

Multi-Input Multi-Channel Analyzer (MIMCA) Using Universal FPGA Board

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ABSTRACT: Instrumentation for nuclear applications is developing very fast, due to fast changing of technology in electronics in connection to Moore's Prediction ("doubling of transistor density integration on an IC for every two years"). The maintenance concept has changed accordingly and moved from repairing at electronic component level to software solving approach, which leads to customize application to fit the local needs. Therefore, Madagascar-INSTN has developed some R&D projects in instrumentation to support and fit to the local needs: one example is the FPGA-based Multi-Input Multi-Channel Analyzer using the UNIO52 standard board from Jülich, which could be used to strengthen the capability and speed-up the routine for radionuclide measurement and analysis of samples. The test results of the MIMCA performance (Linearity, Count-rate accuracy tests) show that the configurable digital system can be used as an alternative issue compared to branded acquisition equipments, which are very expensive and limited technical support from supplier.

KEYWORDS: Pulse Height Analysis, ADC, Multi-Channel Analyzer, FPGA, MIMCA.

I. INTRODUCTION

According to the By-law n° 3961/93, all foodstuffs must be controlled by the Madagascar-INSTN, and must have a non-radioactive certificate, prior to the selling. In that case, the level of radioactivity, especially for artificial radionuclide, must be below the legally accepted values. 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 sample analysis needs a long time for measurement. As a matter of business, customers need to have their certificate to be delivered as rapid as possible, to allow fast clearance of their goods. Using a multiple set of equipments would need more investment and would cost a lot in case of dedicated and branded instruments (Germanium detector with thick lead shield coupled with MCA).

This paper shows the use of a low-cost universal acquisition board to build a Multi-Channel Analyzer with multi-inputs to monitor in parallel up to four samples

II. RELATED WORK

In 1965 Moore argument that integrated circuits would dominate the industry of electronics because of gain entailed (cost and performance) due to continued miniaturization in the technology of silicon planar integrated circuits. [1]. Nowadays it is possible to integrate and configure more complex electronic circuitries on a chip with software, such as with FPGA.

In the meantime associated electronics used for gamma spectrometry system have been gradually improved from simple counter, to single channel analyser (SCA), and to multichannel analyser (MCA). The MCA has also been improved throughout the years, from the conventional single-package MCA to the computer-controlled MCA. Most of the MCA systems today use computers to control the spectroscopy hardware and to emulate the functions of the MCAs [2].

EG&G Ortec introduce in late 1996 a digital gamma-ray spectrometer (DSPEC) which uses digital technology to process with the pulses from preamplifier and become the way of future gamma-ray spectroscopy. The energy resolution with DSPEC has been shown to be about the same as that using analog processing technology with the NIM system [3]. The resolution and throughput performance of the three DSP systems are much better than those of the analog NIM system [4]

Any DSP system is associated with one FPGA family, such as from Xilinx. The UNIO52 board is using Xilinx XC2S150 as FPGA chip, MCA implementation and performance of which were studied and are shown in this paper.

III. FPGA-BASED MULTI-CHANNEL ANALYZER

1. Multi-Channel Analyzer (MCA)

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 mostly used.

Single Channel Analyzer (SCA) is used for counting the number of incoming radiation at selected energy range [5], 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.

Due to the rapid development and integration, applied in electronic technology, FPGAs (Field Programmable Gate Array) are utilized in many applications to control or to process signals, and are nowadays used in most of nuclear instruments. FPGAs are semiconductor devices containing programmable logic and programmable interconnects.

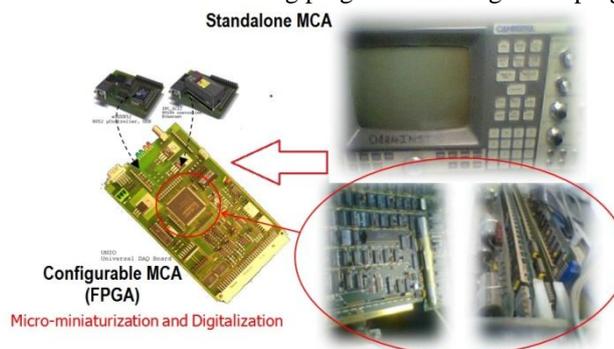


Fig. 1: Miniaturization and Digitization of MCA Canberra series 35 plus electronics

Fig.1 shows an example of refurbishing (miniaturization and digitization) older MCA system with many discrete components and boards, using tiny board with single FPGA, which is integrating all needed hardware to emulate the MCA function.

2. FPGA-based Pulse Height Analysis (PHA) system

For MCA application, the Pulse Height Analysis (PHA) algorithm has to be described in VHDL and the configuration file has to load into the FPGA. The principle and algorithm of Pulse Height Analysis (PHA) is explained with Fig.2, which is based on sampling the current input signal from the ADC until it reaches values greater than the programmed Lower Level (sMcaLL).

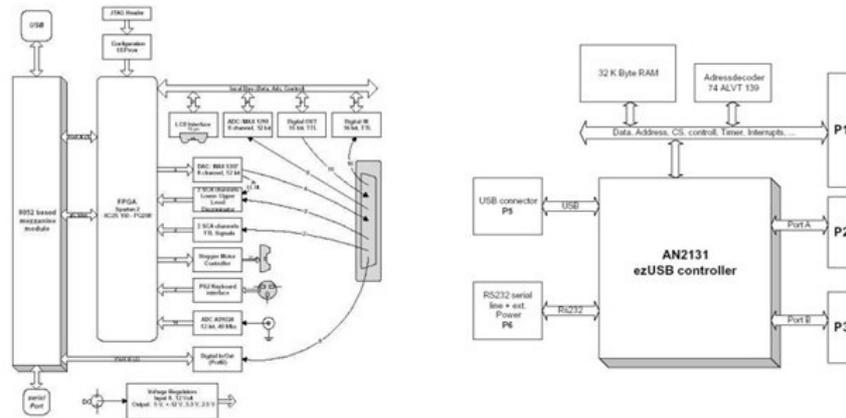


Fig. 4: UNIO52 and USB controller block diagram

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

Logic blocks have also been configured to perform drift control due to voltage or temperature shifting and other complex digital functions such as a peak finder (needed in nuclear instruments) and mathematical functions.

B. The MIMCA complete system

The firmware application code for the ezUSB controller board was developed with Keil C-compiler. The host PC software was designed in the sense that there is a central control for the 4 MCA channel for setting the threshold levels, starting, stopping, clearing the MCA, etc.

Configured UNIO52 boards are assembled in a small 19” Rack, together with 5Volt power supply. In Fig.5, one can see both USB cables which are fed via a USB hub as one single connection to the PC. The two analog inputs are connected by BNC cables. In the background the nuclear test pulser and a detector system can be seen.

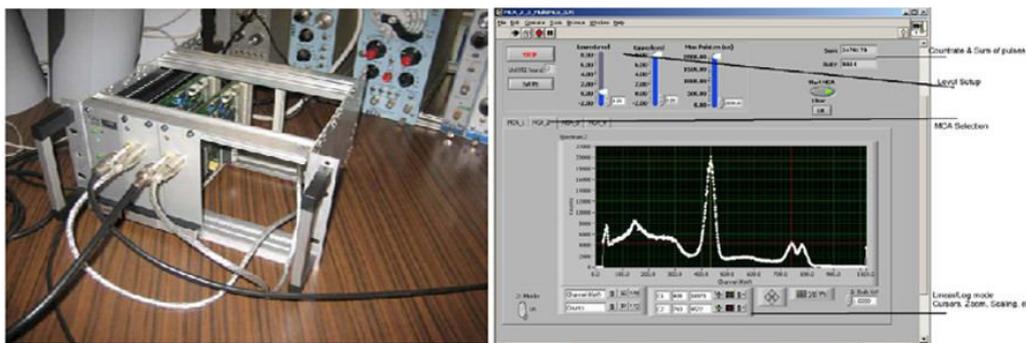


Fig. 5: The Multi-Inputs MCA and collected spectrum of ⁶⁰Co and ¹³⁷Cs point sources

The 4 spectra’s are shown in 4 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. Collected data can be stored to hard disc and can be read by other computing or visualization software such as Matlab and Excel.

V. EXPERIMENTAL RESULTS

Digitized spectrum data are stored and incremented periodically inside memory of the UNIO52 board. For further processing (such as peak search), data have to be download into the PC RAM.

A. Automatic Peak Search

An algorithm to latch “Previous integral spectrum” and subtract it from the “new integral spectrum” is implemented with the analyzing software tools. This is to isolate “actual spectrum” from the “integral spectrum”, and will give information about peak channel shifting depending on the amplitude of the analog input signal, according to the algorithm in Fig.6.

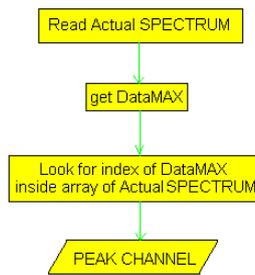


Figure 6: Automatic Peak Search algorithm

This “Automatic Peak Search” function is useful for linearity testing and resolution measurement of the system.

B. Linearity and Accuracy

The main part of a Multi-Channel Analyzer system (MCA), which makes possible the dialogue between the real world of analog quantities (charges released by detector) and digital electronic system is the ADC. The analog-to-digital conversion (ADC) consists of subdividing the input signal range (between V_{MIN} and V_{MAX}) into N equal parts (ideal ADC), and assigning the input signal amplitude V_i to a channel.

1. Linearity

a) Integral Non-Linearity (INL)

With MCA system, precise energy calibration of a spectrum depends on the linearity of the system. For further data processing in the ideal case the linearity should be as a straight line. Set of pulses with defined amplitudes has been fed to the input of the MIMCA.

The Integral Non-Linearity is given as the maximum channel deviation from the estimated linear regression approximation CH_{MAX} expressed in percent of the total number of channel N [7]:

$$INL(\%) = \frac{CH_{Max}}{N} \times 100$$

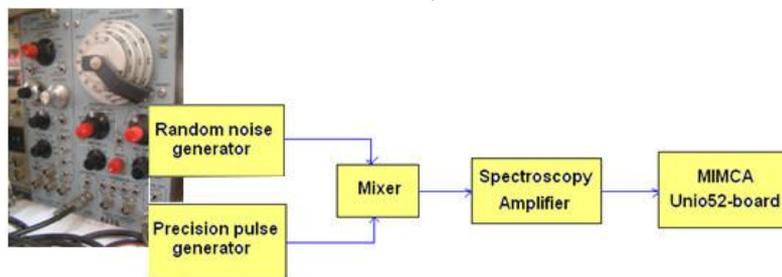


Fig. 7: Set-up for INL Test

Table 1 shows collected peak channel location depending on the amplitude (H: height) of the reference signal (peaks in the spectra would have equal distances when the system is linear).

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Table 1: Peak Height Channel Distribution of MIMCA

DIAL (Reference Pulser)	Signal Height (H in mV)	Peak Channel (CH)
100	400	46
200	800	92
300	1240	138
400	1600	184
500	2000	229
600	2500	275
700	2900	321
800	3300	366
900	3700	411
1000	4000	457
1100	4500	502
1200	5000	548
1300	5400	593
1400	5800	639
1500	6200	684
1600	6600	729
1700	7000	773
1800	7400	818
1900	7800	863
2000	8200	908
2100	8600	951
2200	9200	998
2240	9400	1016

For linear regression approximation of the above collected data (channel [CH] function of signal height [H]), the estimated curve equation is the following:

$$[CH] = 0.1089 \times [H] + 7.4389$$

The calculated integral non-linearity values (10% to 90% of full range) are then **+0.7%** and **-0.6%** [6].

b) Differential Non-Linearity (DNL)

For ideal system, each channel should have exactly the same width, and will reproduce the amplitude of the incoming signal in an accurate manner. DNL test has been performed using input signal from "sweeping pulser" (precision pulse modulated by triangular signal).

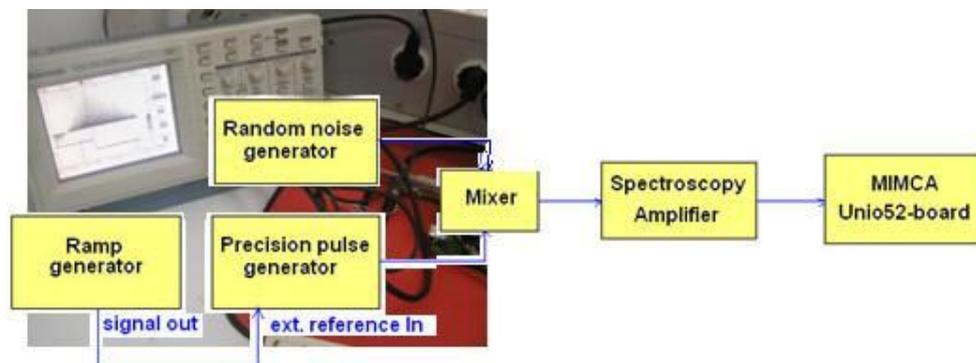


Fig. 8: Hardware set-up for DNL test

The hardware setting up for DNL testing is shown in Fig.8, and configured as follows:

- Period of ramp generator set to 50sec
- Pulse generator switched to external reference source, repetition rate to 10kHz
- Shaping time of 1µs for the amplifier

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Collecting counts over a long period of time (sufficient so that statistical fluctuation can be neglected to the measurement of channel profile), would result uniform and flat distribution of counts in all channels for linear system. Deviation from that uniformity, measures the DNL (expressed in percent) of the MIMCA:

$$DNL(\%) = \frac{\sigma}{\bar{C}} \times 100$$

\bar{C} : Mean value of counts

σ : Standard deviation

Fig.9 shows the result for an overnight measurement (according to the IEC standard 659), which gives a mean value of **54160 counts** for each channel. The standard deviation from the mean is **1236 counts**, and the calculated DNL is then **+/-2.3%**.

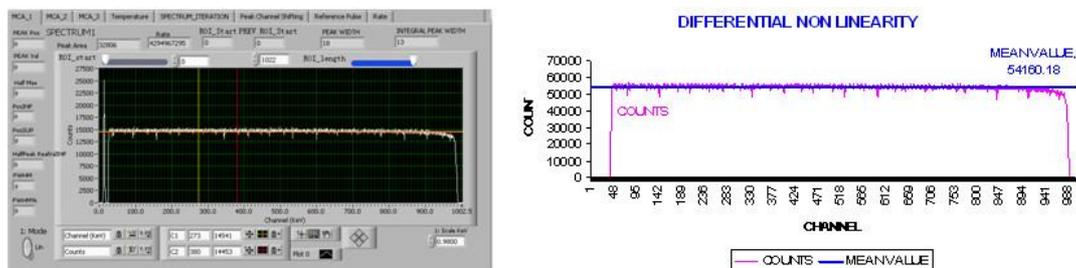


Fig. 9: Displayed DNL test result

2. Count-rate and Peak Resolution Performance

a) Count-rate performance:

For an ideal MCA, all pulses with the same amplitude are stored in one channel, and independent of the count rate.

Fig.10 shows the set-up configuration for testing of the count-rate performance, where the output of a Random Pulse Generator is connected to the spectroscopy amplifier (CANBERRA model 2020), which feed the MIMCA system.

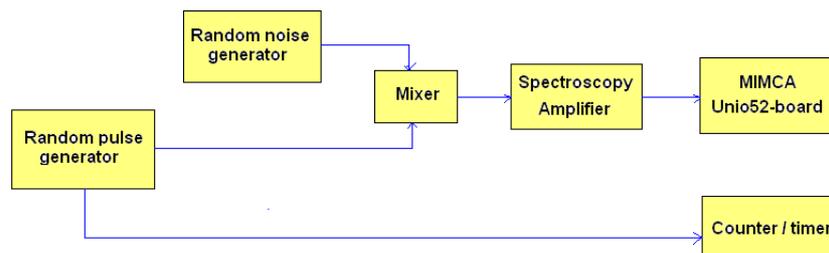


Fig. 10: Test set-up for count-rate performance

The Trigger output of the Random Pulse Generator is also connected to a Counter/Timer (CANBERRA model 1776) to serve as reference.

Peak channel of the generated pulse resolved by the MIMCA and function of its count rate is registered, and presented in the following table

Table 2: Count-rate Performance of MIMCA

Count-rate [Kcps]	Shaping Time			
	1 μ s		4 μ s	
	Peak Channel [ch]	Peak shift [%]	Peak Channel [ch]	Peak shift [%]
1	689	0.00	689	0.00
1.5	689	0.00	689	0.00
2	689	0.00	689	0.00
2.5	689	0.00	689	0.00
5	689	0.00	690	0.15
7.5	689	0.00	690	0.15
10	690	0.15	690	0.15
15	690	0.15	690	0.15
20	690	0.15	691	0.29
25	691	0.29	691	0.29
30	691	0.29	691	0.29
39	692	0.44	691	0.29
50	Double-Peak not resolved		Double-Peak not resolved	

Fig.11 shows the effect of the count-rate to the resolution of the peak by the system, for an input reference signal of 4volts height and with 1 μ s and 4 μ s shaping time.

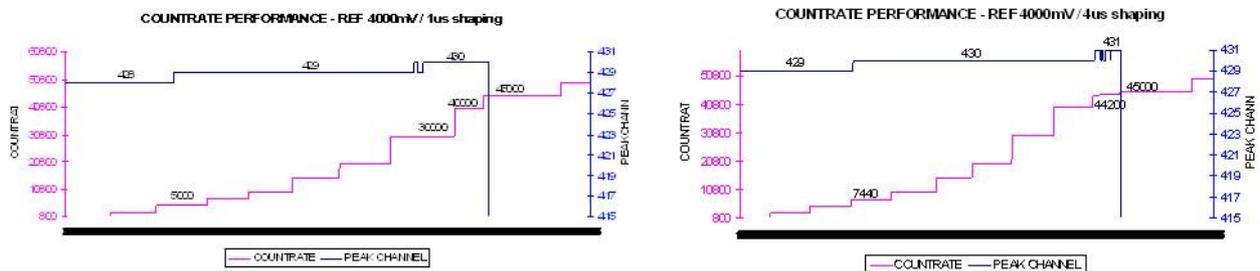


Fig. 11: Resolved Peak channel vs. count-rate and shaping of input signal

b) Peak resolution

The FWHM resolution of the ¹³⁷Cs peak, from collected spectrum within the MIMCA shown in Fig.12 is 21.38%. For comparison, typical FWHM for a MCA35+ CANBERRA system is around 7%.

One of the reason of such difference may be due to the memory limitation made available within the UNIO52 board, which allow only 1K MCA channel resolution

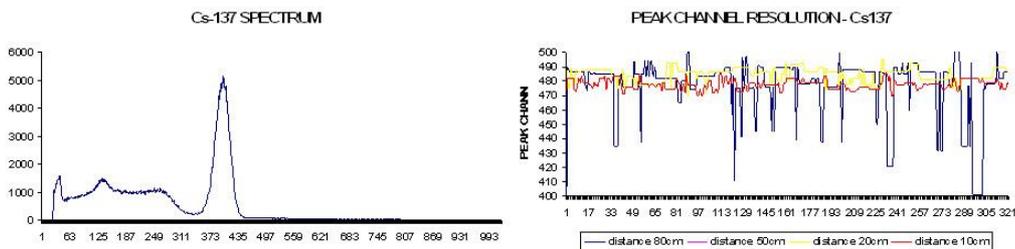


Fig. 12: Resolution of ¹³⁷Cs Peak-Channel

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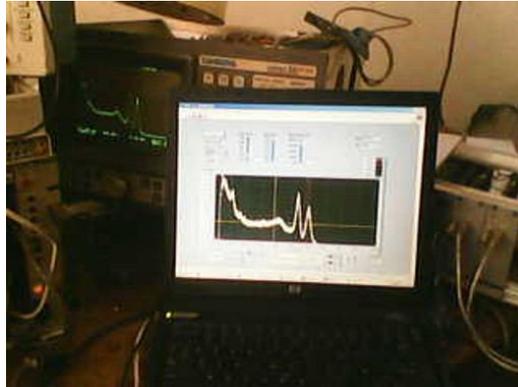


Fig. 13: spectrum of ^{57}Co

VI. CONCLUSIONS

- The performance test results show that the built MIMCA (Multi-input MCA) system can be used to replace and refurbish dedicated, but expensive Multi-Channel Analyzer.
- The peak resolution within the MIMCA system (21.38% for ^{137}Cs peak) seems to be worse if compared to those of CANBERRA's (typical FWHM for a MCA35+ CANBERRA system is around 7 %). But the system performance is very sufficient for qualitative analysis of sample.
- Some blocks are still needed to be configured into the UNIO52 board to get full functions of a MCA (Pile-up rejection and dead time correction). 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).

VII. ACKNOWLEDGEMENT

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BIOGRAPHY



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