UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Ciencias e Ingenierías

Diseño de un nuevo sistema de adquisición basado en Red Pitaya para los detectores de partículas usados en la colaboración LAGO

Proyecto de investigación

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Ingeniería Electrónica

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RESUMEN

Se describen los primeros pasos para el desarrollo de un nuevo sistema de adquisición de datos para los detectores de agua Cherenkov usados en la Colaboración LAGO. El sistema se basa en la tarjeta de código abierto Red Pitaya; se describe también el diseño y la implementación de un primer prototipo de tarjeta de interfaces para conectar todos los periféricos necesarios (PMTs y sensores) así como los módulos de alimentación. Se reportan las primeras pruebas de funcionamiento conectando el PMT que será usado para implementar un detector WCD en el Campus Cumbayá de la USFQ. Se describen además los desarrollos futuros de SW y HW necesarios para completar el diseño de un nuevo sistema de adquisición de datos para detección de partículas.

Palabras Clave. Detección de partículas, Detectores Cherenkov, FPGA, Red Pitaya, Sistema de adquisición de datos, fotomultiplicadores.

ABSTRACT

The first step of the development of a new data acquisition system for the Water Cherenkov detectors used within LAGO Collaboration is described. The system is based in the open source board Red Pitaya; design and development of a prototype of the interface board needed to connect peripherals (PMTs and sensors) as well as power supply is described. First tests of functionality connecting the PMT that will be used to implement a WCD detector in USFQ Cumbayá Campus are reported. Future development in HW and SW in order to have a new data acquisition system for particle detection is described

Keywords. Particle detection, Cherenkov detectors, FPGA, Red Pitaya, Data acquisition system, Photomultiplier

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ARTICULO/ARTICLE SECTION/SECCIÓN

Design of a new data acquisition system based on Red Pitaya for particle detectors used by the LAGO Collaboration

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Abstract

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Resumen

Se describen los primeros pasos para el desarrollo de un nuevo sistema de adquisición de datos para los detectores de agua Cherenkov usados en la Colaboración LAGO. El sistema se basa en la tarjeta de código abierto Red Pitaya; se describe también el diseño y la implementación de un primer prototipo de tarjeta de interfaces para conectar todos los periféricos necesarios (PMTs y sensores) así como los módulos de alimentación. Se reportan las primeras pruebas de funcionamiento conectando el PMT que será usado para implementar un detector WCD en el Campus Cumbayá de la USFQ. Se describen además los desarrollos futuros de SW y HW necesarios para completar el diseño de un nuevo sistema de adquisición de datos para detección de partículas.

Palabras Clave. Detección de partículas, Detectores Cherenkov, FPGA, Red Pitaya, Sistema de adquisición de datos, fotomultiplicadores.

Introduction

Water Cherenkov Detectors WCDs implemented in the LAGO Project are used to detect astroparticles at ground level using the "single particle" technique [1]. A WCD is divided into three main components: a pure water tank[2] isolated form natural light where Cherenkov effect takes place, a photomultiplier sensor PMT which converts Cherenkov radiation into electric impulses [3]. This electric impulses or "signals" are amplified, digitized and pre-processed by a set of electronic boards, a digitizer board developed within the LAGO Collaboration and a commercial FPGA board for pre-processing and control [4] A commercial PC is then used to storage data files containing absolute time, atmospheric pressure and temperature as well as signals.

The key features of this system are the low budget needed to build a detector, the reliability and versatility. Unfortunately the FPGA board used (Digilent Nexys 2 FPGA board) is now discontinued making very difficult and expensive to maintain

WCDs already installed and implement new detectors systems as stated in the LAGO Collaboration development plan [5]. After discussions within the Electronics group of the Collaboration it has been decided to select a new commercial board to replace Nexys 2 in order to speed up the development process rather to design a FPGA board from scratch. Red Pitaya[6], an open-source-software measurement and control tool, has been chosen due to its low price, high performance and versatility.

Present article describes a new data acquisition system based on Red Pitaya Board, the contents of the article is the following: overview of the data acquisition system, a brief description of Red Pitaya board, a description of the interface board “Leopard” designed to connect several peripherals to Red Pitaya, firsts test of control and acquisition of signals from the PMT that will be used to implement the WCD detector “Panchito” in the Cumbayá Campus of USFQ.

Circuit design, development test and characterization has been made at “Laboratorio de Partículas Astroparticulas y Radiaciones LEOPARD” of Universidad San Francisco de Quito.

METHODS AND MATERIALS

Overview of the data acquisition system for a WCD

Electrical signals arriving from PMT are negative pulses of hundreds of millivolts and hundreds of nanoseconds length, Figure 1 shows a typical PMT pulse

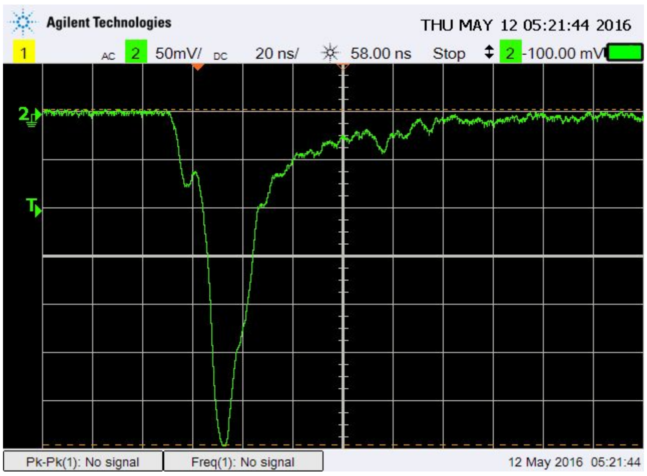

Figure 1 PMT pulse from Photonis XP1805 acquired with a digital oscilloscope

This signal is amplified, inverted and digitized using a digitizer board developed by the LAGO Collaboration, after the signal is digitized a FPGA preprocess and store the information in a file, a trigger module and a baseline compensation is implemented in order to improve Signal to Noise Ratio. This board also generates all the supply voltages (12V, 5V, +3.3V, -3.3V) that PMT needs to operate as well as the control voltage to set the level of the high voltage power supply of the PMT[4]. Figure 2 shows a schematic of the board

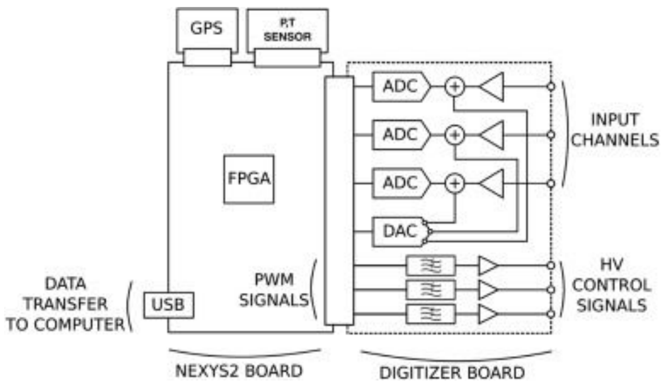

Figure 2 Block diagram of LAGO DAQ system, the system can acquire signal from 3 PMTs, GPS and temperature & pressure sensors are used to off line correction of data. Data is transferred to a local PC for storage and backup.

The main characteristics of the digitizer board are:

- 3 50Ω Analog Input Channels ± 2V Input range
- 3 FADCs 10 bits 40MSPS AD9203A from Analog Devices
- 1 DAC 12 bits MAX5051 from Maxim
- High Voltage supply control signals (3 channels) from 0 to 2.5V (PWM signals)
- 12V, 5V, 3.3V and -3.3V voltage supplies

The main characteristics of the FPGA board are

- Xilinx Spartan-3E FPGA 500K gate
- 16 MB fast Micron® PSDRAM
- Hirose FX2 (used to connect to digitizer board)
- Four 12-pin Pmod connectors (used to connect sensors)

The Red Pitaya board

Red Pitaya is an open-source-software measurement and control tool [6], it follows a block diagram of the board and list of main characteristics

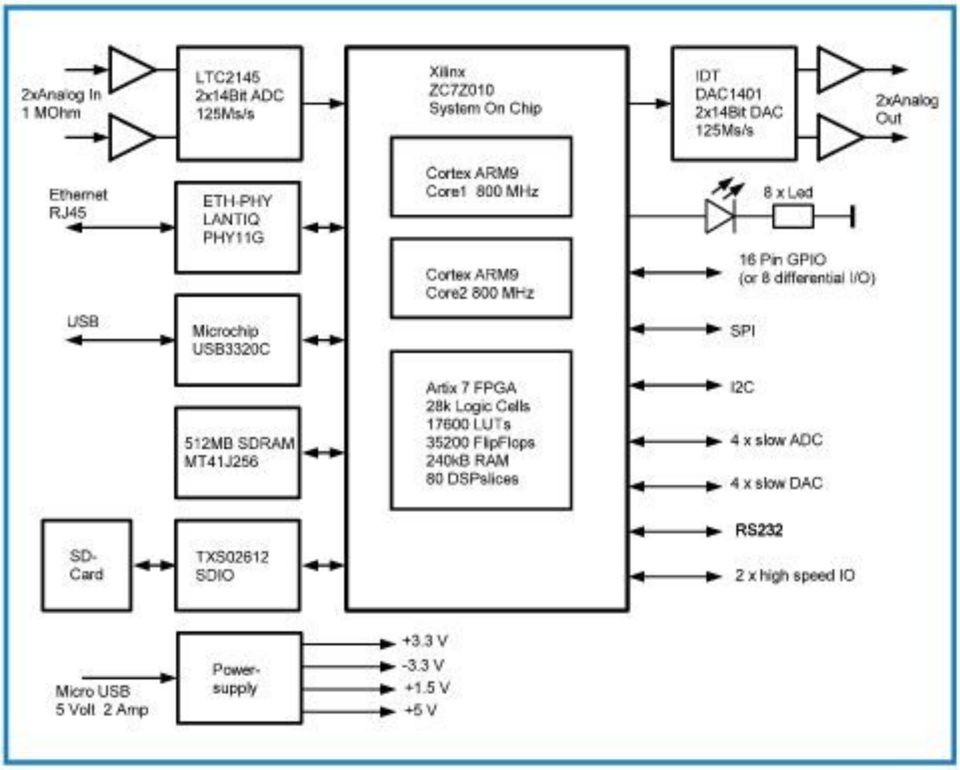

Figure 3 Red Pitaya block diagram [6], besides a FPGA it contains two signal acquisition channels, an ARM µP, USB, Ethernet, I2C communication ports and SD card bay.

The main characteristics of the Red Pitaya board are listed, focusing in the most important for our application

- 2 1MΩ analog input channel ±1V voltage range
- 2 FADC 14 bits 125MSPS

- Xilinx ZC7Z010 System On Chip which contains 2 ARM 9 uP, Artix 7 28K FPGA
- I2C, SPI, RS232 interfaces
- 16 GPIO digital pins
- 8 slow ADC outputs
- SD Card slot
- USB and Ethernet port

All these features makes the Red Pitaya not only an ideal replacement on the FPGA for particle detectors but a novel platform to develop every kind of data acquisition system. In particular in our case we can reduce the present DAQ system (PC, Nexys II and digitizer board) into two boards: Red Pitaya and an interface board.

It follows a detailed description of the interface board needed to implement all the features that a Data acquisition system for LAGO WCD must have.

Leopard Interface Board

In order to replicate the functionalities of the original data acquisition system a "daughter board" has been developed. This board should implement

- Power supply block: All the voltages needed to power the PMT base, the sensors and the Red Pitaya itself must be generated from a single 12VDC power supply
- Slow control block: In order to generate a slow voltage control to High Voltage power supply of the PMT.
- I2C connection bus: to connect sensors (GPS, temperature & pressure, etc)
- 2 PMT connections: supply & control voltages, HV read signal and PMT temperature signal

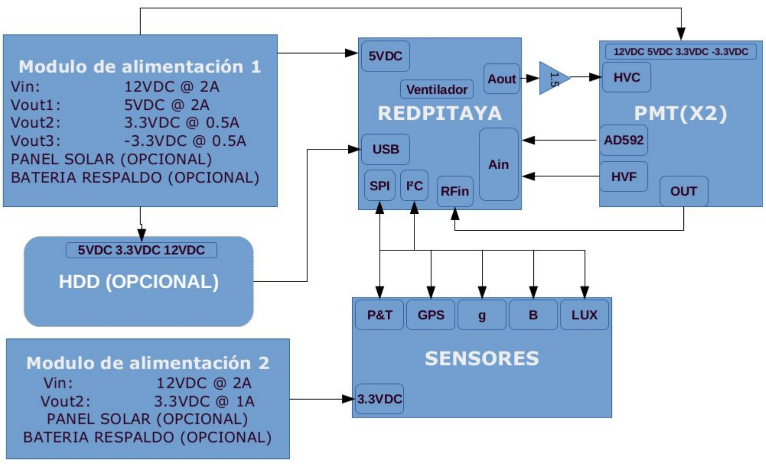

Figure 4 Block diagram of the "Leopard" Interface board, in the prototype version the power supply modules are not implemented, an external power supply is used, only -3.3V is generated in the board.

Two signals from PMT are connected to Red Pitaya:

- HVF: this is a voltage signal (0 – 2.5V) that senses the actual value of high voltage applied to PMT. This signal will be used to implement a control loop to monitor and correct high voltage value. To avoid high voltage derives is crucial to maintain WCD well calibrated.
- AD592: this is a temperature sensor current signal that can be used to monitor temperature inside de water tank. This signal will be used to off-line data correction.

Using the I2C, SPI and UART communication interface several sensors can be connected. To replicate the functionalities of the present DAQ system a GPS (Venus GPS) and a Temperature&Pressure sensor (BMP180) are used.

- GPS sensor is connected for synchronization purposes; Venus GPS generates a PPS (Pulse Per Second) signal used to attach a time stamp in the data file.

- Temperature and atmospheric pressure data from BMP180 sensor are attached to data file too for off-line data correction.

Studies of solar physics and space weather [7] can also be performed analyzing data from detectors, in order to have environmental data to complement particle detector other sensors are planned to be connected to de DAG system, i.e.:

- Luminosity sensor: to monitor total light flux (Solar physics applications)
- Accelerometer sensor: to monitor vibrations of the surface (Geophysics applications)
- Magnetometer sensor: to monitor magnetic field strength (Space Weather applications)

Since I2C interface allows connecting up to 127 devices, the ones listed above are only an example. Adding other sensor can allow DAQ system to act as an enhanced weather station [8].

RESULTS

Test of functionality and first attempt to collect data

Prototype of the DAQ system was tested in two different phases: with a test bench and with the PMT.

Test Bench Test: The test bench used is shown in figure 5

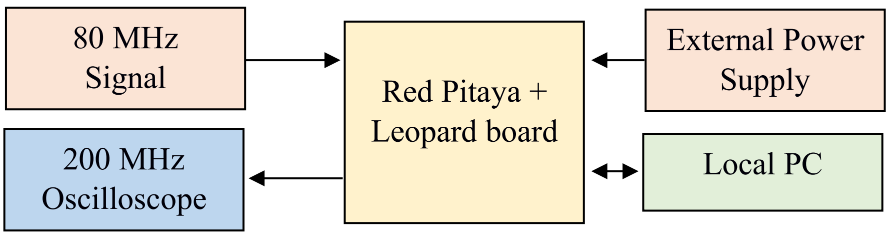

Figure 5 Block Diagram of the test bench used. Signal generator is used to generate a typical PMT pulse, Oscilloscope is used to visualize HV voltage control. Local PC is used to program Red Pitaya and visualize data.

HV Control signal Test: A 0 -1.8V PWM signal is generated by Red Pitaya, Leopard board includes a scaler circuit which amplifies the original signal to achieve HV power supply voltage control range (0 -2.5V)

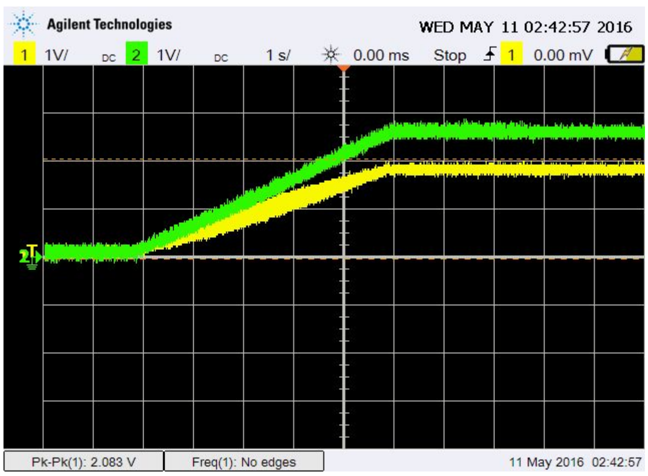

Figure 6 Yellow line is the PWM signal generated by Red Pitaya, voltage ramp should be 5 seconds long to avoid PMT damage. Green line is the output of Leopard board

Since PMT high voltage supply operates from 0 to 2500 V, HV control signal must be a slow ramp (typical 5 seconds) to avoid PMT damage. Figure 6 shows the behavior of the control signals which complies with specifications.

Figure 7 shows a first acquisition attempt using a pulse generated by signal generator

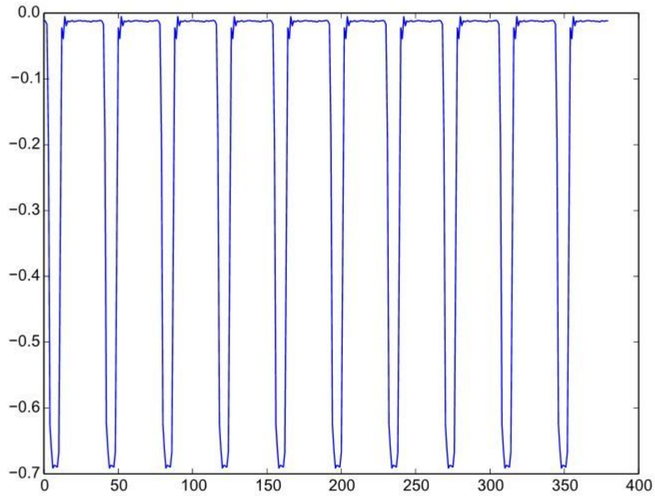

Figure 7 Acquisition of a periodical signal generated with a signal generator. Y axes is in volts, X axes is in ADC steps

Test with PMT attached

Figure 8 shows the test bench used for the following test

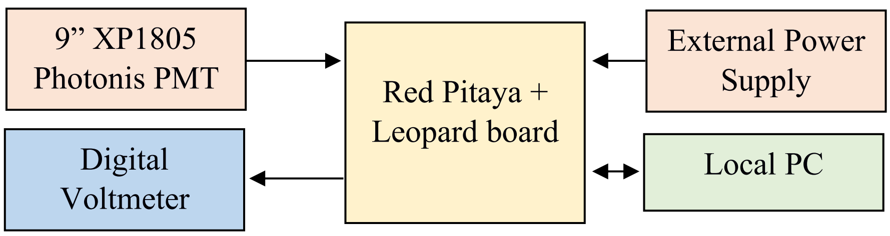

Figure 8 Test bench used to characterize PMT. Digital voltmeter monitors HV level measured at PMT base

A Photonis 9” PMT with control base designed for the Auger Collaboration [9] was used to test the DAQ system. A HV signal of 1.8V corresponding to 1890 V was generated. Figure 9 and 10 shows that the DAQ system can acquire all the PMT signal inside the data buffer without loss of data or superposition.

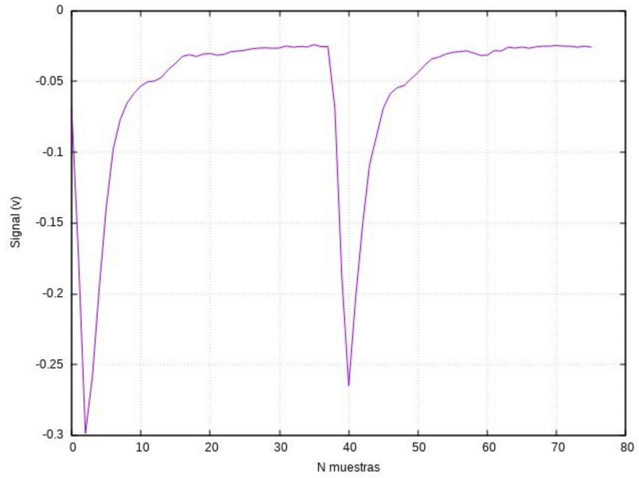

Figure 9 Capture of an actual PMT signal; HV = 1890V and trigger set to 150 mV

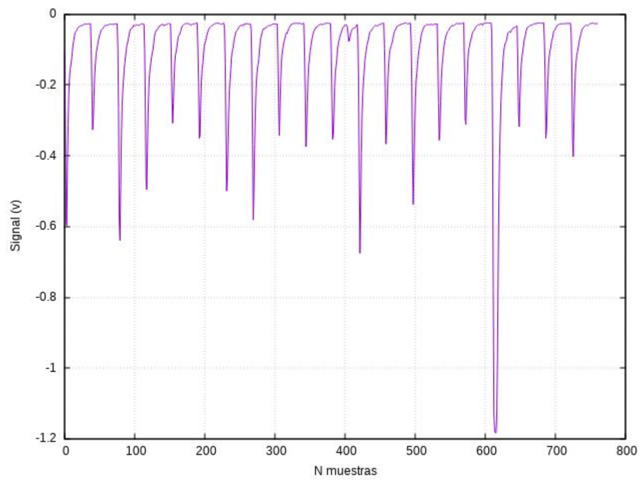

Figure 10 Acquisition of PMT signal with HV = 1890V and trigger set to 300mV, each sample is 300ns long

CONCLUSIONS

- Present work shows that a new DAQ system for particle detection based on Red Pitaya is a valid alternative to new generation of electronics for WCD of the LAGO Collaboration.
- With the DAQ system as it is now a PMT characterization procedure can be development. HV voltage can be monitored and data can be acquired with different levels of trigger.
- DAQ system was programmed used C++ language, no substantial modifications were made in the FPGA code proving the easy to use feature of the system.
- Using Ethernet interface the DAQ system can be accessed without a physical connection, data download, monitor and reprogramming of the DAQ system can be performed in remote way, making the system ideal to develop a stand-alone WCD which can be installed in difficult access points like top of mountains or other places at high altitude

- ◆ With only SW modifications the DAQ system can be used to acquire signals from other types of particle detectors, in particular Leopard Lab is interested into explore SiPMs (Silicon Photomultipliers) technology to implement a hybrid version of WCD

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