SOFIA, 2011 VOLUME 5, NUMBER 1 ISSN 1313-1842

# ANNUAL JOURNAL

# OF

# ELECTRONICS

Technical University of Sofia

Faculty of Electronic
Engineering and Technologies

# ANNUAL JOURNAL OF ELECTRONICS




The Journal is issued by the FACULTY OF ELECTRONIC ENGINEERING AND TECHNOLOGIES, TECHNICAL UNIVERSITY of SOFIA, BULGARIA.


The Journal includes the selected papers from the International Scientific Conference Electronics ‘11, held on 14 – 16 September 2011 in Sozopol, Bulgaria.

# CONTENTS

## BOOK 1

## BOOK 2

# Measuring Time Properties of Correlated Signals from Extensive Air Shower Detector Clusters

Georgi Genchev Zhelyazkov, Aleksandar Vladimirov Velchev and Mityo Georgiev Mitev

*Abstract* - **In the following article, we take a look at a system for registration of the events of Extensive Air Showers, where the measured properties are the delays between the activation of the different detectors in the cluster block. The system presented is intended for use in data acquisition and accumulation in the measuring station.**

*Keywords* – **Extensive Air Showers, signal correlation, event registration**

## I. INTRODUCTION

### A. Cosmic Rays

It is now 99 years since the discovery of cosmic rays by the Austrian physicist V. F. Hess (1883 - 1964). For this he was awarded the Nobel prize in physics in 1936. From that point and up until now, probably the most expensive systems and complexes constructed, are designed for measuring the properties of the primary and secondary cosmic radiation. Observations are conducted via means of high-altitude balloons, as well as additional satellites in many observatories (both at sea-level and at high-altitudes), with the area of the detector systems reaching 100 km$^2$ [1].

### B. Extensive Air Showers - EAS

When cosmic particles interact with the upper layers of the Earth's atmosphere cascades of secondary radiation are formed (Extensive Air Showers - EAS). Their area when they reach the Earth is dependent on the energy of the primary particle and may reach tens of km$^2$ for the highest ever recorded energy particles (~$3.10^{20}$eV). As a result of multiple interactions and transformations, a huge amount of secondary particles form in the trek - pions, protons, neutrons, muons, electrons, positrons and photons [2,4].

### C. Registration of EAS Components

The basic principles applied for measuring of cosmic rays are driven from their interaction with matter They include:

- registration of charged particles as they pass through appropriate physical environments (detectors);
- registration of Cherenkov radiation, caused by the passing of relativistic particles through the Earth's atmosphere;
- registration of low-frequency (1 - 10 KHz) radio pulses, appearing in the plasma pinch of the atmosphere shower.

In the first case, mainly organic plastic or liquid scintillation detectors are used along with fast logic gates. In the second case - aerial Cherenkov detectors, designed with Photoelectron Multipliers. In the third case - ultra long wave radio receiver systems combined with scanned spectral analyzers [2].

Some of the largest observatories in the world have systems with several hundred scintillation detectors in areas from 12 to 100 km$^2$.

### D. Recent Trends in the Design of Systems for Cosmic Ray Detection

The widespread availability of the Global Positioning System (GPS) gives the opportunity, for stations employing a low number of detectors, to be united in a network after a precise time synchronization of the registered events.. Also it is worth noting that:

- construction of smaller stations with global synchronization is available to individual universities;
- it is possible to build many stations located at large distances from one another.

In the USA, Canada, as well as many European countries, such systems are either in the process of being built or in the process of construction [3]. European stations are currently uniting in a single network - Eurocosmics.

Usually every station has a detector system, consisting of several scintillation or Cherenkov detectors. Their signals are united by logic gates. When an EAS event takes place, the exact time of the event is recorded. Rarely, the systems can also register the intensity of the radiation (the amplitude of the signals), but when they do, this parameter is also recorded.

In the following processing, the signals from several neighbour stations are processed. The accuracy of the calculated origin of the trek, caused by the primary particle, depends on the relative accuracy in accordance to the common time scale and distance between the stations.

### E. The idea

A possible combination of the two approaches is interesting. This requires for each station to contain a cluster of several detectors, positioned not far away from each other (in the range of 10-20 meters). The main difference is that the electronic system doesn't seek matching events in a particular time window (as it is done

G. Zhelyazkov is a PHD student in the Department of Electronics and Electronics Technologies, Faculty of Electronic Engineering and Technologies, Technical University - Sofia, 8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria, e-mail: joro_zh@abv.bg

A. Velchev is a student in the Department of Electronics and Electronics Technologies, Faculty of Electronic Engineering and Technologies, Technical University - Sofia, 8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria, e-mail: liquidalex@gmail.com

M. Mitev is with the Department of Electronics and Electronics Technologies, Faculty of Electronic Engineering and Technologies, Technical University - Sofia, 8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria, e-mail: mitev@ecad.tu-sofia.bg

in existing systems), but measures the time delay between the activation of the individual detectors.

The recent developments in available components offer the possibility of designing a multichannel system for registration of correlated time intervals in the nanoseconds (the delays should be in this region), as well as a system for processing of those signals. This way the frame of data for a certain event would contain information about the exact moment of the event, the number of detectors that have registered an event, the delays between individual detectors, and the direction of the EAS.

## II. METHOD

*A. Detector system - time correlations and constraints*

In order to implement the suggested approach in signal processing, the accuracy of time-of-event registration in the detector must be more than 1ns. This makes the selection of detectors, as well as the method of acquiring and forming of signals, critical.

It is known [1,5] that the duration of Cherenkov radiation in the atmosphere caused by EAS is from several hundred ns to 1-2 μs. The edges of the signal captured from the detector would be in this region, making it impossible to obtain nanosecond accuracy. This fact proves that Cherenkov detectors are not suitable for application in this case.

The solution is to use the classically established organic plastic or liquid scintillation detectors. They register the muon component of EAS and are the fastest known detectors - up to 20 ns, allowing them to accurately acquire the time-of-event.

In order to implement the proposed principle, one cluster needs to utilize 4 to 8 organic scintillation detectors, positioned 10 to 20 m apart from each other (the following proposed implementation is designed for 8 detectors, but could easily be converted for any number).

*B. Detector signal capture and formation*

Figure 1 shows the schematic for the implementation of signal capture and formation for detectors S1 - S8. The foremost requirement is to guarantee exact time capture in the moment of event occurrence.

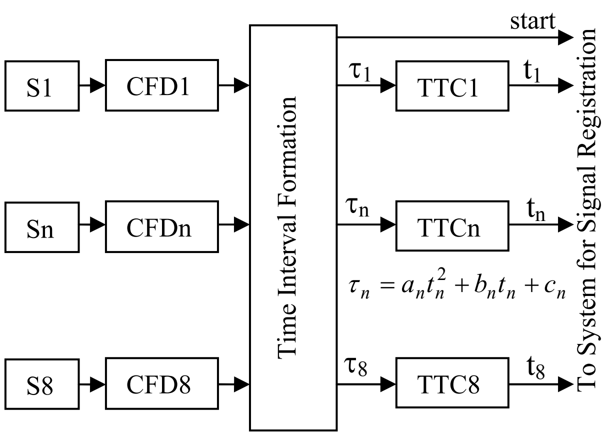


Fig. 1. Front End Electronics

Amplitude fluctuations in the output levels of signals necessitate the use of Constant Fraction Detectors - CFD. In the Interval Formation block, the first registered pulse triggers a "start" signal, which is output to the registration system. The delays from the other detectors relative to the first one form the time intervals $\tau_n$, whose duration is up to 20 ns. In order to measure these intervals with high precision, time expanders are introduced to the circuit. These are Time-To-Time Converter circuits - TTC. The output of every TTC forms a pulse $t_n$ which is about a 1000 times longer than the input pulse $\tau_n$. The duration of these output signals is captured in the System for Signal Registration.

*C. System for Signal Registration*

The system for registering of signals is based on simple digital logic implemented in an ALTERA Cyclone IV FPGA. Measurement is done by the well-known method of Input Capture with a high-frequency clock signal. This system is tested on an ALTERA DE2-115 demo board, which contains an internal high-stability low-jitter 50MHz clock.

There are several main blocks in this system:

-**Input logic** (Fig.2), which assures that no measurement, is triggered unless there is an actual event (with all channels having an actual signal).

The signal START works as an enable signal for the system. It triggers the D-type Flip-flop which enables the passing of Channels 1 to 8 through the logic NAND gates. This signal also outputs a SM signal, which stands for "State - Measuring" and means the system is in a state of measuring. Both START and SM have a high-active state.

The input signals for the system are random in nature, and therefore they are asynchronous with the entire system. To remove this problem, all measured signals (labeled here CHx - for each of the channels) are routed through a D-type Flip-Flop, which is connected to the System Clock. The enabled signals are inverted and then are fed to the next block via signals CHx.

There are two ways of resetting the system. They are both triggered in a state of measurement. The first one is when all of the channel input signals have passed through the logic, and are now in their default states. That means that the N-input NAND gate will produce a '0' at its output. This NAND gate is controlled by a clock signal, and is designed to only give a short reset signal, enough to put the system in a 'reset' state for 1 clock cycle.

The **Counter Block** performs the actual measurement of the signals by using the Input Capture method.

The counter block is composed of several blocks. The first one is a 48-bit free running counter. It is started, when the entire system is reset. The reason for this is, that with a 50MHz clock, a counter of this size would need about 65 days to overflow, and we can use the data of the counter, to determine exactly when an event occurs. This counter is used for synchronization with a GPS receiver. Every second, the GPS sends a "beginning of second" signal. Then the data from the counter is stored in a register. When an event occurs, the counter value is stored in another register, and the value from the beginning of the second is subtracted from it. The date and time is then received from the GPS module via RS-232 or another means of communication. In the end, the system has acquired the exact time (down to a second) from the GPS, and has a register that contains information how much clock pulses have passed since the beginning of the second. This leaves us with the ability to calculate the precise time down to the

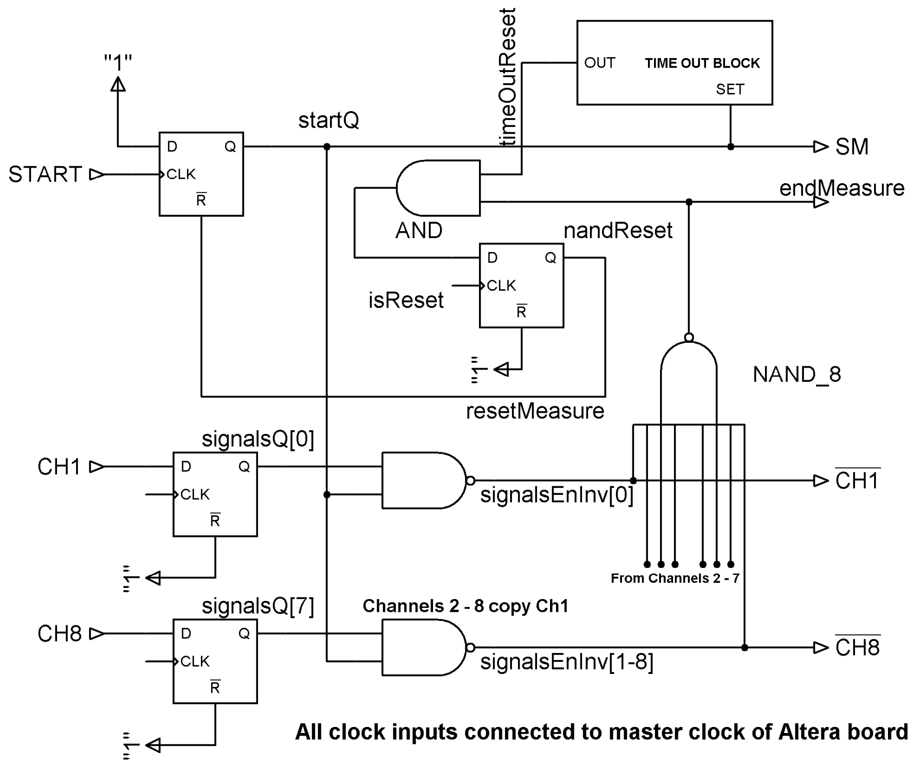


Fig. 2. Input Logic Block

period of the system clock (in this case 20ns). Let's take a look at the schematic for this block (Fig.3.). This schematic features the Input Capture method.

The FROM COUNTER input signifies the 12 least significant bits (LSB) of the counter. The measured intervals should not exceed 20 μs, so 12 bits are more than enough.

The first register is assigned the value of the counter in the beginning of the input CHx. The second one is assigned the value of the counter, when the duration of the signal has ended. Obviously, we should subtract one from the other and calculate the output value. However, there is a possibility that, while the signal measurement is in progress, the 12 LSB of the counter will overflow. This

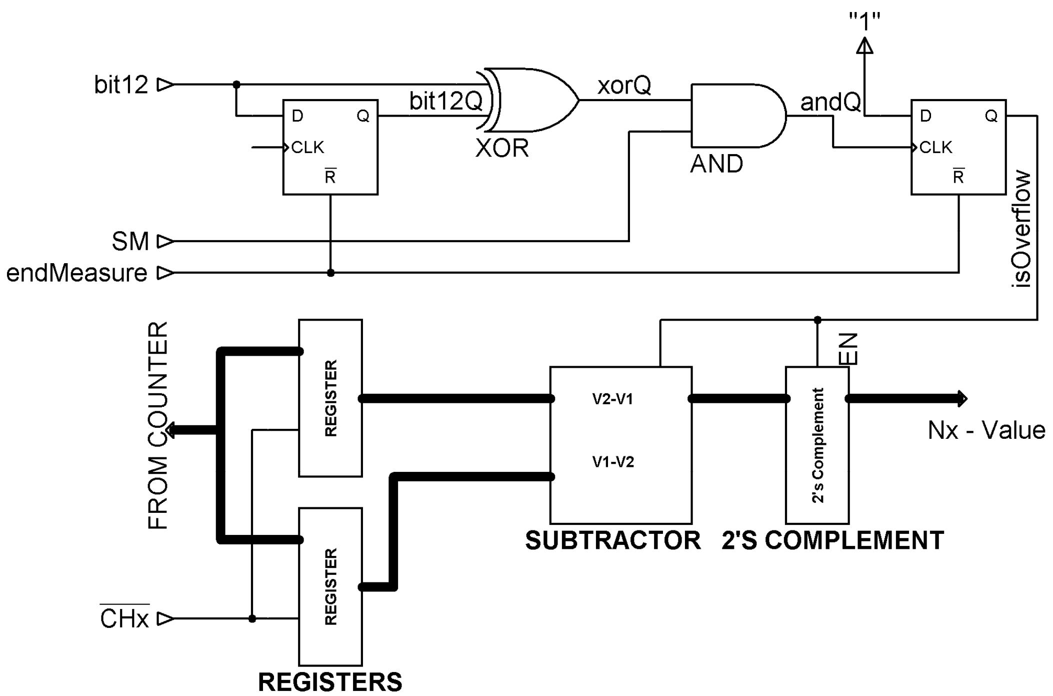


Fig. 3. Counter Block

means that there will be a change in the next bit of the counter, so the logic in the top of the schematic outputs a logical '1' when the bit has toggled and the system is measuring. In the event of this happening, the subtractor subtracts the End value from the Begin value, and the result is transformed into 2's complement code, as if it were a negative number. This produces the desired result in 12-bit binary code.

The value Nx is then routed through a binary to ASCII converter and then sent to a PC via the RS-232 interface. Communication to a PC is managed via a RS-232 serial interface. After a signal for the end of the measurement, the output of the counter block is serially set to the UART core. This number is chosen because 19200 baud is a standard frequency in RS-232 and the events are rare enough, so that there will be no flow of data due to buffer overflow. Both the Receiver and the Transmitter are connected to FIFO (First In First Out Buffers), in case there is no data to transmit and receive, or the flow of data is faster than the Tx/Rx speed of the UART.

The chosen RS-232 configuration is 8 data bits, no parity bit and 1 stop bit.

### *D. Data Processing*

After the data is received in a PC, it should be processed. So far, we have only acquired the number of clock pulses for each channel and the time of the event. The Time-to-Time Converters described are analog units and therefore have certain fluctuations. The input output ratio is described by a 2nd order polynomial:

$$\tau_n = a_n t_n^2 + b_n t_n + c_n \qquad (1).$$

The coefficients are calculated when fine-tuning the system, by sending low-jitter test signals into the system and monitoring the output. Each channel has their own polynomial and since the properties of components tend to change over time, this check must be run over a period of time.

### *E. Data Storage*

In the case of measuring correlated signals, we must assume that the nature of these signals is random in the time domain. However, since these signals are correlated, it is possible to define the measurement of a group of signals as an "event". The occurrence of these events must not be with a frequency larger than the maximum possible frequency of measuring a single event. This means that this system is suitable for events that occur not that often. In the given example of cosmic particles, the rate is well below once per millisecond.

That said, the algorithm for data storage should be DATA LIST. This means that the data is stored chronologically. Each event carries with itself the time of occurrence as well as the associated parameters (in this case time properties, but could be more - temperature, other nonelectrical properties, etc.).

## III. CONCLUSION

The preliminary research confirm the assumptions that when performing output signal capture from groups of scintillation detectors that register the muon component of EAS based on response delay time, it is necessary to accurately register the time of the event and to convert the measured time intervals to intervals with a longer duration. The latter should be measured with a specific counter structure, with the optimal solution being programmable digital logic. In the given example FPGA is used because it provides the opportunity to easily implement digital logic that would otherwise require tens of discrete components and also because of speed and jitter considerations.

## ACKNOWLEDGEMENT.

The present research is supported by the Technical University - Sofia under Contract 112ПД051-3.

## REFERENCES

[1] Grieder, P. K. F. *Cosmic rays at earth : researcher's reference manual and data book.* ELSEVER, Amsterdam, p 1093 (2001).
[2] Сокуров В.Ф., *Физика космических лучей: косми-ческая радиация.* Ростов н/Д.: Феникс, 2005. 188 с.
[3] http://livni.jinr.ru
[4] Мурзин, В.С. *Введение в физику космических лучей.* 2-е изд., доп. Москва: Атомиздат, 1979, - с. 304.
[5] Cecchini S. et all. *Solar panels as air Cherenkov detectors for extremely high energy cosmic rays.* arXiv:hep-ex/0002023v1 (7 Feb 2000).