PING : A New Approach for Nuclear Fuel Cycle Instrumentation

S. Normand, V. Kondrasov, G. Corre, C. Passard

Abstract— **We introduce here a new concept of nuclear instrumentation system. We have developed a new and flexible system for nuclear measurement called PING. PING stands for New Generation Instrument Platform. This new measurement system could be able to do measurements in active neutron condition, especially time stamping, as well as photon gamma spectrometry. This development is done in order to optimize Nuclear Process Control systems. In fact numbers of used instrumentations are specific and most of them are no longer supplied by any firm. Then the main idea that conducts this project development is to concentrate all hardware requirements inside one device. Only the software embedded inside the FPGA is considered as the real measurement part of the device. Any hardware upgrading should not modify measurement performances. Thus which is durable is the software.**

***Index Terms*—ADC, FPGA, Nuclear instrumentation,**

I. Introduction

The main device inside PING is an analog to digital converter, designed at 130 MHz with 16 coding bits achieving a noise level below 20 μVolts, that is directly connected to the Virtex-4 Xilinx FPGA. Data flow is analyzed by processing chains downloaded into FPGA programmable area. The processing unit realizes data analysis and extracts critical values. First stage of processing includes data flow filtering. A discrimination stage allows us to determine neutron timing distribution and extracts information. These information are stored in local memory and transferred to a distant PC. Communications are realized by USB or Ethernet protocol, which depends on the available network capabilities. A control unit manages the overall programmable architecture with a finite state machine. This kind of architecture is very flexible and can easily be adapted to several classes of measurement in nuclear instrumentation context [1-8].

In this paper, we focus on neutron measurement performances achieved by this system at the CEA Cadarache Promethe facility. Promethe measurement cell is designed for nuclear waste fissile material measurement. It uses a neutron generator SODERN GENI36, which emits up to 2.10^9 neutrons per second. The helium-3 system is made by proportional counter inside a moderator (polyethylene) covered by cadmium foil, in order to be only sensitive to fast neutron. These neutrons are specially emitted by fissile mater and could be then easily discriminated from thermal asking neutron. The timing distribution of neutron is then used to discriminate neutron in the prompt timing signal part versus the delayed timing signal part. Thus it is very important to be able to sense neutron as soon as possible after the neutron generator end of pulse. And it is very important to count neutron during all the sense part without any lack due to baseline fluctuation. Systems used at that time are based on analog electronic and take a long time for the recovery even in the region of interest.

The idea is to develop a system that could recover a short time after the end of generator pulse. Therefore for each impinging neutron detected by Helium-3, each pulse is analyzed. First of all, the height of each signal is registered, as well as the pulse duration and a time stamping. Then an internal filtering gives the time analysis. A basic graphic interface leads us to obtain both an oscilloscope mode and also a time analysis of pulse neutron arrival time. But one has to take into account the communication time between FPGA and PC to be sure about dead time. We have checked several parameters for the PING system. The PING system provides a couple of interesting results. First, interface to Promethe measurement cell is very simple and PING system provides quickly useful data with its USB mode communication capabilities. Developments and adjustments are very fast and simple. Comparisons to classics active neutron condition measurement system show a shorter recovery time after pulse from the generator.

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II. PING DESIGN

A. Electronic design

The global schematic is given in Figure 1. One could notice the high integration of commercially available components.

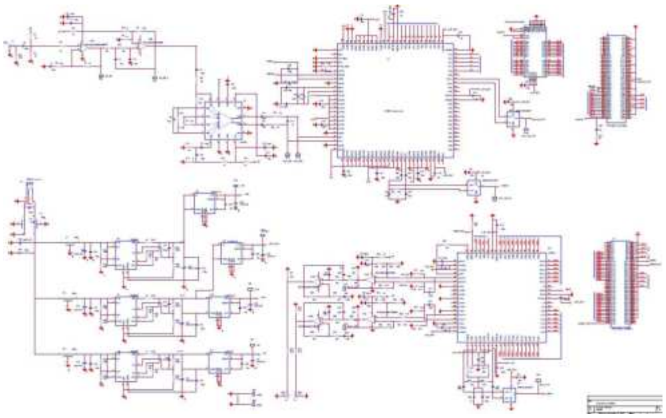

Figure 1 : PING ADC Design

Then the ADC was coupled to the demo board which embedded the Virtex-4 FPGA as shown in Figure 2. This FPGA, due to its high computation performances enable us to do all signal treatment inside and to manage the information communication to PC. Figure 4 shows us this implementation. Several ports for communication are available. We consider in a first level only the USB port but we are already working on the implementation of the Ethernet part, in order to have high information flux between PING to PCs that elaborate the real physical information, making then it exploitable by operators.

Figure 2 : Virtex FPGA with the ADC connected making the global PING system concept.

All the information available on a digitalized pulse is extracted in order to make it promptly available for physical algorithms. Several applications could be implemented on FPGA (time stamping, spectrometry gamma, active and passive neutron measurement …). Next section illustrates how to configure FPGA to realize experiment for Nuclear Fuel Cycle Instrumentation.

III. EXPERIMENTAL SETUP

First of all, the system was tested with nuclear sources available at our lab. It enables us to check if all our software developments are able to identify clearly neutron sources activities, in a passive acquisition mode.

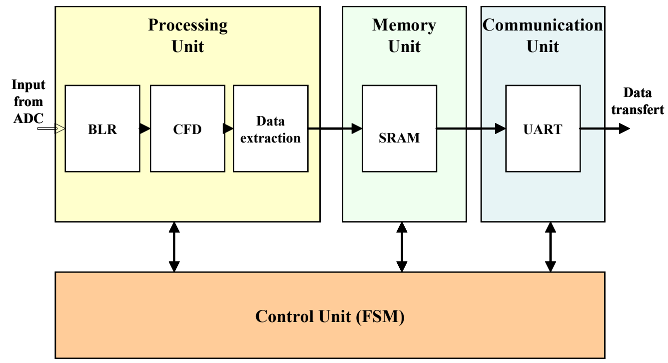

Figure 3 : FPGA configuration for Nuclear Fuel Cycle instrumentation

The Processing unit developed for this experiment (Cf. Figure 3) includes Base line restorer, Constant Fraction Discriminator and data extraction to provide pulses count per channel. Pulses counts per channel are stored in SRAM memory during 125 generator cycles. Then, system transfers data to a host PC for post processing and results visualization. The diagram illustrates acquisition and processing implement during this experiment.

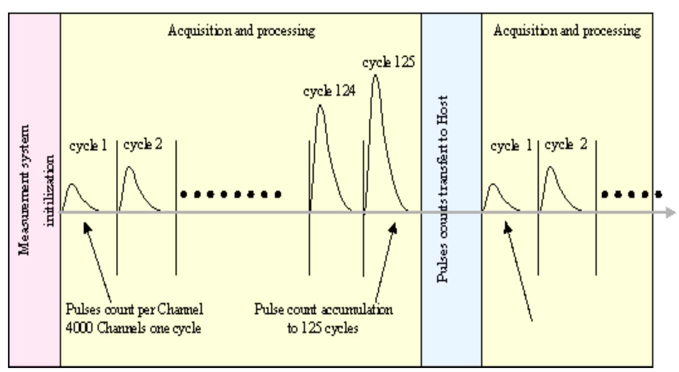

Figure 4 : Measurement process implement on FPGA

We have used the Promethee facility at CEA Cadarache. The neutron generator makes it possible to check our instrumentation chain in order to measure fissile material even in low mass.

Time between acquisition sequence and communication one could be adjusted by user for its own needs to optimize dead time.

IV. Experimental Results

A. Measurement System Validation

Experiments allow us to validate our measurement systems (analog and numeric parts) compared to existing systems such as ADSF (stands for Amplificateur Discriminateur à Seuil et Fenêtre, which is the commonly system used for neutron measurement (passive and active one).

Figure 5 and Figure 6 give us some experimental results obtained by our PING system. This time measurement neutron analysis is conducted in order to estimate the fissile material mass in reprocessing plant using active neutron methods.

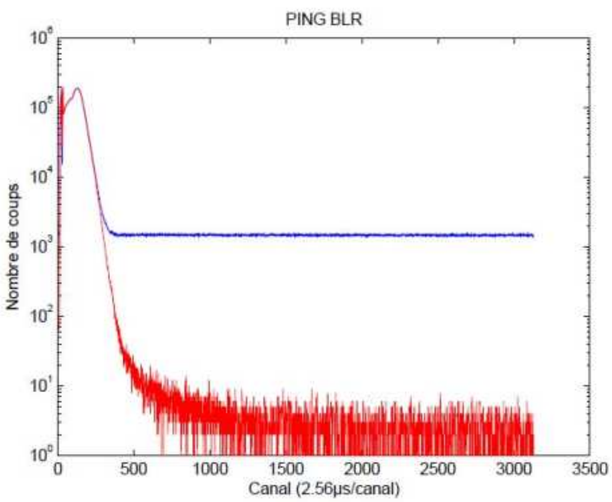

Figure 5 : PING measurement for cell background (red curve) and cell background plus a continuous neutron flux 252-Cf source (blue curve)

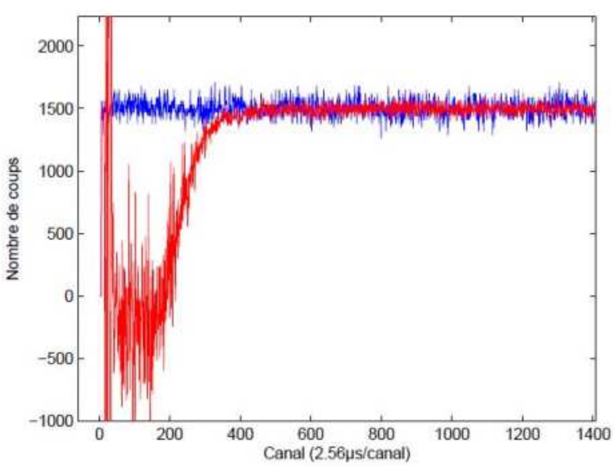

Figure 6 : It is a zoom on the time zone just after the neutron generator end of shoot.

Figure 6 exhibits the time part on which we currently see problem with existing electronic ADSF. In this time part, the whole system should restore the fastest to make possible immediately measurement after the neutron generator shoots. Figure 7 leads us to estimate the measurement leakage in the prompt neutron timing zone. The blue curve is for measurment and red one is obtained by a filtering using recursiv mean of experimental data for the best estimated of this leak. Compared to the existing system which is based on ADSF system, we have a significant improvement of 458 %.

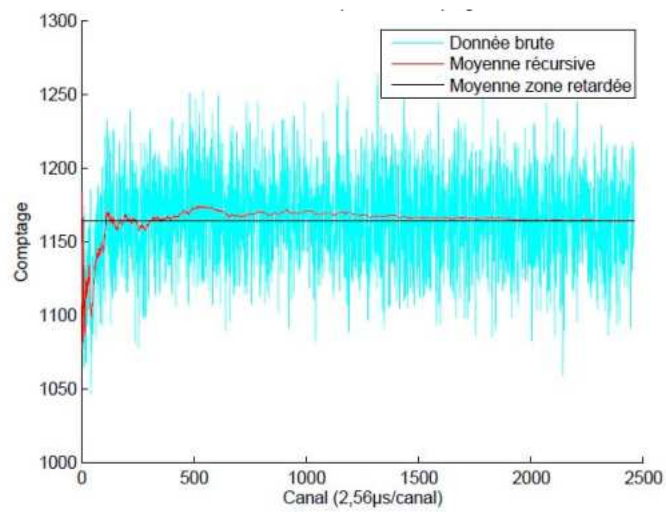

Figure 7 : Measurement leakage estimation of our measurement system

B. U-235 Fissile Material Mass Measurement

Figure 8 shows us a real measurement of 4 g of U-235 sample. This comparison was conducted at Prométhée facility with the acquisition system available. The main goal of this part is to validate the linearity response of our new system. All measurements were realized in same experimental setup. In Figure 8, blue curve is for the active neutron cell background, and the red one is for 4 g of U-235. We then find a ratio of 1.95 instead of 1.94 between reference instrumentation chain and our system, for the measurement of 2 g and 4 g U-235 samples.

This result shows that our system and is able to do metrological fissile mass evaluation.

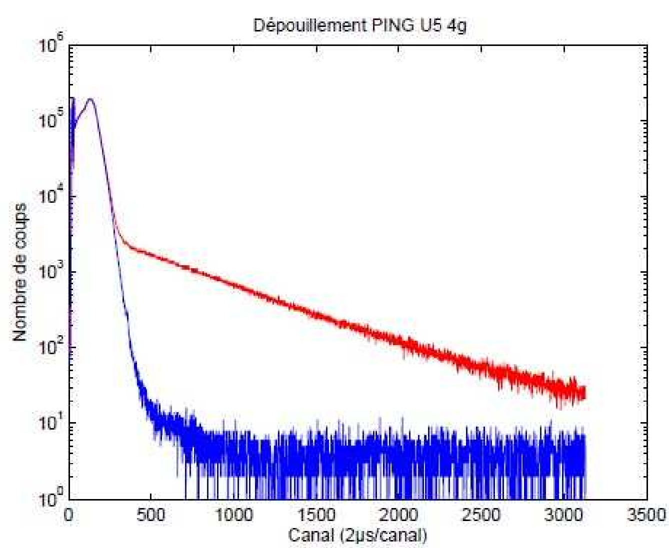

Figure 8 : Ping measurement for fissile material of U-235

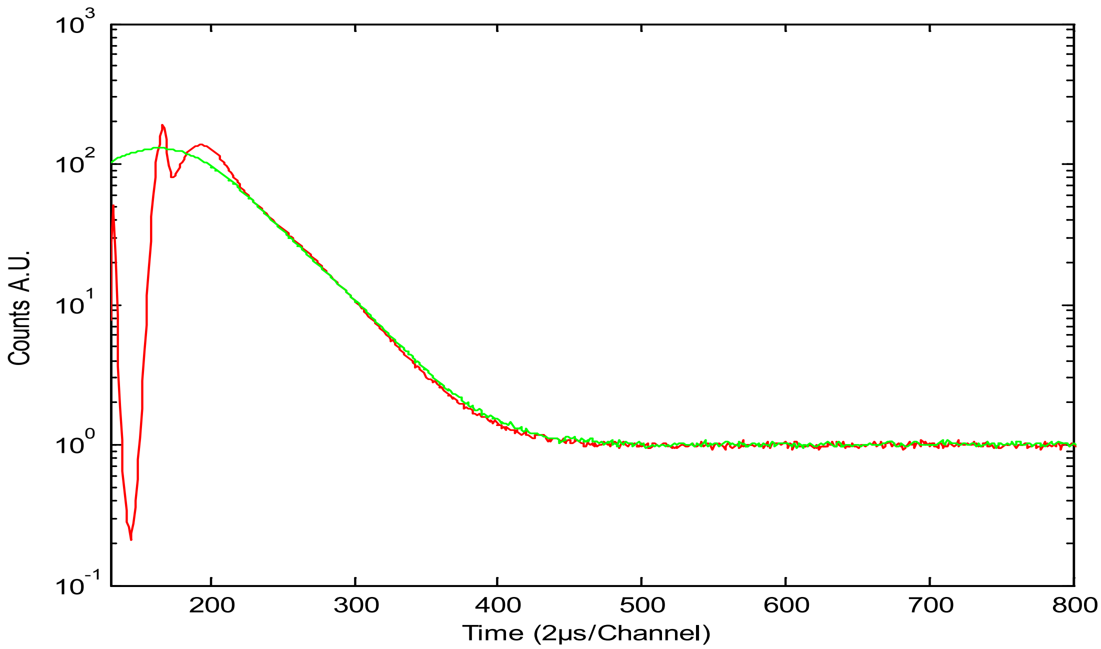

Figure 9 : Comparison between PING system (green curve) and standard ADSF measurement system (red curve)

C. *PING/ADSF Comparison*

Figure 9 compares standard acquisition system based on ADSF (well known in the neutron measurement system) and our new one. We can notice that PING gives information sooner than the current system (the green curve begins its non saturated zone before the red one, channel 175 instead of channel 210). In the section between channels 400 to 600, the green curve is above the red one, which means that we partially restore faster the system measurement performances with PING than the old one. In this part we have currently leak of counts. This problem could be partially solved by this new approach.

So we have noticed two kinds of improvement. First the system is able to measure sooner than the DAQ system currently used at Prométhée. Secondly, we have a system that exhibits large potentialities for a high level of versatility in nuclear instrumentation and measurement.

V. Conclusion

This test is the first step, it deals only with neutron measurement. The next one will include gamma spectrometry capability for the system without any change in the main electronic. This new functionality consist to develop new processing modules and to include them in the flexible programmable FPGA architecture. Only the front analog preamplifier part will differ, due to the fact that each sensor has its own preamplifier. This new approach is very promising and network of such systems will be designed and evaluated for industrial application of a new nuclear waste reprocessing plant. Ethernet part for communication will be soon integrated and will provide a significant improvement for networking of measurement, especially in Ethernet system.

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