FPGA-based technology for Pulse Height Analysis in nuclear spectrometry system

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Facing the rapid technology development applied in nuclear instruments, Madagascar-INSTN has taken measures to establish and enhance the national capabilities in their maintenance, calibration, design/modification and repair, which is a key factor in the development of sustainable nuclear technology. The maintenance will be more convenient if all technical resources are made available: this is only possible when the access to designer side of the instruments is permitted. Research and instrumentation development projects have been developed to support and to fit the local needs: Pulse Height Analysis algorithm is designed within FPGA and VHDL programming technics to build a Multi-Input Multi-Channel Analyzer. Description and measurement results with the MIMCA will be described in the present paper

1. INTRODUCTION

The INSTN has set up an agreement with the Trade Ministry, from January 1997 regarding the implementation of the regulation. Mainly the rate of radioactive contaminating element is very low, therefore the acquisition time should be longer which is not convenient for customers, because they want to proceed as fast as possible the clearance of their goods. Getting a new set of equipments from specialized manufacturer will be an expensive investment, and with today's technology repair and maintenance are not possible without support from the manufacturer.

So the idea is to do customized design from available and cheap readymade acquisition board. The UNIO52 board is based on digital electronic design controlled by FPGA (Field Programmable Gate Arrays). FPGAs are semiconductor devices containing programmable logic and programmable interconnects, hence design effort can be channeled to software and interface with such readymade board.

This paper presents an implementation of a FPGA-based Multi-Channel Pulse Height analysis function for nuclear spectrometric measurement system. Basic performance of the system has been tested and can be compared with standard instrument with similar set-up. A good system with NaI(Tl) detector has a resolution better than 7% [2].

2. MULTI-CHANNEL PULSE HEIGHT ANALYSIS IN NUCLEAR SPECTROMETRY SYSTEM

2.1. Pulse Height Analysis

There are various methods of measuring amplitude of pulses depending of the application, but single channel analysis (SCA) and multi-channel analysis (MCA) methods are the mostly used.

Single Channel Analyzer (SCA) is used for counting the number of incoming radiation at selected energy range [1]: with two adjustable levels , only pulses with amplitude falling in between the two levels are counted

Input pulses are observed by two discriminators set at *LL (Lower Level)* and *UL (Upper Level)* respectively.

MCA method has to be used to have the distribution of pulse heights.

2.2. Pulse Height Multi-Channel Analysis mathematical model

The principle of Pulse Height Analysis (PHA) algorithm is then based on sampling the current input signal from the ADC until it reaches values higher than the programmed *Lower Level (sMcaLL)*. From this point on (Figure 1), the FPGA continuing sampling data until the signals goes lower than *Lowest Lower Level* reference value *(sMcaLLL)* or the number of sampled points is more than *sMaxPulsLen*. If so, the pulse will be discarded and the search for the next pulse starts.

During the pulse sampling, the FPGA always compares the current value (*sMcaPeak*) against the last value and holds in a register the maximum of the values (*sMcaPeakMax*). So after the signal goes lower than *Lowest Lower Level* this register holds the Pulse maximum. This is now compared with *Upper Level (sMcaUL)*. If higher than *Upper Level* the pulse will also be discarded; if not, an Interrupt for the microcontroller is generated so that the µC can readout the Event-Maximum.

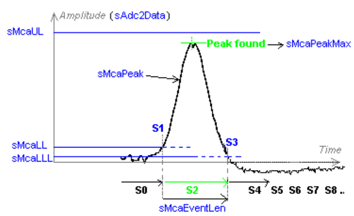

Figure 1: Nuclear PHA sequence

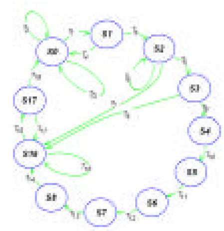

Figure 2: PHA State Diagram

The PHA algorithm above described can be stated from four main states: S0, S1, S2, S3.

S0: a state where the status of input signals from ADC (*sAdc2Data*) are checked,

- input event really dedicated for MCA processes,
- sAdc2Data greater than the Lower Level reference (*sMcaLL*) and if so, outputs an over of lower level flag (*sMcaOverLL*).

S1: checking again if input signals (sAdc2Data) is really greater than the Lower Level reference (*sMcaLL*), and confirming by setting the register *sMcaPeak* with the actual input signal value (sMcaPeak <= sAdc2Data)

S2 is the digital stretcher state: finding the maximum value (*sMcaPeakMax*) of registered input signals (*sMcaPeak*) until it is below the Lowest Level reference (*sMcaLLL*), and keep the stretched maximum value (*sMcaPeakMax*) if the number of sampled input data (*sMcaEventLen*) during the current state is less than the maximum programmed length (*sMcaEventLenMax*); otherwise pulses pile-up may occurred and event should be discarded.

S3: checking and keeping the stretched maximum value (*sMacPeakMax*) if it is below the upper limit of our range of interest (*sMcaUL*); otherwise event will be discarded too.

Additional state machines (S4 to S8) are needed for memory organization of the Multi-Channel PHA: counting event by setting the register flag *sMcaEvent*, setting the address (*sMcaMem_addrb*) for the specified memory location, incrementing the specified data (*sMcaMem_dinb*) and output data memory (*sMcaMemdoutb*).

3. PHA IMPLEMENTATION ON FPGA

The logic previously described has been implemented on the FPGA (Xilinx XC2S150), which is the central component of the UNIO52 board. A fast free running ADC, is delivering with 24 MHz, 12 bit data into the FPGA.

The UnIO52 board is an universal data-acquisition and processing board. It consists of a fast ADC, a powerful FPGA and a USB microcontroller to establish the communication with the PC.

All these components are programmable by the user. Therefore this is an ideal platform for the development of a dedicated instrument.

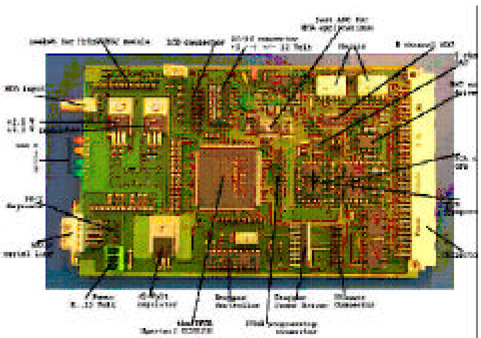

Figure 3: The UNIO52 acquisition board

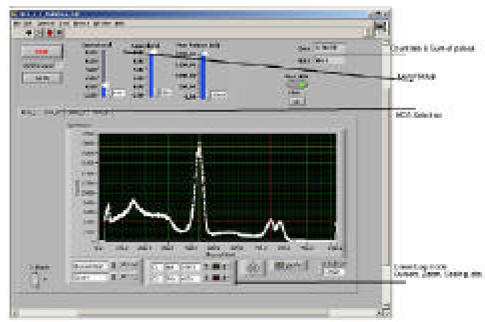

Figure 4: PC Software

Spectra's are shown in different graphs which placed in a tab control. By clicking on the "MCA Selection" one of the 4 tabs are selected to show the spectra of the according MCA channel. The MCA's have a resolution of 1024 channels which were tested with a nuclear pulser.

4. TEST AND RESULTS

4.1. Integral Non-Linearity (INL)

The integral non-linearity measured over the full range was **+0,7%** and **-0,02%.** For comparison, INL of a MCA add-on card developed by another research centre was measured to be **+1,8%** and **-0,1%** and about **+/- 0,13%** for a CANBERRA system.

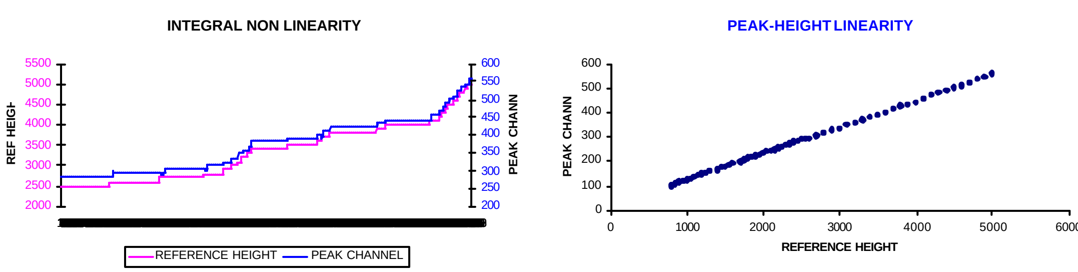

Figure 5: "Peak-Channel" vs. input signal height

4.2. Differential Non-Linearity (DNL)

In an overnight measurement (according to the IEC standard 659), the number of counts in each channel was around 54160 counts, and the calculated DNL is +/- 2,3%

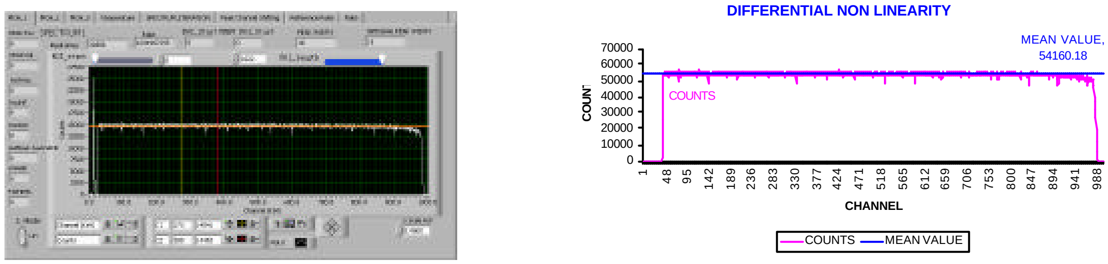

Figure 6: DNL test result

4.3. Countrate Performance

Peak channel of generated pulse resolved by the MIMCA, for different countrate is registered and plotted.. Table I below shows results comparison between the designed FPGA -Based MCA (MIMCA) and a commercial Add-On MCA card.

Table I: Countrate performance comparison table for the designed MIMCA and a commercial Add-On MCA card:

FPGA Based MIMCA

	Shaping time			
	1 µsec		**4 µsec**	
Count-rate [Kcps]	**Peak Channel [Ch]**	**Peak Shift [%]**	**Peak Channel [Ch]**	**Peak Shift [%]**
1	689	0	689	0
2.5	689	0	689	0
5	689	0	690	0.14
7.5	689	0	690	0.14
10	690	0.14	690	0.14
15	690	0.14	690	0.14
20	690	0.14	691	0.29
30	691	0.29	691	0.29
50	Not measured: double peak			

MCA Add-On Card

	Shaping time			
	1 µsec		**4 µsec**	
Count-rate [Kcps]	**Peak Channel [Ch]**	**Peak Shift [%]**	**Peak Channel [Ch]**	**Peak Shift [%]**
1	1707	0	638	0
2.5	1707	0	639	0.06
5	1708	0.06	638	0
7.5	1708	0.06	639	0.06
10	1709	0.11	639	0.06
15	1710	0.17	639	0.06
20	1710	0.17	639	0.06
30	Not measured: double peak		640	0.12
50			640	0.12

The calculated Peak Shift values for the FPGA based MIMCA are comparable to those of the commercial Add-On MCA card. The results show even a better performance because the shifting is almost the same for large range of the countrate.

4.4. Peak Resolution

The ^{137}Cs peak resolution, measured by the PC software for a collected data spectrum from the MIMCA was 21,38%. For comparison, typical FWHM for a MCA35+ CANBERRA system is around 7%.

The reason of such difference is that 1K MCA resolution is only used due to the memory limitation of the UNIO52 board.

5. CONCLUSION

- The behavior and performance of the designed system is comparable with any commercially available instruments from industrial company.
- The performance of the PHA circuit implemented inside the MIMCA (multi-input MCA) system shows that numerical technique can be used as an alternative solution for standard design using analog discrete chip technology.
- FPGA-based instrumentation can be used to modernize and to extend life of expensive old equipment.
- Since the UNIO52 board was developed as a universal data-acquisition and processing board (RS232; relays, etc..); it can be used to upgrade old equipments.
- Design effort can be channeled to software and interface with such readymade board.
- Feature can be added and specifications modified according to user requirements.
- This is an open system design, so in the future all the information for maintenance and modification is available.
- Opportunity is provided to learn and to be familiar with new technology of Digital signal Processing, which is more and more used in modern instruments.

OUTLOOK

- With its actual version, it cannot be used for high resolution spectrum analysis application: it needs a real upgrading of some components.
- One perspective of the MIMCA system is also to use it as a air stack monitor (air pollution monitoring).
- Other research projects are scheduled to be done in order to use the development system in nuclear instrumentation improvement (FWHM with low cost spectrometry system).

Acknowledgments

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References

[1] IAEA, “Selected topics in nuclear electronics”, IAEA TECDOC 363, Vienna, 1986.

[2] IAEA, “Radiation Detectors”. Nuclear electronics laboratory manual, IAEA TECDOC 530, Vienna, 1989, pp 206-244.

[3] IAEA, Troubleshooting in Nuclear Instruments, IAEA TECDOC 426, Vienna, 1987.