A PCI Based Data Acquisition System for Ground Array Detectors With Wireless Synchronization Through GPS

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Abstract

The synchronization of ground based cosmic ray detectors is a recurring problem. Traditional acquisition systems usually drive signal cables from each station of an array of detectors to a central acquisition system. In the context of ULTRA, a support experiment for the EUSO mission, a distributed wireless acquisition system based on a PCI board with synchronization through GPS was developed. The System is composed by several units, one per station and time-tags each event on each station. The time differences between the several stations are computed offline. Each unit includes a low-cost, commercial GPS receiver (GPSboard), a custom PCI board (LIP-PAD) and a Personal Computer. The PCI board performs the fine time-tagging and also acquires the PMT signals of the ground array detector. PMT signals are shaped, amplified and then digitized by a 10 bits flash ADC with a frequency of 100 MHz. A digital trigger unit allows to implement several online trigger conditions. On trigger, event data is stored on an onboard memory. The board control and data readout is performed using the PCI bus. The overall time accuracy has been estimated to be better than 5ns.

1. Introduction

ULTRA[1], a support experiment for the EUSO mission[2], plans to collect the UV light generated by an Extensive Air Shower (EAS) that is reflected on several surfaces (land, water, snow, etc.). ULTRA is composed by a UV telescope to collect the UV light (UVScope) and a conventional ground array of scintilator detectors (ETscope) responsible for the detection of the EAS.

For every event in each ETscope station the energy deposited in the scintilator and the arrival time are estimated. Coincidences among different detectors are then found off-line, using the arrival time at each unit. Since the expected single counting rate at sea level is 180 Hz/m2, the contamination by random coincidences is negligible.

The estimation of the direction of the primary cosmic ray is based on the measurement of the time differences between the arrival of the shower front at the different stations and the distance between them. The ULTRA requirement of $8°$ for the error on the direction estimation is translated in a precision of 10ns

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on the measurement of the time differences, assuming that the stations are 20m apart from each other.

ULTRA plans to collect data for several surfaces and for several configurations of ETscope. To overcome the problems of cables under water environments and the difficulty of changing signal cables for the different configurations, a distributed wireless data acquisition system was developed for the ETscope. The system consists of several units, one per station. Each unit is composed by a commercially available GPS receiver, a custom PCI board (LIP-PAD) and a Personal Computer.

The GPS receiver provides a synchronization pulse each second. The LIP-PAD board acquires PMT signals directly, performs a digital trigger and time-tags each trigger on each station. The data collected is stored locally and/or transmitted to a Central Control and Communications Point.

2. GPS synchronization

GPS satellites act as beacons emitting a synchronization signal at each UTC second. The GPS receiver acquires the signal and, as the distance between the receiver and the satellite is known, the propagation delay of the signal can be computed and corrected for, enabling the GPS receiver to output a signal (PPS) synchronized to the UTC seconds.

The errors present in GPS synchronization are mainly due to the inaccurate knowledge of the propagation of the synchronization signal from the satellites to the receivers, namely the propagation in the atmosphere under several atmospheric conditions. Nevertheless the important parameter for ULTRA is the relative accuracy of the PPS pulses. The ETScope stations are very near each other and it can be assumed that the signal from a satellite has the same propagation characteristics for the different stations. Thus most of the errors can be viewed as systematic errors that cancel when taking time differences between the different stations.

The search, based on the quoted accuracy, for a low cost, commercially available GPS receiver led to the choice of Motorola UT+ ONCORE[3], which was also previously chosen by the Auger Collaboration[4]. Data, such as position, visible satellites and time (day, hour, minute, second) is transferred via a RS232 protocol. UTC seconds are marked by the PPS signal and identified through the serial interface. The PPS pulse is a TTL signal and is outputted with an offset, different for each PPS and each receiver. The offset value is made available, in each second, through the serial interface and varies roughly from -50 to 50ns. It is therefore imperious to take into account this correction in order to achieve maximum accuracy.

Motorola states an absolute accuracy of 40ns in the synchronization between the PPS signal and the UTC seconds for the UT+ model. Tests of the GPS receivers were performed to estimate the differential error inherent to the GPS. The measured relative accuracy was better than 3ns.

It should be emphasized that the GPS errors only cancel, in differential mode, if the conditions for the different receivers are similar. Namely it is necessary to ensure that the set of satellites used to compute time are the same for all the receivers. This can be done by pre-programming the set of satellites to be used at each time.

3. The LIP-PAD Board

The LIP-PAD board is a PCI based acquisition board and has three main blocks:

- The Time Measuring Subsystem (TMS), composed by a TDC and a 32 bit counter running at 50MHz.
- The Analog Acquisition Subsystem (AAS) with 6 analog acquisition channels, each composed by a shaper, an amplifier and a 10 bits flash ADC of 100MHz. An onboard memory and a digital trigger unit are also part of the AAS and are common to all channels.
- A control and readout unit with a PCI interface.

The digital units are implemented on a PLD in which, by reprogramming, logic units can be easily modified, e.g., the trigger modes can be easily changed.

3.1. The Time Measuring Subsystem (TMS)

The TMS is responsible for the measurement of the time difference between the synchronization pulse from the GPS board, and an event. This subsystem must comply with the accuracy required and have a dynamical range of 1s, since the event can occur at any moment between two PPS signals. The system developed consists of a clock (50 MHz oscillator and counter) combined with a TDC. The use of a clock allows the 1s dynamic range while the use of a TDC allows the necessary precision without having a 1GHz frequency oscillator. The oscillator period is calibrated with the time interval between two consecutive PPS. Preliminary tests have been performed and indicate that the TMS has a precision better than 3ns. Combined with the GPS synchronization error, this brings the overall time-tagging error to values below 5ns.

3.2. The Analog Acquisition Subsystem (AAS)

In the AAS the PMT signals are shaped, amplified and then digitized by the ADC. The ADC samples the signal voltage with a frequency of 100MHz and writes the values to a buffer memory. This high sampling frequency is justified by the need to have enough samples of an event signal in order to reconstruct the signal shape. The digital trigger unit can implement various trigger conditions (e.g. simple threshold, muon, double pulse, shower). On trigger, the data is saved on memory and read by the PC through the PCI bus. The total amount of data recorded is defined on the PLD and is, to this date, of 256 positions. This means that 2.6 μs of data is recorded. The position of the trigger in this interval is defined in the DAQ software (from 0 to 255). Choosing the middle value allows to save 1.3 μs of data before and after the trigger. Thus, trigger generation does not assume such a crucial role as in charge integration acquisition systems that require a precise interval for integration. The analysis software must be able to select the relevant data of an event and extract the important parameters of the signal, such as the area that corresponds to the charge, which is proportional to the deposited energy on the scintilator.

4. Summary

A data acquisition system based on a PCI board with synchronization through GPS was developed. The system was successfully tested in a laboratory setup and during the engineering run of ULTRA. The overall time accuracy for the synchronization between the several stations of the detector was estimated to be better than 5ns.

5. Acronyms List

AAS - Analog Acquisition Subsystem
ADC - Analog to Digital Converter
DAQ - Data Acquisition
GPS - Global Positioning System
PCI - Peripheral Component Interconnect
PLD - Programmable Logic Device
PMT - Photomultiplier
PPS - Pulse Per Second
TMS - Time Measuring Subsystem
UTC - Universal Time Coordinated

6. References

1. see in these Proceedings O. Catalano, et al., “The EUSO instrument” and M. Teshima et al. “Physics with EUSO”
2. see in these Proceedings G.Agnetta, et al., “The ULTRA experiment: a supporting activity for the EUSO Project” and G.Agnetta, et al., “The ETscope ground array for the ULTRA experiment”
3. ”Oncore users guide”, Motorola, http://www.motorola.com/ies/GPS
4. F. Meyer, F. Vernotte, ”Time Tagging Board Tests at Besanon Observatory”, GAP-2001-050 (2001).