High Rate Read-Out Of LaBr(Ce) Scintillator With The CAEN V1720 FADC

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Abstract. The energy resolution of a LaBr(Ce) detector has been studied as a function of the count rate up to 340 kHz by using a 12bit 250 MS/s V1720 digitizer. The time resolution achieved by processing off line the digitized signals has been also determined. When results are compared with the ones obtained by using standard NIM electronics, it appears that energy resolution obtained with the V1720 digitizer is better than the one with standard whereas the time resolution is poorer. However the time resolution by using the V1720 digitizer about 1.2 ns [FWHM] seems to be sufficient for applications in Non-Destructive Analysis of large objects with tagged neutron beams.

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INTRODUCTION

The SMANDRA (Sistema Mobile per Analisi Non Distruttive e RAdiometriche) [1] mobile inspection system has been designed to detect and identify sources of ionizing radiation or dangerous and/or illegal materials inside volumes tagged as “suspect” by conventional X-ray scanners. The SMANDRA detector unit includes gamma-ray and neutron detectors and it can be used in standalone mode as well as detector package connected to neuron generator for active interrogation of voxels inside a load using the Tagged Neutron Inspection System (TNIS) technique [2].

The dual use of SMANDRA (active and passive interrogations) sets stringent requirements: a) low background, high efficiency detectors for gamma and neutrons, b) capability of discriminating the two components of the radiation in the passive mode and c) high count rate capability to operate in coincidence with the associated particle counter hosted in the neutron generator. The VME front end electronics is based on a CAEN-V1720 digitizer used to perform digital pulse processing by FPGA.

In this paper results are reported on laboratory tests aimed at comparing the capability of this VME front end with respect to a traditional NIM based electronics. Results are presented for a LaBr(Ce) scintillator used for gamma ray spectroscopy.

EXPERIMENTAL DETAILS

The SMANDRA system includes a 2” x 2” BrilLanCe™ 380 LaBr(Ce) that offers the ultimate energy resolution for photon spectroscopy [3]. A distinctive fact of the SMANDRA system is that both operating modes (passive and active) are managed by a CAEN VME electronic front end based on fast digitizers. The front end makes use of a prototype battery operated VME mini-crate with a Bridge USB V1718. The mini-crate hosts a HV system V6533 Programmable HV Power Supply (6 Ch., 4 kV, 3 mA, 9 W) and a V1720 8 Channel 12bit 250 MS/s Digitizer. Inside the V1720, Digital Pulse Processing (DPP) algorithms are implemented by using FPGA, providing on-line for each event a) a time stamp, b) a complete integration of the signal, c) a partial integration of the signal used for Pulse Shape Discrimination (PSD) and d) the possibility of storing a selected part of the digitized signal.

The LaBr(Ce) scintillator performance has been also studied employing traditional NIM shaping amplifiers and constant fraction discriminators (CFTD) together with an existing acquisition system.

The radioactive gamma ray sources available in our laboratory have a typical activity of 400 kBq each. Variable count rates have been obtained by changing the source-detector distance and/or stacking more sources together. An AmBe neutron source was also used.

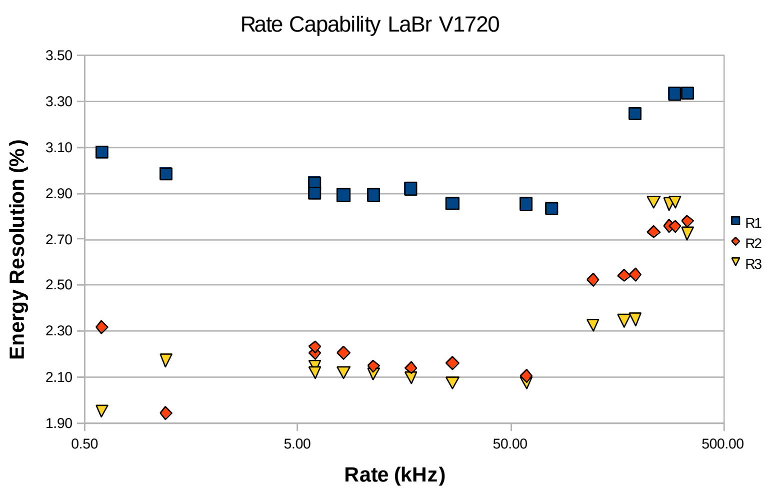

Figure. 1 Energy resolution of the LaBr(Ce) scintillator with the V1720 read-out as a function of the count rate. R1 indicates data point relative to the ^{137}Cs gamma line (0.661 MeV) whereas R2 and R3 are related to the ^{60}Co lines (1.33 and 1.17 MeV).

The energy resolution of the LaBr(Ce) scintillator was first tested up to about 20 kHz by using standard NIM electronics. The measured energy resolution is rather constant with the rate and in agreement with the producer specification (i.e. energy resolution lower than 3.5% at 661 keV). Results obtained with the V1720 digitizer, after an optimization of the DPP parameters, are reported in Fig. 1 measured with ^{137}Cs (R1; 0.661 MeV) and ^{60}Co (R2,R3; 1.17 and 1.33 MeV) sources.

It appears that the measured energy resolution reported in Fig.1 is generally better than the values measured with standard NIM electronics and maintains lower than the producer value up to very high rates, i.e. 340 kHz. Those high rates were obtained by stacking on the front face of the scintillator all available radiation sources. The resulting energy spectrum in reported in Fig.2 after an energy calibration using ^{241}Am, ^{22}Na, ^{137}Cs and ^{60}Co lines. In the spectrum of Fig.2 a transition is seen at an apparent energy of about 3.8 MeV that is identified as the 4.4 MeV line from the AmBe source. This transition resulted to be at a wrong energy, revealing a non-linearity in the energy response of the detector. This non-linearity can be compensated by using an additional quadratic term into the energy calibration.

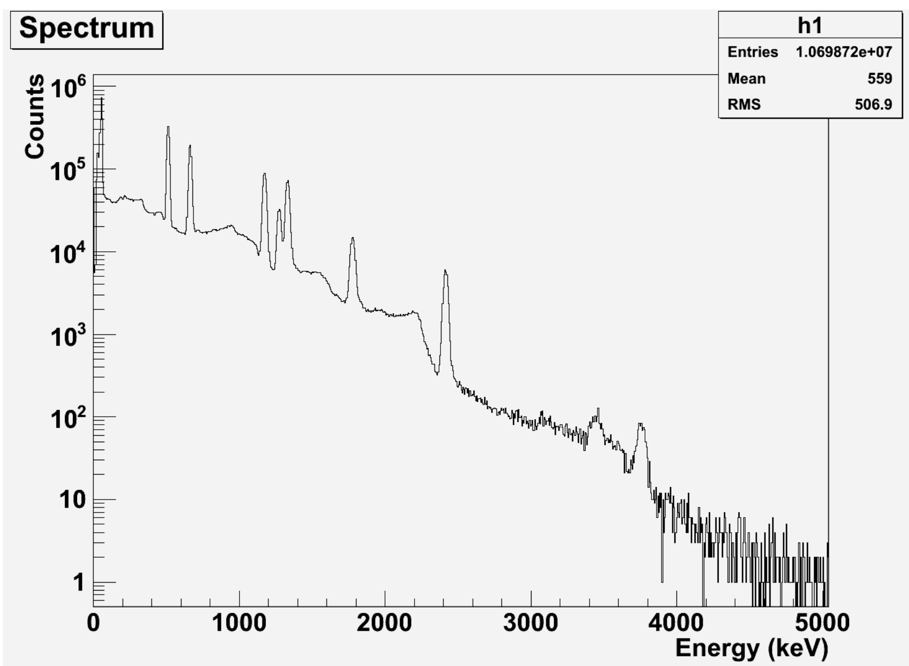

FIGURE 2 Gamma ray spectrum taken with a cocktail source at the rate of 340 kHz. For details see the text.

A further problem with the LaBr(Ce) detector is that a positive shift of a given gamma ray line appears in increasing the count rate. This shift is very large, about 40% when the count rate reaches 340 kHz. The shift was also seen in using standard NIM electronics, so that it seems to be caused by some detector component rather than by the front end electronics. Further studies of this effect has been performed by looking to digitized signals recorded at different count rate for a given gamma ray line. Results demonstrated that the shape of the signal does not depend on the count rate, ruling out possible effects in the scintillation mechanism as the after-glow. Consequently the shift is likely to be due to the PMT voltage divider.

The measurement performed with a variable count rate obtained by changing the number of sources and their distance from the detector front face, offer the possibility of determining also the V1720 dead time. The measurements performed at low rate with each source placed at relatively large distance from the detector front face fits indeed nicely with what expected from the source activity and the geometrical factors. Consequently the number of gamma ray hitting the detector front face in different geometrical configuration can be obtained by proper scaling of the geometrical coefficients.

Results presented in Fig.3 show that the measured dead time is about 10% at the higher measured rate. It has to be mentioned that this figure is obtained by using one out of the 8 FADC channels available in the V1720 card and without writing the digitized signal but storing only the FPGA produced data.

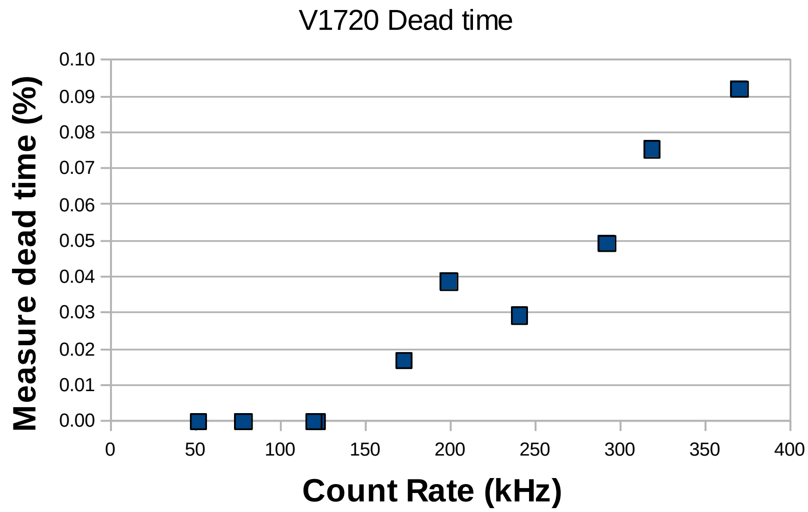

FIGURE 3. Measured dead time of the V1720 digitizer measured as a function of the detector count rate when only one of the 8 available channels are used storing only FPGA processed data.

A second part of our study has been devoted to the time resolution achievable by processing the digitized signal. Timing properties are important in our application when the system is used in active interrogation with tagged neutron beams. In this case, indeed, the associated alpha particle emitted in the final state of the neutron emitting reaction D+T is detected inside the neutron generator providing the emission time of the neutron and its flight direction, as defined by kinematics. The detection time of the neutron induced gamma rays inside the material allows determining essentially the travel time of the neutron. In this respect the time resolution of the system define the depth of the voxel investigated by the neutron beam [1,4].

One of the appealing facts of the LaBr(Ce) scintillators is the fast signal with a primary decay time of 26 ns which allows sub-nanosecond time resolution.

Time resolution measurements have been measured by collecting gamma-gamma coincidences against a EJ228 fast plastic detector with a ^{22}Na source. Time resolution of about δt=0.65 ns [FWHM] are obtained by processing the PMT's anode signal with NIM CFTDs operated with a threshold of 500 keV.

When both anode signals of the LaBr(Ce) and EJ228 scintillators are processed by the V1720 card, the FPGA provides a time stamp for the events in the two detectors. Off-line software analyzes the event file reconstructing the coincidence events and the time correlation between detectors. Since in this case the width of each time bin of the digitizer is 4 ns, the achievable time resolution is relatively poor. Better results can be obtained by storing the interesting part of the digitized signal for off-line analysis. In this case, the time interval from the start time of the digitization and a given fraction of the front part of the signal is determined for each detector, correcting for the amplitude effects. The time correlation reconstructed after this analysis yields a time resolution better than the V1720 sampling bin (4 ns). Laboratory tests using gamma-gamma coincidences yield a time resolution of δt=1.15 ns [FWHM] for LaBr(Ce) against fast plastic with the lower threshold discrimination set software at about 500 keV.

The time resolution obtained with the V1720 card by extracting the time coincidence with a simple algorithm correcting only for the signal amplitude seems to be not as good as the one achieved by using NIM CFTD with compensation for amplitude and rise time. We are still working to implement such corrections in our software. However, it has to be noted that the time resolution already obtained with simple algorithms is enough for the present application: a δt=1.2 ns time resolution reflects in about 6 cm depth for the inspected voxel by using the 14 MeV tagged neutrons beam.

SUMMARY AND CONCLUSIONS

The energy resolution of a LaBr(Ce) scintillation detector has been studied as a function of the count rate up to 340 kHz by using a 12bit 250 MS/s V1720 digitizer. Results obtained are better than the ones obtained with the same detectors with standard NIM shaping amplifiers up to 20 kHz.

Moreover the time resolution achieved by processing off line the digitized signals in a gamma-gamma experiment against a fast plastic scintillator is about δt=1.2 ns [FWHM] to be compared with δt=0,65 ns [FWHM] when standard NIM Constrat Fraction Time Discriminators are used. However the time resolution by using the V1720 digitizer is sufficient for application in Non-Destructive Analysis of large objects with tagged neutron beams.

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