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Digitalized two parametric system for gamma/neutron spectrometry

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INTRODUCTION

Many types of detectors like stilbene, NE-213 etc. in conjunction with photomultiplier loaded with low working resistance produce pulses of approximately 100 ns length and contain information about deposited particle in the trailing edge. Using fast analog to digital converters (ADC) and field-programmable gate array (FPGA) it is possible to create a spectrometric system working in mixed gamma and neutron fields which is not loaded dead time. The count rate of processed pulses can reach more than one million per second.

Such a high count rate of processed pulses can be achieved due to the pulse processing is implemented in FPGA. The output of this pulse processing is amplitude which describes the energy of deposited particle and discrimination parameter whereby it is possible to discriminate photons and neutrons. To increase the dynamic range of energy of detectable particle the signal from photomultiplier is separated into two branches with different amplification. Each branch is digitalized by separate ADC. Components from which the system is composed are so light that the spectrometer can be easily transported. Its weight is less than 3 kilograms.

Spectrometer was tested in the research reactor LR-0 in Rez near Prague (Czech Republic). The measured data was processed using deconvolution into a neutron flux density and compared with nowadays used analog spectrometer and simulation result. Measured neutron spectrum of Cf-252 is included.

THE AIMS OF DIGITAL SPECTROMETER

Neutron spectra in research reactor LR-0 in Rez are nowadays measured by analog spectrometer which uses photomultiplier with high working resistance load on anode. [1] Therefore the length of measured pulses approaching 1 millisecond. The information about deposited particle is situated in leading edge of pulse. The advantage of long pulses is low demands on evaluation electronics because it is not necessary to work with high frequencies. The disadvantage is a low count rate of processed pulses which is up around 1000 pulses per second.

The analog spectrometer processes separately the amplitude of pulse and pulse shape discrimination parameter. The digitalization occurs at the end of the signal processing.

The problem of analog processing is a high susceptibility to external noise and disturbances caused by aging. The analog spectrometers are typically based on Nuclear Instruments Modules (NIM) and therefore contain many configurable components and connectors. These components are due to the aging the source of disturbance. The first aim of the digital spectrometer is to minimize the number of components which are susceptible to change the parameters due to aging, especially analog adjustment elements.

The second aim of digital spectrometer is to increase the count rate of processed pulses per second. Using the low working anode resistance of photomultiplier the pulse length is reduced approximately to 100 ns. The information about the type of deposited particle is now situated into the trailing edge of impulse – the discrimination is still possible. [3]

The third aim is improving the resolution and pulse shape discrimination at low energies. The signal from the detector is separated into two branches which consist of amplifier and analog to digital converter. Each branch has different amplification.

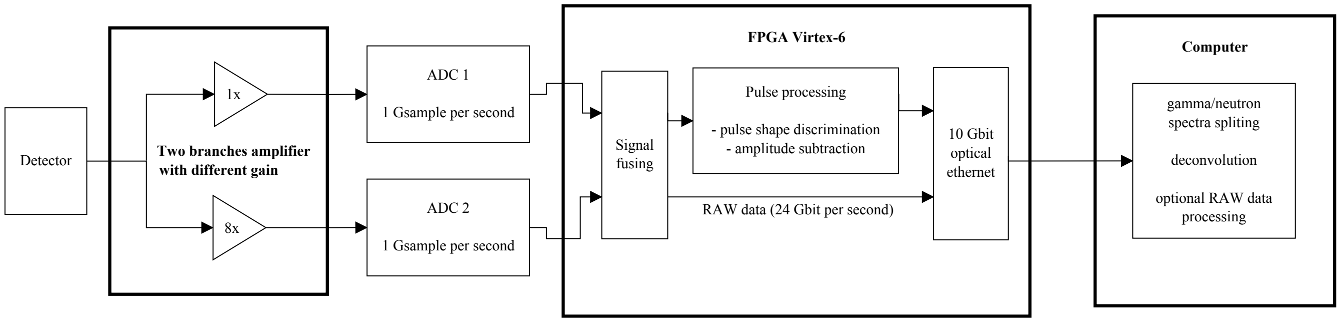

Fig. 1. Scheme of two parametric digital spectrometer.

SPECTROMETER DESCRIPTION

The digital spectrometric system is built as a modular system which allowing replacement of individual parts according to the needs of the experiment (i.e. replacing the amplifier when the detector is replaced). See Fig. 1. The analog part consists only of the operating amplifiers which adjust output signal of detector to input range of ADC. All other signal processing is done in digital part.

Fig. 2. Two parametric digital spectrometer. From the right: detector, amplifier with one input and two branches with different amplification, digital spectrometer.

Amplifier

The analog amplifier splits the signal from detector into two branches. Each branch is differently amplified and digitalized by separate ADC. This different amplification increases the dynamic range of energies of particles that the spectrometer is able to process and increase the signal to noise ratio. The ratio of amplification of signal branches is about 8.

Both signal branches of amplifier do not change the phase of the signal. Therefore it is possible to fuse the signal at the beginning of digital processing and the future processing is easier because it works only with one signal path.

ADC card

The input analog signal is digitalized by two fast ADC Texas Instruments ADC12D1000 working on sampling frequency 1 GHz. Digital signal processing is implemented in FPGA Xilinx Virtex-6. FPGA is able to process all data flow from both ADC (24Gbits per second). It means that the spectrometer is not loaded by the dead time. Implemented discrimination algorithm reduces the data flow to no more than several hundreds of megabits per second.

It is possible to transfer raw data from ADC to computer for future offline processing. This option is ideal while designing and testing discrimination methods.

Computer

The computer is used to control the spectrometer and for saving and processing of measured spectra. The deconvolution of measured spectra is realized in the computer. The connection between the ADC card and the computer is realized by 10 Gbit optical ethernet. The high speed is ideal while saving raw data from ADC.

PHOTON AND NEUTRON DISCRIMINATION

Digital spectrometer uses integration method which is based on the principle of charge comparison (CC). The principle of this method lies in comparison of area limited by a trailing edge of the measured response with area limited by the whole response. [3]

$$Q_1 = \int_{t_1}^{t_2} i(t)dt, \quad Q_2 = \int_{t_0}^{t_2} i(t)dt, \quad D = \frac{Q_1}{Q_2}$$

Integrals Q_1 and Q_2 over the individual impulses can be expressed numerically. The specific shape of impulses depends on the used measuring apparatus. The result of classification function D is a ratio between numerated values of charges Q_1 and Q_2. Value t_0 is always determined by time of reaching maximum (amplitude) and values t_1 and t_2 are set depending on the type of used measuring apparatus. These are mainly a type and parameters of the detector, photomultiplier parameters and also range of energies of registered particles. Fig. 4 shows framework layout of these parameters.

For evaluation by suggested methods it is not necessary to standardize impulse responses. The suggested methods have linear computing complexity, which is suitable to use for OFF-LINE as well as for ON-LINE evaluation. This method does not require any pre-processing of the measured data.

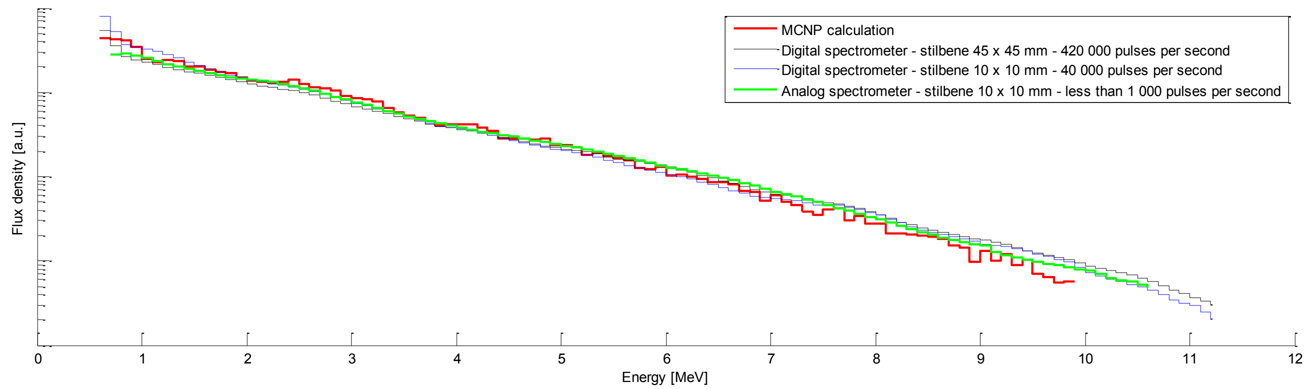

Fig. 3. Neutron spectra in research reactor LR-0 and comparison with analog spectrometer and MCNP calculation.

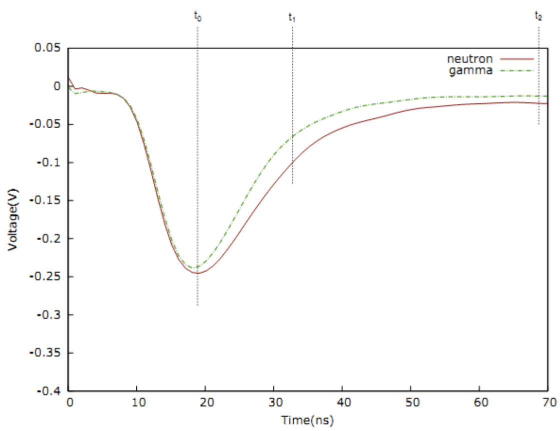

Fig. 4. Framework layout of parameters of integration method.

EVALUATION PROCESS

The presented digital spectrometric system was tested in research reactor LR-0 in Rez near Prague (Czech Republic). The neutron spectrum of Cf-252 is included.

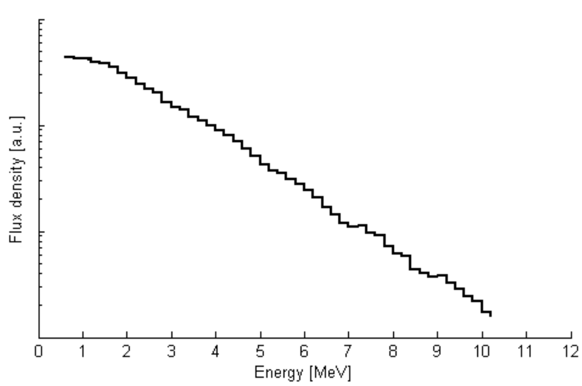

Fig. 5. Neutron spectrum from spontaneous fission of Cf-252.

The neutron spectra were measured in the energy range from 1 to 10 MeV by the proton-recoil method using a stilbene scintillator. The neutron spectra were measured with a cylindrical stilbene detector of the dimensions of 10x10 mm and 45x45 mm. The deconvolution of the measured recoiled proton spectra was done using the Maximum Likelihood Estimation. [2]

Fig. 5. shows the measured Cf-252 spectrum and Table I. shows the spectral indexes. These are the ratios between flux density in two energetic intervals. Based on it is possible to compare the shape of two spectra. The reference spectrum is described in [4].

Table I. Comparison of certain spectral indexes

Spectral index (ratio between neutron flux in two energetic intervals)	Digital spectro-meter	Spectral indexes by Sajo et. al. [4]
(1 MeV, inf.) / (2 MeV, inf.)	1.70	1.67
(1 MeV, inf.) / (3 MeV, inf.)	2.99	2.97
(1 MeV, inf.) / (5 MeV, inf.)	10.21	10.18
(1 MeV, inf.) / (7 MeV, inf.)	36.44	38.22
(2 MeV, inf.) / (3 MeV, inf.)	1.76	1.77
(2 MeV, inf.) / (5 MeV, inf.)	6.01	6.08
(2 MeV, inf.) / (7 MeV, inf.)	21.45	22.85

Evaluation on LR-0 research reactor

Fig. 6. shows the LR-0 active zone arrangement. The active zone consists of nine fuel cartridges and the detector is situated in the center of the zone where there is a high neutron flux. It causes a high count rate of detected impulses and therefore it is possible to evaluate the spectrometer on different count rate of processed impulses.

Fig. 7. shows the discrimination data from the spectrometer before the deconvolution process. The neutron gamma discrimination is lower than 0.5 MeV.

Fig. 5. shows the measured neutron spectra and comparison with measurement using analog spectrometer which was done at the same place. [1] The result of Monte-Carlo MCNP calculation is enclosed.

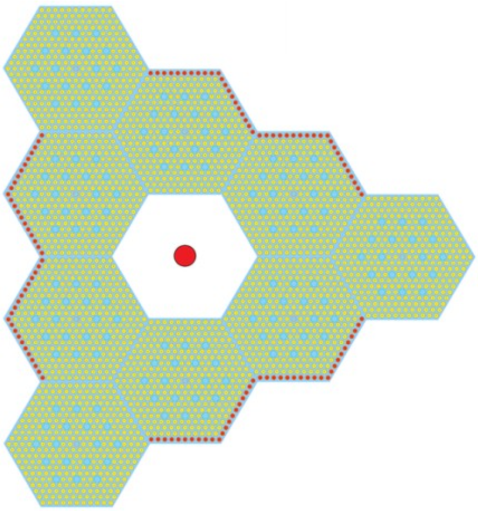

Fig. 6. Research reactor LR-0 active zone arrangement. The zone is symmetrical and consists of 9 fuel cartridges. The detector is situated in the center of the zone.

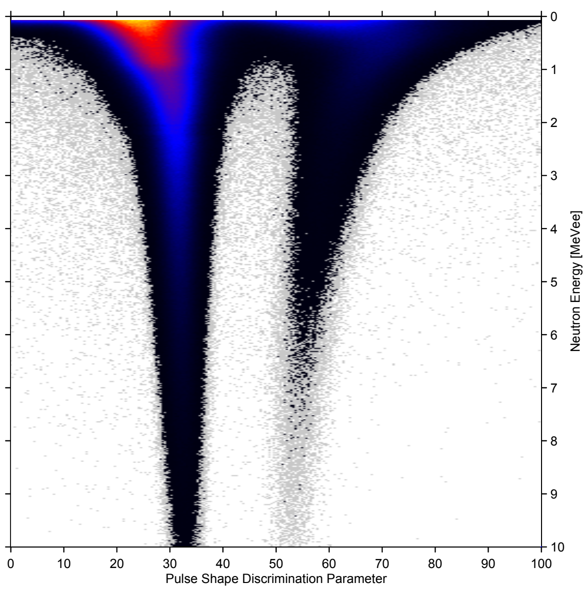

Fig. 7. Pulse shape discrimination data from 10x10 mm stilbene (measured in LR-0 reactor). Photons are on the left and neutrons on the right.

RESULTS

The presented results shows two parametric digital spectrometric system designed to measure at high count rate of pulses without dead time. This count rate can exceed one million pulses per second. The spectrometric system consists of fast analog to digital converters with sampling frequency 1 GHz and FPGA. The pulse discrimination is realized by integration method which is based on principles of charge comparison methods.

The spectrometer was evaluated in research reactor LR-0 in Rez near Prague. Measured count rate of pulses exceeds 400 000 pulses per second. Additional evaluation was carried out using Cf-252 neutron spectrum.

During the future improvement of digital spectrometer it is necessary to focus on pulse superposition. Due to high count rate of measured pulses the probability of detection two or more pulses with small time spacing increases. Then it is not possible to discriminate it. Solving this problem allows the measurement at count rate exceeding one million pulses per second.

ACKNOWLEDGMENTS

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