MCA and HV/LV power supply capabilities. Sampling rate: 100 Ms/s. Available dynamic ranges: 0.6, 1.4, 3.7 and 9.5 Vpp.

- **DT5770**: MCA integrating a 16k-channels digital MCA and a LV power supply capability. Sampling rate: 100 Ms/s. Available dynamic ranges: 1.25 and 2.5 Vpp.

- **DT5725**: digitizer integrating 8 independent 16k-channels digital MCA. Sampling rate: 250 Ms/s. Available dynamic ranges: 0.5 and 2.0 Vpp.

- **DT5730**: digitizer integrating 8 independent 16k-channels digital MCA. Sampling rate: 500 Ms/s. Available dynamic ranges: 0.5 and 2.0 Vpp.

The characterization of MCAs and digitizers and the study of their behaviour with the change of several parameters and experimental conditions was performed making use of a large set of HPGe detectors which are currently used in nuclear physics experiments at LNL. These devices could also be compared with analog electronics thanks to the presence in the laboratory of a full analog chain composed of high and low voltage, shaping amplifier and MCA. Figure 1 shows a picture with the typical set-up for measurements in our dedicated laboratory. From the left to the right we can see detector 1 with a radioactive source, detector 2 (for description of detectors see text below), the two MCAs, the laptop with the MC^{2}Analyser software for acquisition and spectra analysis, the rack with all the modules of the analog electronic chain.

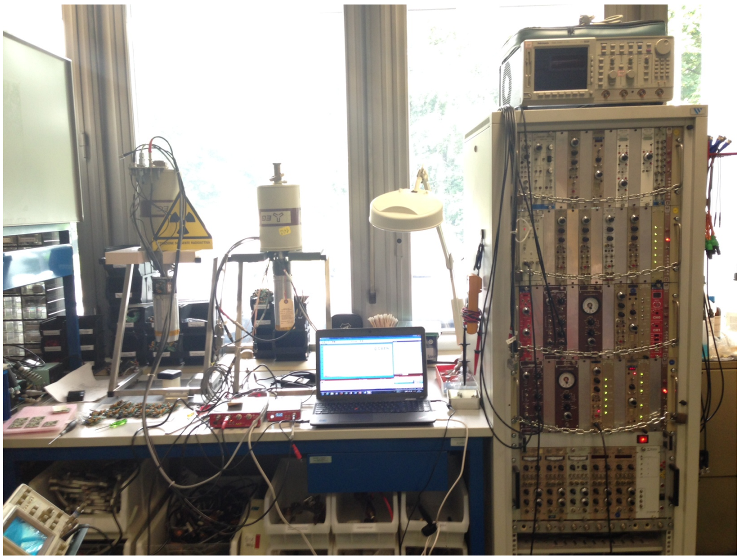

Figure 1: Experimental set-up for the measurements described in this application note. See text for details.

In this specific comparison we used the following set-up.

Detectors

- **Detector 1**: n-type HPGe detector with an intrinsic efficiency of 78.8%;
- **Detector 2**: n-type HPGe detector with an intrinsic efficiency of 36% shielded by a Beryllium window 0.5 mm thick. This detector is more suitable for measurements with low-energy γ rays.

Sources

- a low-intensity ^{60}Co source (nominal activity = 1 μCi)
- a high-intensity ^{60}Co source (nominal activity = 10 μCi);
- a high-intensity ^{133}Ba source (nominal activity = 10 μCi);

In Figure 2 two typical spectra obtained with the two sources used in these measurements are reported.

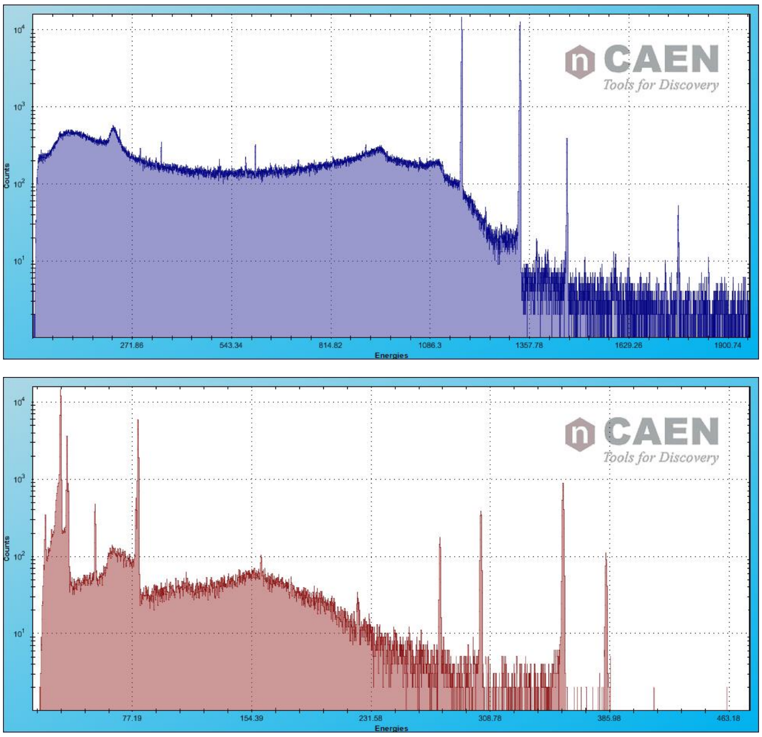

Figure 2: Top: ^{60}Co spectrum acquired with detector 1. Bottom: ^{133}Ba spectrum acquired with detector 2. Both spectra are plotted in logarithmic scale. For the ^{133}Ba spectrum the x-axis range has been reduced to the low-energy region.

Acquisition parameters and measurements

The aim of the analysis is to determine which of the four spectroscopy devices has the best performance in terms of energy resolution and it is therefore necessary to choose properly the acquisition parameters. When the counting rate on the detector is not too high (< 10 kHz) and the signals from the preamplifier have an amplitude of about 150 mV, which is usually the case in these kind of applications, the best resolution can be obtained with the smallest ADC input range available and with both long shaping times (rise time of the trapezoid filter = 9 μs and flat top = 1.5 μs) and high number of samples to calculate the mean value of the baseline (N = 4096). At this rates the shaping time in the analog amplifier can be set to 6 μs.

In these conditions we performed a specific comparison between the two MCAs DT5780 and DT5770 and the two digitizers DT5725 and DT5730 in a wide energy range of the γ radiation going from few tens of keV to about 3 MeV, with the two detectors described above. We will now present the main results of this analysis, while in the next Section we will discuss which are the proper acquisition parameters to set in order to mantain a good resolution also in high counting rate measurements.

Comparison between the two MCAs: DT5780 and DT5770

To compare the performances of the two MCAs we started with detector 1 (see previous Section for details). When connected to the analog chain, in low counting rate conditions ($\sim$ 700 Hz) with the low-intensity ^{60}Co source, we obtained a resolution of 2.21 keV for the peak at 1332 keV.

We supplied the high and low voltage from the DT5780 and analysed the output spectra from the readout channels of the DT5780 and the DT5770. The relevant acquisition parameters were set as explained above; the only setting that was changed during the tests was the trapezoid gain, which allows to spread the spectrum over more channels, thus exploiting all the dynamic range of the ADC. The trapezoid gain for the two MCAs were set in order to have the Cobalt peaks around the central channels of the full spectrum range and at nearly the same position for both the DT5780 and the DT5770. The resulting resolutions at 1332 keV are reported in Table 1.

	Analog	DT5780	DT5770
FWHM @ 1332 keV	(2210 ± 10) eV	(2050 ± 3) eV	(2223 ± 4) eV

Table 1: FWHM at 1332 keV obtained for the two MCAs with the best parameters for resolution measurements.

The DT5770 gives a result that is comparable with the resolution obtained with the analog system, while the DT5780 is almost 10% better. The increase in trapezoid gain with respect to the default value of 1 results in a substantial improvement of the resolution for both the MCAs (about 0.1 keV). The slight difference between the two may arise from the different input ranges of the ADCs (1.25 V for the DT5770 versus 0.6 V for the DT5780).

The comparison was carried out also in the low-energy range using detector 2 and the ^{133}Ba source (counting rate on the detector $\sim$1 kHz). The parameters for the acquisition were left as in the previous measurements, except for the input range of the DT5780 that was increased to 1.4 V to have an end point of the spectra at 2.5-3 MeV. In Table 2 one can see the resolutions FWHM obtained for some low-energy lines of ^{133}Ba with the two MCAs and the analog system.

	Analog	DT5780	DT5770
FWHM @ 35 keV	(512 ± 8) eV	(532 ± 8) eV	(551 ± 5) eV
FWHM @ 53 keV	(553 ± 10) eV	(606 ± 16) eV	(624 ± 10) eV
FWHM @ 81 keV	(643 ± 10) eV	(611 ± 6) eV	(661 ± 1) eV
FWHM @ 356 keV	(931 ± 11) eV	(970 ± 8) eV	(979 ± 7) eV

Table 2: FWHM at some low-energy lines of ^{133}Ba obtained for the two MCAs.

The resolutions obtained with the two MCAs are very similar also in the low-energy range and definitely comparable with those obtained with the analog system.

Comparison between the two digitizers: DT5725 and DT5730

As in the previous analysis, we started by using detector 1 with the low-intensity ^{60}Co source. The input range of both the ADCs was set to 0.5 V, the other parameters exactly as before. Also in this case the trapezoid gain was increased to spread the spectrum over more channels. The resulting resolutions for the peak at 1332 keV are reported in Table 3.

	Analog	DT5725	DT5730
FWHM @ 1332 keV	(2210 ± 10) eV	(2344 ± 4) eV	(2401 ± 5) eV

Table 3: FWHM at 1332 keV obtained for the two digitizers with the best parameters for resolution measurements.

The resolution obtainable with these digitizers is always slightly worse with respect to the MCAs. This result was expected since their performances are not addressed to the best energy resolution.

As in the previous case, we compared the two digitizers also in the low-energy range with detector 2 and the ^{133}Ba source (counting rate on the detector $\sim$1 kHz), increasing the input range of the ADCs to 2.0 V and leaving the other parameters unchanged. In Table 4 the resolutions for some γ lines are reported.

	Analog	DT5725	DT5730
FWHM @ 35 keV	(512 ± 8) eV	(532 ± 15) eV	(572 ± 4) eV
FWHM @ 53 keV	(553 ± 10) eV	(633 ± 24) eV	(659 ± 4) eV
FWHM @ 81 keV	(643 ± 10) eV	(636 ± 15) eV	(696 ± 5) eV
FWHM @ 356 keV	(931 ± 11) eV	(936 ± 12) eV	(1042 ± 5) eV

Table 4: FWHM at some low-energy lines of ^{133}Ba obtained for the two digitizers.

The two digitizers have very similar performances, even though the resolutions obtained with the DT5725 are always slightly better. We remind that the main difference between the two devices is the different sampling rate (higher for the DT5730 with respect to the DT5725). Moreover at these low energies the difference between MCA and digitizers seems much more reduced: they both give good results, fully comparable with each other.

Comparison at high counting rate

It is also interesting to test the performances of the digitizers when the counting rate (CR) on the detector is increased. In typical low-energy nuclear physics experiments the maximum CR on a detector rarely exceed 15-20 kHz. The comparison was carried out between the analog system and the MCA and the digitizer which give the best results in terms of resolution, namely the DT5780 and the DT5725. We used detector 1 and the two ^{60}Co sources. The shaping time of the shaping amplifier, the rise time of the trapezoid and the number of samples to calculate the mean value of the baseline had to be lowered as the counting rate increased over 10 kHz in order to avoid as much as possible the pile-up contribution and the consequent deterioration of resolution [3]. In Table 5 are the two different sets of parameters that were changed from low-rate to high-rate measurements.

	CR $<$ 10 kHz	CR $\geq$ 10 kHz
Analog shaping time (μs)	6	3
Rise time (μs)	9	6
Baseline mean (samples)	4096	1024
Peak holdoff (μs)	5	10

Table 5: Parameters for high-resolution measurements in condition of low and high counting rates.

The resolutions obtained in these conditions are reported in Table 6 after being normalized to the resolution at 1332 keV in the lowest counting rate conditions. This makes it easier to compare the different performances with the change of CR independently of the specific characteristics of each device, as it can be seen in Figure 3.

CR (kHz)	Analog	DT5780	DT5725
0.5	1.000	1.000	1.000
1	1.009	0.999	1.005
5	1.067	1.017	1.048
10	1.040	1.036	1.058
15	1.071	1.058	1.107

Table 6: Normalized resolutions obtained in the comparison between analog, MCA and digitizer in different counting rate conditions. See text for details.

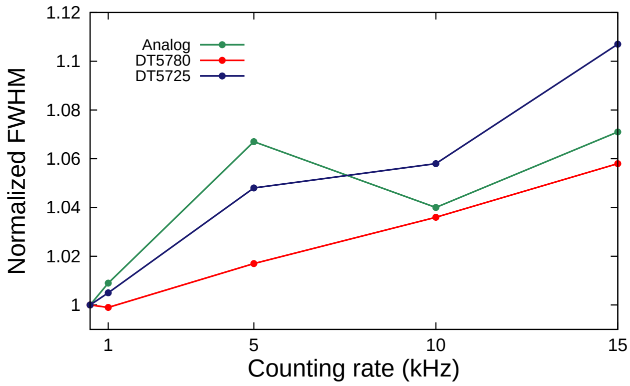

Figure 3: Trend of the resolution at 1332 keV for analog system (green), MCA (red) and digitizer (blue) normalized to the FWHM obtained with the lowest counting rate for each device.

The DT5780 shows the best (relative) performance at high counting rates. In the case of the DT5725 the variation in resolution between the lowest and the highest CR does not exceed 11% (corresponding in our case to ~ 0.2 keV). Further developments to diminish (and possibly invert) this gap are still under analysis.

References

[1] S. Akkoyun *et al.*, Nuclear Instruments and Methods in Physics Research A **668** (2012) 26-58.

[2] Web site *http://www.caen.it*.

[3] G. F. Knoll, *Radiation Detection and Measurement*, 4th Edition, Wiley, New York (1979).

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