Digital data acquisition system for neutron metrology

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Abstract. Within the neutron metrology and spectrometry community digital pulse processing systems are being developed for measurements of fast neutron fields in a wide variety of contexts. Investigations have been completed into the suitability of a CAEN DT5730 digitiser unit an alternative to a traditional analogue system for data acquisition for fast neutron metrology. Experiments were undertaken at the fast neutron facilities of AMANDE using a BC501A scintillation detector and both the DT5730 digitiser and an analogue system based on NIM electronics and an MPA-3 multichannel analyser acquisition unit, under identical conditions using a broad range of beam conditions available at the AMANDE facility. The measurements covered an energy range from 0.5 MeV to 20 MeV, over a large range of intensities allowing for the digital system to be benchmarked against the metrology standard acquisition system for a large range of contexts. The results of the study indicate that digital data acquisition systems have matured, such that they may be considered for neutron metrology measurements in the laboratory and in field.

1. Introduction

Metrology is the science of measurement, and fundamentally has as its focus the activity of counting with reference to a set of standards. Neutron metrology may be understood as the process of counting free neutrons, with the two main quantities of interest being the number of neutrons (either crossing a region of interest or emitted by a source), and the energy distribution of these neutrons. The measurement result is often presented as a fluence rate (number of neutrons per unit time), which can further be presented as a function of the neutron energy. This process is often complicated by the energy dependent fluence being influenced by the directionality of the neutron source [1].

Neutron fields can vary widely with respect to context, energy and fluence [2], with each of these aspects introducing an additional degree of complexity. The energy of neutron fields can range from cold neutrons produced at facilities like CNRF [3] and HANARO [4], below the meV range, to very high energy (on the order of GeV) neutrons produced in accelerator facilities or by cosmic rays interacting with the atmosphere. Similarly, the possible intensities span from a few neutrons cm^{-2} s^{-1}, having importance to radiation protection, to 10^{15} neutrons cm^{-2} s^{-1}, occurring at the core of high intensity nuclear fission reactors.

The way in which neutrons are detected varies greatly with energy and intensity. Neutron interaction cross-sections are highly dependent on the material type and the energy of the irradiating neutrons [5, 6]. On the higher end of the intensity range, detecting individual neutron events becomes more difficult and estimating the number of neutrons interacting with the material often relies on a calculation rather than direct measurement [1].

Direct measurements of neutron energy and fluence requires well characterised response functions for the detector used if spectrum unfolding is required. Unfolding relies on convolving the response functions to fit the measurement to determine the fluence distribution as a function of energy [7]. For these measurements pulse shape discrimination techniques are required to separate the events associated with incident neutrons and gamma-rays.

Metrology laboratories such as the IRSN (France), PTB (Germany), NPL (UK) and iThemba LABS (South Africa), use a BC501A organic liquid scintillator coupled to an analogue pulse processing acquisition system as the reference for measurements of neutron fields. These reference systems are based on NIM-standard pulse processing modules and an analogue ADC-based multi-parameter analyser (MPA) [8]. These systems are expensive, difficult to use outside of the laboratory and have a limited technological horizon.

The advent of digital data acquisition systems (dDAQs) for nuclear radiation measurements has brought several new approaches to the acquisition and analysis of data. However, rigorous benchmarking is required before such a system can be deployed in a neutron metrology scenario. A comparison of an off-the-shelf CAEN DT5730 digitiser [9] to the metrology standard analogue acquisition system is presented.

The measurements, made at the AMANDE facility [10], were taken with a BC501A detector coupled with either the standard analogue metrology acquisition system (MPA-3) [11, 8] or an off-the-shelf CAEN DT5730 digitiser [9]. The measurements covered an energy range from 0.5 MeV to 20 MeV, over a large range of intensities giving an effective range for the neutron fluence rates at the position of the detector of 10^3 cm^{-2} s^{-1} to 10^4 cm^{-2} s^{-1}. Unfortunately the detector is also sensitive to gamma photons, and mixed neutron-gamma fields always occur within the contexts studied. To account for this, responses for both neutron and gamma events are recorded, and pulse shape discrimination (PSD) is used to differentiate between neutron (proton recoil) and gamma (electron recoil) events. The results for the measurements of the 7.000(6)MeV neutron field at the standard beam current of 0.57 µC are presented.

The energy and intensity response for both systems and digital configurations were investigated based on the unfolding of measured light output spectra using an existing neutron response matrix for the detector. The quality of the measured neutron spectra were compared through uncertainty budgets designed for both systems.

2. Results and Analysis

The analogue acquisition system determines the light output parameter (L) through the integration of the slow output (dynode) of the detector. The analogue pulse shape parameter (S) is determined using the zero cross over method [12, 13, 14] and implemented using a FAST Comtec 2160A PSD unit [11]. The digital measurements consisted of sampling the anode waveform and determining the analysis parameters post acquisition. The light output parameter was calculated as the integral of the sampled waveform for an integration time of 500 ns, and the pulse shape parameter was determined through the charge comparison method [15, 16, 17]. The digital pulse shape parameter was defined as the ratio of an integral over 30 ns to L.

The measurements of events as a function of S and L allow for the neutron events to be selected for through pulse shape discrimination (PSD) techniques [11, 18]. The events as a function of S and L can be seen in figure 1 for the MPA-3 and DT5730 acquisition systems, where L is presented in a MeV$_{\mathrm{ee}}$ scale defined by the units of MeV for recoil electrons. The measurements are in good agreement with each other and exhibit the same features. The only significant difference being related to pile up event management which is attributed to the difference in the definition of S.

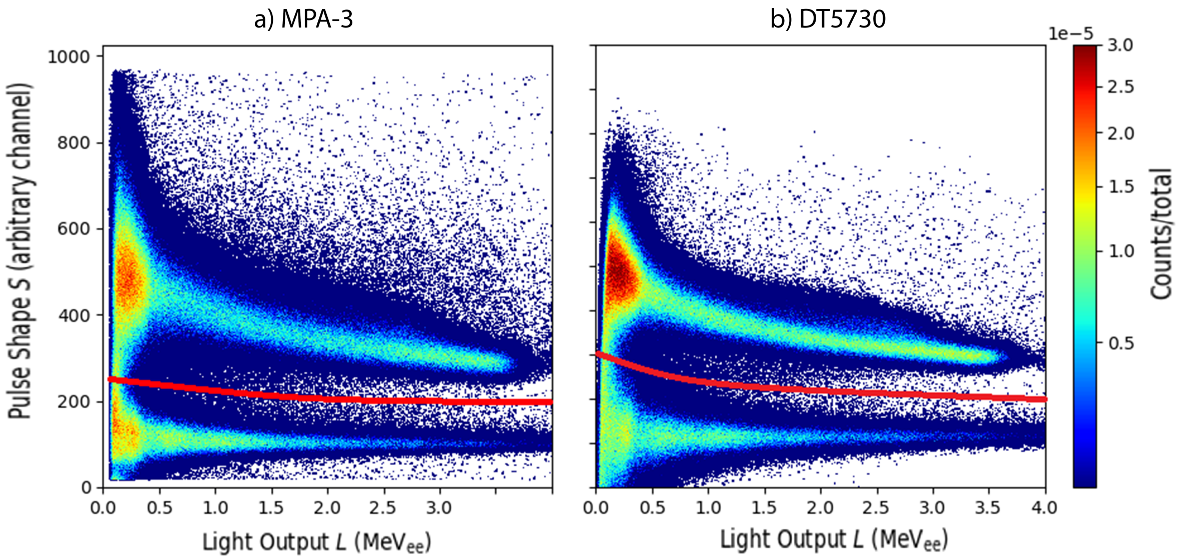

Figure 1. Events as a function of S and L (MeV$_{\rm ee}$) for (a) the MPA-3 acquisition system and (b) the DT5730 CAEN digitiser for the 7.000(6)MeV neutron field measurement. The neutron-gamma cuts are indicated by the red lines where the neutron events have a higher S value.

The separation of the loci associated with neutron and gamma-ray events can be determined through a Figure-of-Merit (FoM) value, which is defined as:

$$FoM = \frac{|\mu_p - \mu_e|}{\mathrm{FWHM}_p + \mathrm{FWHM}_e} \tag{1}$$

where $\mu_{p,e}$ and FWHM$_{p,e}$ refer to the mean and full width half maximum of the proton and electron recoil loci respectively. The distributions presented in figure 1 can then be compared using the FoM as a function of light output, as seen in figure 2. Below a FoM value of one, the loci are considered inseparable. The quality of separation is equivalent for the two acquisition systems, with their lower energy limits in agreement with each other.

From these measurements neutron cuts are applied (indicated in red in figure 1), selecting for events which are only associated with neutrons. The neutron light output spectra can be seen in figure 3(a) along with the associated neutron energy spectra 3(b). The normalised neutron light output spectra are in good agreement indicating that the shape of the spectra behave as expected. The neutron energy spectra seen in figure 3(b) exhibit the same features, with the smaller secondary peaks in good agreement across the two acquisition systems. The disagreement in the primary neutron energy peak is attributed to the small difference in the edge of the neutron light output spectra seen in figure 3(a) due to differences in the light output parameters.

The results for the measurements of the primary energy peak for the 1.200(3) MeV, 2.500(4) MeV, 5.000(3) MeV and 7.000(6) MeV neutron fields are presented in table 1 with their associated standard uncertainties. The results all agree with the expected values, calculated from beam conditions, within 2σ.

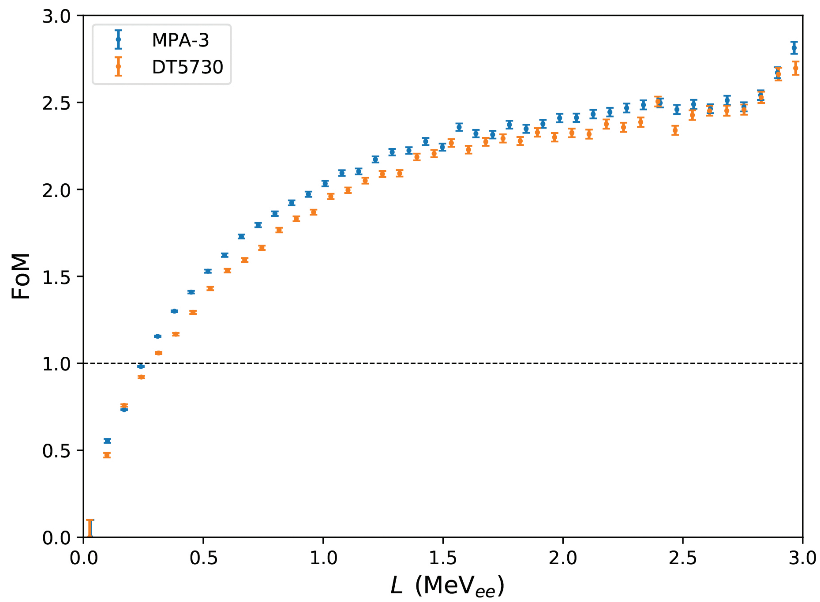

Figure 2. Figure-of-Merit (FoM) as a function of L (MeV$_{ee}$) for the 7.000(6)MeV neutron field measurement for both acquisition systems, indicating equivalent PSD quality for the two acquisition systems. FoM values were calculated from slices along the L-axis of width 0.1 MeV$_{ee}$.

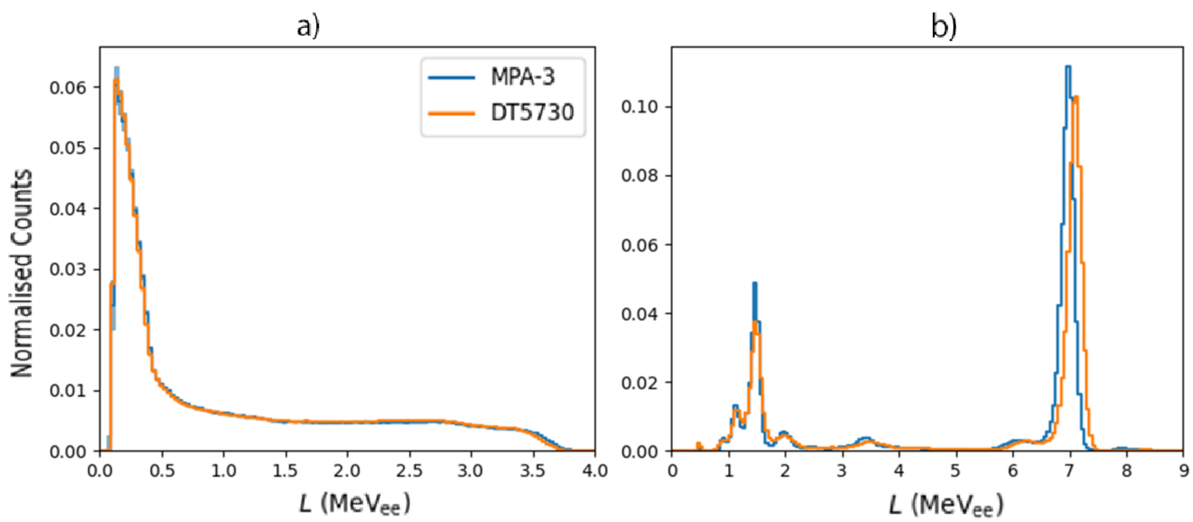

Figure 3. The (a) neutron light output spectra and (b) the associated neutron energy spectra, normalised by the total counts, as measured by the MPA-3 acquisition system (blue) and the DT5730 CAEN digitiser (orange) for the 7.000(6)MeV neutron field measurement.

3. Conclusion

In conclusion, the measurements reported here made with a CAEN DT5730 system suggest that modern digital systems are now offering a reliable alternative to the well characterized reference acquisition systems based on analogue NIM modules. The measurements demonstrated similar quality PSD separation, with good agreement in unfolded energy distributions between the two data acquisition systems for the four measured neutron energies. Present measurements were made with the DT5730 module connected by USB-2 cable to a regular laptop. Further improvements in stability, reliability, and performance are expected by utilising the optical cable connection between the DT5730 and an appropriate desktop PC. Rate related measurements and characterisation are required to fully investigate dead time effects and stability.

Table 1. Neutron energy measurements for the 1.200(3) MeV, 2.500(4) MeV, 5.000(3) MeV and 7.000(6) MeV neutron fields for the analogue and digital systems along with the expected values of the neutron energies calculated from beam conditions.

Expected Neutron Energy [MeV]	1.200(3)	2.500(4)	5.000(3)	7.000(6)
MPA-3 Measured Energy [MeV]	1.145(26)	2.515(42)	4.994(82)	6.98(11)
DT5730 Measured Energy [MeV]	1.160(30)	2.582(63)	5.053(97)	7.10(14)

Further investigations on a large range of beam conditions will enable a comparison of neutron energy spectra determined from both neutron time-of-flight and unfolding techniques. For a larger range of applicability, analysis of measurements taken with other detectors and at other facilities (UCT and iTL) will be completed.

The present investigations have demonstrated that there is now value in seriously considering implementation of a digital acquisition system for fast neutron metrology in a laboratory setting. Furthermore, a compact digital unit, such as the DT5730, offers the advantage of deploying the same metrology reference system in both laboratory and field environments.

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References

[1] Thomas D, Nolte R and Gressier V 2011 *Metrologia* **48** 225–38
[2] Nolte R, Allie M, Böttger R, Brooks F, Buffler A, Dangendorf V, Friedrich H, Guldbakke S, Klein H, Meulders J, Schlegel D, Schuhmacher H and Smit F 2004 *Radiation Protection Dosimetry* **110** 97–102 ISSN 0144-8420
[3] Arif M, Dewey M, Greeneand G and Snow W 1993 *Journal of research of the National Institute of Standards and Technology* **98(1)** 135–144
[4] Kim Y K, Lee K H and Kim H R 2008 *Nuclear Engineering and Design* **238** 1664–9 ISSN 0029-5493
[5] Block R, Danon Y, Gunsing F and Haight R 2010 *Neutron Cross Section Measurements* (Boston, MA: Springer US) pp 1–81 ISBN 978-0-387-98149-9
[6] Carlson A 2011 *Metrologia* **48** S328
[7] Beni M, Krstic D, Nikezic D and Yu P 2019 *Nuclear Science and Techniques* **30**
[8] FastComtec *Model MPA-3, PC-card Multiparameter Multichannel Analyzer System*
[9] DT5730 / DT5730S - 8 Channel 14 bit 500 MS/s Digitizer - CAEN - Tools for Discovery online: https://www.caen.it/products/dt5730/ (Accessed on 02/09/2020)
[10] Gressier V, Guerre-Chaley J, Lacoste V, Lebreton L, Pelcot G, Pochat J, Bolognese-Milstajn T and Champion D 2004 *Radiation Protection Dosimetry* **110** 49–52 ISSN 0144-8420
[11] 2160a https://www.fastcomtec.com/nim/2160a (Accessed on 02/09/2020)
[12] Roush M, Wilson M and Hornyak W 1964 *Nuclear Instruments and Methods* **31** 112–24 ISSN 0029-554X
[13] Sperr P, Spieler H, Maier M and Evers D 1974 *Nuclear Instruments and Methods* **116** 55–9 ISSN 0029-554X
[14] Onge R, Galonsky A, Jolly R and Amos T 1975 *Nuclear Instruments and Methods* **126** 391–5 ISSN 0029-554X
[15] Moszynski M, Bizard G, Costa G, Durand D, El Masri Y, Guillaume G, Hanappe F, Heusch B, Huck A, Peter J, Ring C and Tamain B 1992 *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **317** 262–72 ISSN 0168-9002

[16] Kaschuck Y and Esposito B 2005 *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **551** 420–8 ISSN 0168-9002
[17] Esposito B, Kashchuk Y, Rizzo A, Bertalot L and Pensa A 2004 *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **518** 626–8
[18] Brooks F 1979 *Nuclear Instruments and Methods* **162** 477–505 ISSN 0029-554X