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# Digitisation techniques applied in nuclear measurements

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Digitisation techniques are being rapidly adopted to nuclear measurements due to large progress made in computing performance. Waveform digitisers are able to record the complete detector output signal with a high dynamic range. This method has obvious advantages compared to the traditional analogue technique, where separate electronic units are applied for selection and storage of the information: Full information contained in the output signal of a detector is recorded and makes possible to apply different signal processing algorithms during data analysis to focus on different aspects of the given experiment using the same data set repeatedly. The choice is limited only by the imagination of the experimentalist.

It is also possible to increase the counting rate while maintaining successful particle discrimination still being able to fully determine the physical properties of events separated by a few hundreds of nanoseconds.

The rapid increase in computer power and in data storage capacity stimulated the use of waveform digitizers as a new technique for nuclear experiments. The apparent advantages have been demonstrated in recent feasibility studies. It has been shown, that this technique improves the quality of particle identification, the dynamic range as well as the electronic stability during the experiment.

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## 1. Introduction

Use of the wave-form digitisation (WFD) equipment in neutron induced reaction experiments is becoming more and more popular. This is due to the fact that computing power and storage capacity has tremendously increased over the past decade. The use of WFD-technique has advantages compared to the standard analogue technique. With analogue-to-digital converters (FADC) it is now possible to record the complete pre-amplifier output signal during an experiment. In case of ionisation chambers, which are generally used for fission fragment spectroscopy, this signal contains all necessary information on the particle kinetic energy, mass and charge as well as its emission angle. Since all this information is contained in the signal shape, it is possible to apply any method for signal processing/data analysis. In consequence, most of the front-end electronics is obsolete because it may be simulated by software algorithms during off-line data processing. With this method it is also possible to handle a much higher counting rate, while maintaining successful particle discrimination and still being able to fully determine the physical properties of events separated by only a few hundreds of nanoseconds.

Pioneering work has been accomplished at IPPE, Obninsk, Russia on the use of a fast CAMAC digitizer applied together with a high resolution double Frisch-grid ionisation chamber [1,2] and at the Joint European Torus (JET) facility [3].

Experimental investigations are striving more and more for measuring subtle changes in the fission fragment properties e.g. as a function of incident resonance neutron energy or reaction cross sections of highly radioactive actinide material. Hence, it becomes important to eliminate any possible distortion of the raw signals, such as pileup, baseline shifts and spurious events. With the digital signal processing this becomes feasible.

## 2. Digitiser equipment

Presently two companies are competing on the market for high-speed, high performance digitisers, Acqiris [4] and FAST Comtec [5]. Acqiris high-speed digitisers provide sampling rates from 100 MS/s to 8 GS/s and feature wide bandwidths and acquisition memories up to 1 GSamples per channel. Using high-speed 8-, 10-, and 12-bit analogue to digital converters (ADC), Acqiris has presently the lead in the competition. The Acqiris digitizers are available in the popular PCI, CompactPCI and PXI formats.

The CompactPCI format is ideal for use in large multi-channel systems. Up to 4 synchronously sampled input channels are available per card and up to 10 digitizer cards can be synchronized using an Acqiris proprietary bus.

The FAST Comtec MI.30xx series offer a wide range of fast 12 bit A/D converter boards which are PCI bus compatible. These boards offer a choice of one to four input channels with a maximum sample rate of 200 MS/s. Optionally 4 digital inputs per channel can be recorded synchronously.

On-board memory of up to 256 MSample can be used for storing digitised signals. Several boards of the FI.30xx Series can be interconnected by an internal bus to operate from the same time base.

Several laboratories are working on their own design of FADC's for specific applications including on board pre-processing possibilities. Additionally, small companies are also providing customer driven solutions.

## 3. Applications

The digitisation technique is presently used at different neutron time-of-flight (TOF) facilities based on white spectrum neutron sources and also mono-energetic neutron sources driven by Van de Graaff accelerators. Examples are GNEIS at PNPI, Gatchina, Russia [6], DANCE at LANSCE, Los Alamos, USA [7], KURRI at Kyoto, Japan [8], n_TOF at CERN, Switzerland [9] and GELINA at IRMM, Belgium. Due to the fact that the detector signal is being sampled by a waveform digitiser and stored for further off-line processing, many processing possibilities can be thought off. It gives also rise of solving those problems, which historically where considered not solvable with analogue techniques.

### 3.1 Applications to gamma ray detection

Neutron capture experiments, which are the main applications at the different sites mentioned above, suffer from dead time effects due to variable counting rates e.g. in the resonance region or overload effects due to the strong gamma flash accompanying the neutron production process at several white spectrum neutron sources based on electron linear accelerators. Using digitisation equipment, both mentioned effects can be tackled.

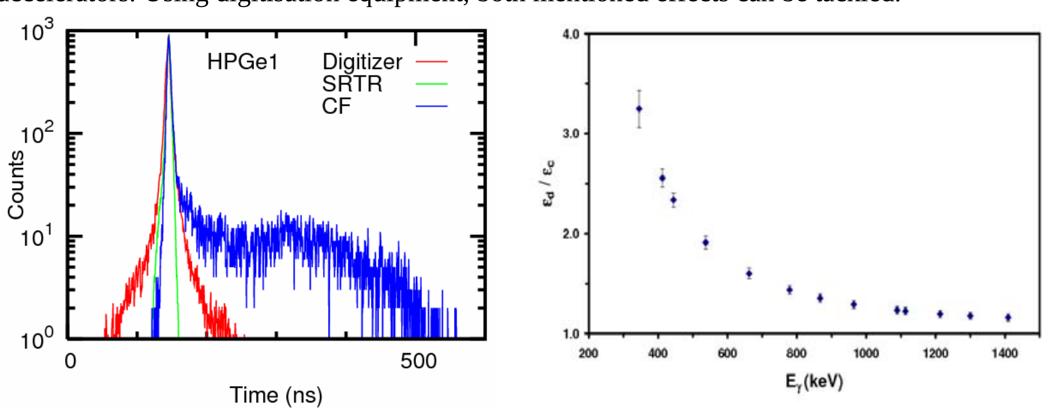



Fig. 1: Left side: Time resolution spectrum showing the problem of slow rise-times present in a HPGe detector (blue curve). Rejection of those slower times (green curve) improves very much the timing resolution, but reduces strongly the efficiency. Use of digitisation (red curve) yields a similar time resolution with increased efficiency. Right side: Ratio of efficiencies using digitisation equipment compared to conventional electronics

The application of digitisers has reduced dramatically the dead time of the data acquisition systems. This is especially important when carrying out measurements in the resonance region or close to the gamma flash. In both cases very variable and large counting rates are occurring, deteriorating the spectrum shape. Another problem occurs in the case when HPGe detectors are used. In high resolution TOF experiments the timing properties of HPGe detectors show a large tail indicating a delayed timing. This tail contains 40-60% of the total events and is deteriorating the TOF resolution (see left side of Fig. 1, blue curve). With conventional electronics the only remedy is to use the slow rise time rejection (SRTR) method (see left side of Fig. 1, green curve), which cuts out all times longer than a preset time, hence reducing the efficiency of the detector. Using digitisation (see left side of Fig. 1, red curve) one can cope with this intrinsic detector effect and improve the efficiency drastically (see right side of see Fig. 1).

### 3.1 Applications to neutron detection

For neutron spectroscopy normally organic scintillators are used coupled to fast photomultiplier tubes. Liquid scintillators have been used for many years in neutron detection due to their excellent timing performance and good pulse shape discrimination (PSD) properties. This PSD performance relies on the fact that different particles (γ-rays, neutrons) generate different pulse shapes with differences in the intensity of slow and fast components with very much difference in the decay times. A typical signal shape for electron and proton pulses with the same total charge is given in Fig. 2.

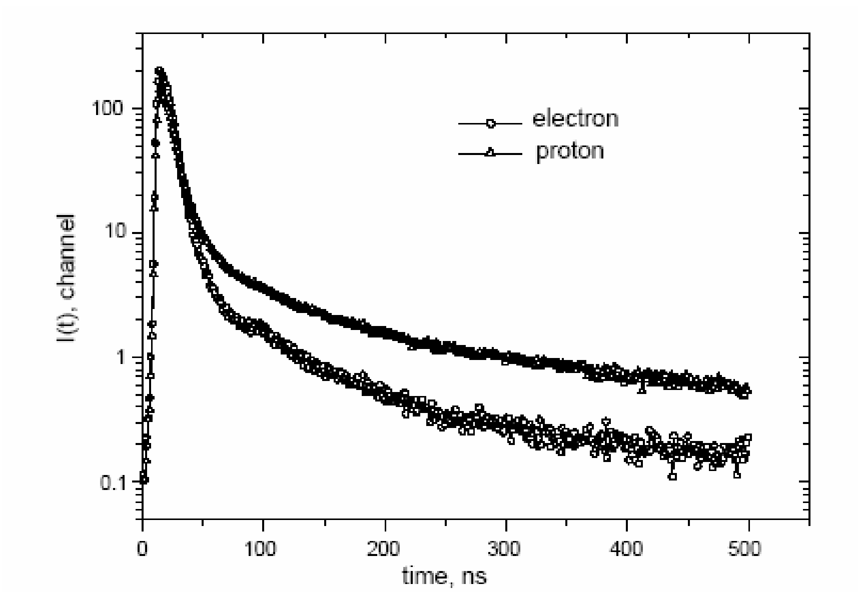



Fig. 2: Time distribution of the detector signal generated by proton and electrons in a liquid scintillator with the same total charge.

This phenomenon has been studied since several decades and analogue PSD modules giving good n/γ discrimination are available on the market. The use of high-speed digitization opens new possibilities in the sense that the complete pulse shape is digitized and can be treated with different algorithms to achieve the best PSD discrimination. In Ref. [10] the traditional method of integration of a slow and a fast component of the spectrum shown in Fig. 2 has been compared to a correlation method. The latter showing improved PSD discrimination (see Figs.3, 4). A comparison of analogue to digital electronics has demonstrated that in both

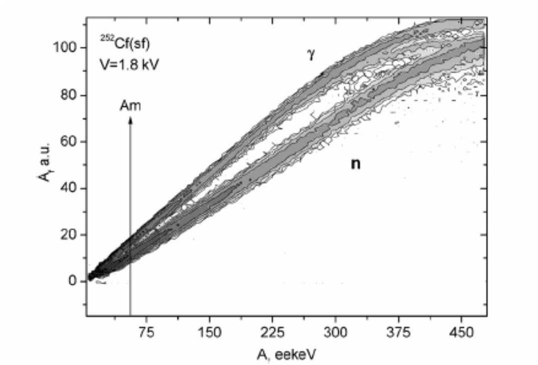



Fig. 3: Quality of the particle identification using the slow and fast rise time integration method [10].

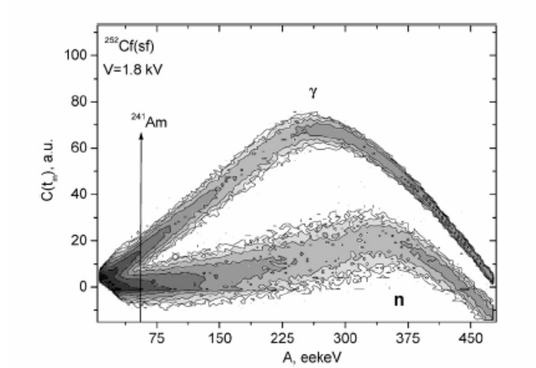


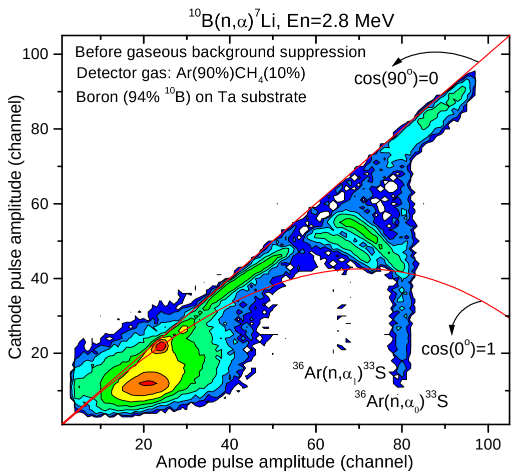

Fig. 4: Improved quality of the particle identification using the correlation method [10].

cases comparable TOF resolutions can be achieved [11]. Even though high speed digitizers with high pulse resolution of 10 or 12 bit are not having a really high sampling frequency (only recently Acqiris overcame this boundary) of 1GSamples or more, the timing resolution achieved can be considerably better than the time width of a single digitizer bin. In certain applications time resolutions down to 100 ps at full-width-half-maximum have been obtained with a 100MSample 12 bit digitiser [12].

### 3.2 Applications to charged particle reactions

Also in case of light charged-particle reaction products the use of the digitisation technique offers substantial advantages compared to the traditional technique. As an example measurements of the $^{10}B(n,\alpha)^{7}Li$ reaction cross section at MeV incident neutron energies is shown in Figs. 5,6 taken from Ref. [13]. In case of ionisation chambers as reaction product detectors, also secondary reactions within the particular gas mixture used may occur.

Those reactions are observed in the spectra as background lines (see Fig. 5). With conventional electronics a separation of foreground and background would not have been possible. The use of fast digitisers, however, allowed an unequivocal separation since, dependent on the shape of the digitised signal, the particle track can be reconstructed and particles originating from the gas volume can be rejected, giving much more clean spectra for final cross section determination (see Fig. 6) [2].



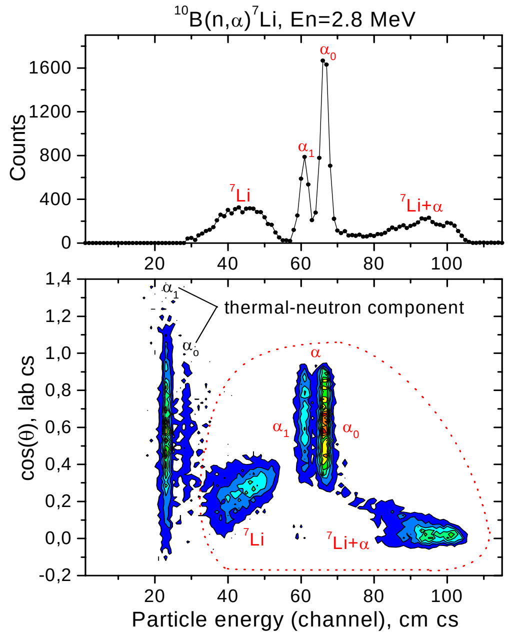




Fig. 5. Two-dimensional pulse amplitude spectrum of the cathode versus the anode pulse height for the $^{10}$B(n,α)$^7$Li reaction at $E_n$ = 2.8 MeV. Background lines from the Ar component from the Ar-$CH_4$ gas mixture are identified [13].

Fig. 6. Two-dimensional spectrum of the cos (θ) versus particle energy after background suppression. The marked region contains all foreground events of interest [13].

## 4. Conclusions

In this paper several examples have been presented, where the digitisation technique has improved the quality of experimental results. The market of high speed digitisers is still in a very fast development cycle, opening up further possibilities in the future and reducing remaining limitations of present day digitisers for certain experiments. The investment side should also not be forgotten since digitisation equipment is rather expensive, but on the other hand WFD's can replace many analogue devices meaning a substantial saving. Nevertheless, state-of-the-art experiments will very much profit from this technique. Also in other fields digitisation has made its introduction, as is seen on the number of papers published e.g. in Nuclear Instruments and Methods A in the past couple of years.

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