The Data Acquisition System for a Compton and Pair-creation sensitive instrument

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***Abstract*— A data acquisition system has been developed for the prototype of the Medium Energy Gamma-ray Astronomy (MEGA) telescope. It reads out two different types of detectors: The first type, called tracker, is a stack of Silicon strip detectors. The second is a calorimeter consisting of CsI(Tl) bars coupled to Silicon PIN-photodiode arrays. Analyzable photon interactions in the detectors cause either coincident events in both detector types or hits in multiple subsequent strip detectors. Once such a pattern is detected, all channels of both detector types are read out. This leads to data from 11328 channels, which is reduced to the channels containing interactions and written to the computer hard disk. The whole system is designed around the front-end chip TA1, which is used for both types of detectors. It is a charge sensitive device including discriminators for trigger generation. The triggers from all chips are evaluated by our coincidence electronics, a self-made VME-bus card. Nearly all logic of this card is implemented in a programmable logic device. An additional RAM forms a lookup table for trigger patterns that should start the readout of the whole detector. Commercially available VME modules perform the analog to digital conversion and generate the readout sequence. A single-board computer takes care of the instrument control, the data reduction and storage, collects housekeeping data etc. Its software is written in C++, so that a high modularity and several abstraction layers can be achieved easily. The system showed stable operation over several weeks during laboratory measurements as well as during beam tests.**

***Index Terms*— data acquisition, Compton-scatter, pair-creation, trigger processing, self-triggering.**

I. INTRODUCTION

THE Medium Energy Gamma-ray Astronomy (MEGA) telescope is a concept for a combined Compton scatter and pair creation telescope at MeV energies (0.4 – 50 MeV) [1]. It consists of a stack of Si strip detectors [3] (the tracker) and a CsI calorimeter [4] (Fig. 1). Besides the detector technology the data acquisition system is challenging, in particular since the envisioned final instrument will fly on a space mission.

To achieve good spatial resolution, the detectors have to be finely segmented, resulting in a large number of channels. Every channel needs to generate a trigger in order to be able to select analyzable events. This selection should be implemented in a flexible way to accomodate a tradeoff between quality and quantity of the data in a wide range of situations. In addition, the pulse height for every interaction needs to be measured in order to reconstruct the incoming photon's energy *and* direction. In a balloon flight or on a future satellite, charged particles pass the detector and generate patterns similar to those of photon interactions. For their suppression an anticoincidence shield (ACS) needs to be included in the system to allow vetoing the readout of such events. Because of the large number of channels a very low power consumption of the front-end electronics is crucial especially for a satellite version (the envisioned satellite instrument will have about 100.000 channels).

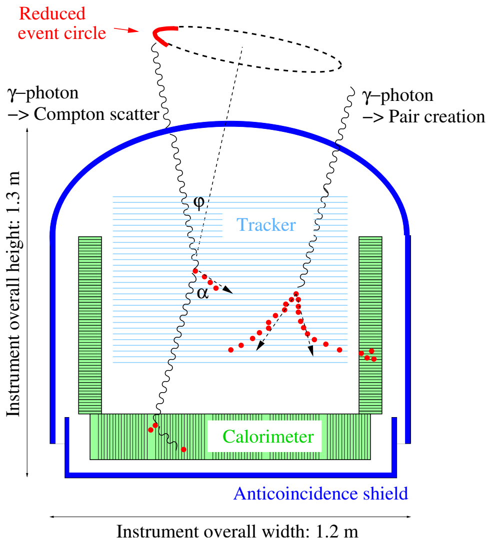

Fig. 1. The MEGA principle of detecting γ-rays. Compton scatter and pair creation events can be used for reconstructing the origin of the photon.

As important as appropriate hardware is the control software, which has to reflect the modularity of the hardware and which need to be tolerant to failures like defective channels.

II. THE PROTOTYPE

To prove the feasibility of the MEGA telescope, a prototype of the instrument has been built at the Max-Planck-Institut für extraterrestrische Physik. The prototype tracker has 11[1] layers of double sided strip detectors stacked up (Fig. 2). Each layer has 384 channels on the top side and the same number of channels on the bottom side. The calorimeter is divided into 20 blocks à 120 CsI(Tl) crystals (Fig. 3). They are read out by monolithic PIN-diode arrays (10 × 12); each crystal has its own diode. Moreover, the four bottom blocks have diodes on both

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[1] The DAQ system supports up to 12 layers; unfortunately, only 11 are working.

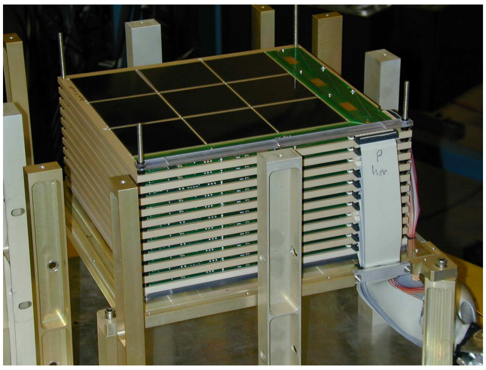

Fig. 2. Stack of Silicon strip detectors

Fig. 3. Open calorimeter blocks. The long bottom calorimeters have two-sided, the side calorimeter one-sided readout

ends of the crystals. This gives a total of 8448 (tracker) + 2880 (calorimeter) = 11328 channels. The ACS consists of plastic scintillator plates and surrounds the whole detector. Wavelength shifting fibers are glued into grooves in the plates and guide the scintillation light to 6 photomultipliers.

III. READOUT ELECTRONICS

The Silicon strip detectors as well as the PIN-diode arrays are connected to the same ASIC, the TA1 developed by IDEAS (Oslo, Norway). This chip provides 128 readout chains, each having a preamplifier, a shaper, a sample&hold and a level discriminator. The analog signals are read out sequentially by multiplexing all channels to one output. The 128 trigger signals generated by the discriminators are logically or'ed to a common output, but the chip allows to block each channel individually. The power consumption we achive with our settings is as low as 0.5 mW/channel (with recommended settings 1 mW/channel). This already meets the constraints for a satellite version. Unfortunately, the architecture of the TA1 causes problems with the measurement of the deposited energy (the reasons are discussed in [5]). While this does not affect the proof of the measurement principle, much effort needs to be invested into corrections for correctly evaluating the capabilities of the whole detector. This work is still ongoing.

The front-end chips demand a very low noise power supply, which is implemented in the so-called repeater cards (developed by Albedo GmbH, K.-H.Schenkl, Munich, Germany). These cards also convert the chip's digital levels (± 2 V) to TTL levels and generate the (programmable) analog threshold levels for the discriminators on the TA1.

Optocoupler cards galvanically separate the front-end from the computer environment (VME-bus). They are needed for two reasons: First, the grounds of the front-end chips on top and bottom side of a tracker layer are at the respective bias potentials, i.e. they must not be connected electrically. Second, this separation decreases the induction of noise from the instrument computer to the sensible front-end electronics.

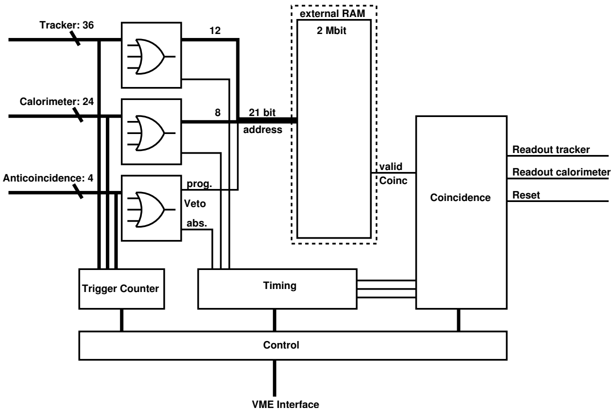

Fig. 4. Diagram of the logic implemented in the coincidence electronics FPGA

In contrast to the tracker and calorimeter a new design for the readout of the ACS was not necessary because the flight spare PMTs and associated electronics (Main Electronics Box and Low Power Control) of the ACS of EGRET (a former satellite experiment [2]) were still available and work well.

IV. COINCIDENCE ELECTRONICS

The decision whether to read out the detector after a trigger or not is made in the coincidence electronics board, a self-designed VME-bus card. To provide high flexibility, all logic is implemented in a FPGA (XILINX SpartanXL), which is configured by the instrument CPU via the VME-bus. A 2 Mbit RAM on the board serves as lookup table. It contains the information, whether the current pattern of chips with activated trigger should lead to a readout or not. The current design (Fig. 4) has 36 trigger lines available for the strip detectors (only the triggers generated on the top side of a strip detector are used, thus up to 12 layers can be connected), 24 lines for the calorimeter block and 4 lines for the ACS. The trigger rates of the 64 connected lines can be monitored individually. Since the RAM has only 21 bit, the trigger signals have to be combined into 21 groups. Then each group corresponds to one address bit of the RAM. To accomplish this, the three trigger lines of a tracker layer are or'ed together (12 groups) and the triggers of the calorimeter are or'ed to 8 groups. The last bit is needed to implement a programmable veto. When the veto trigger of the bottom ACS plate is connected to this bit, a readout can be allowed even if an interaction took place in the bottom plastic plate (this would be the case for high-energy pair-creation events). There is also an absolute veto implemented which inhibits the readout. Because of the flexibility of the FPGA design, additional functions, such as a command interface to the ACS system or some monitoring tasks needed during an accelerator measurement, can be implemented.

V. Instrument Control

The coincidence electronics board, a sequencer (CRAM sequencer Mod. 551 from C.A.E.N., Viareggio, Italy,) and 8 ADCs with FIFO (CRAMs Mod. 550, each containing 2 ADCs with FIFO, also from C.A.E.N.) form a subsystem. It operates independently from the instrument CPU. The coincidence unit starts the (readout) sequencer when it recognizes a valid trigger pattern. The pulse heights converted by the ADCs during the readout sequence are stored in the ADC's FIFOs only if the measured pulse height exceeds a given threshold.

After the sequence is completed, i.e. after the whole detector has been read out, an interrupt is sent to the instrument CPU (a Pentium III single board computer from Concurrent Technologies, Ann Arbor, Michigan, USA). The contents of the ADC's FIFOs are transferred to the CPU memory for further processing and storage. Then the readout is reinitialized for the next event.

Besides the instrument CPU, the sequencer, and the ADCs, the DAQ hardware has a digital I/O module (MDIO-96, MATRIX/CETIA, now Thales Computer, USA) for loading the trigger block registers of the TA1 and the threshold DACs on the repeater cards.

VI. Software

Since the time-critical part of the readout runs without interaction of the instrument CPU, a real-time operating system is not necessary. For portability reasons we use Linux. The whole instrument software is written in C++ and heavily uses the ROOT [7] C++-library developed at CERN. The instrument software splits into several layers, which reflect different degrees of abstraction: The hardware access layer is the lowest layer and handles directly the hardware via a variety of interfaces (VME, serial, etc.). Here the data are plain numbers, which are read from the different hardware registers of the (VME) modules. The next layer is the hardware abstraction layer (HAL). Its interfaces include no information about how to access the hardware. Instead the HAL contains the information and functionality which the corresponding hardware represents. The data in this layer are ADC counts for each channel of the front-end chips or alternatively positions and energies of the hits in the detector. The detector itself is represented by calorimeter and Silicon strip instances. Adding a new strip detector layer to the detector means creating just an additional instance of the SiStrip class. This reflects the high modularity and therefore flexibility of the software. The data acquisition layer is the supervising layer and takes care of the data collection and storage. Here the data are represented by events, consisting of hits, times, etc. The interface addresses topics like the different operation modes of the detector and where to store which information. An user interface layer directs the different ways of user inputs to the data acquisition. The user can command the program either interactively by a graphical user interface (GUI), automated by a macro file, or remotely via TCP/IP.

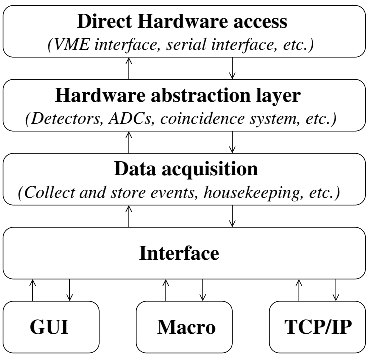

Fig. 5. Abstraction layers of DAQ software

VII. The Whole System

This readout system is a prototype, its performance is far from being optimized. The readout time for one event is typically 7.5 ms, thus the readout rate is lower than 130 counts per second. This is due to the low parallelization (8 ADCs) of the readout of the over 10000 channels. Also the instrument CPU is heavily loaded when reducing the data. An approach featuring much higher performance would be an "intelligent" front-end control. This means having for a low number of front-end chips (≤ 3) an individual ADC with data reduction logic next to the front-end electronics in order to parallelize the time consuming tasks. This was not feasible for the prototype.

Nevertheless, this system worked flawlessly for many weeks in the laboratory and during a 2 1/2 week measurement compaign at an accelerator. By evaluating the collected data, we proved that the MEGA principle of detecting γ-rays in the range of 0.5 – 50 MeV works [6]. Moreover, building this prototype was an important step towards a satellite. A lot of the experiences made were already included in a Pre-Phase-A satellite study (performed by DJO, Jena, Germany). Preparations for the next step, the balloon flight, are already ongoing (for example the ACS). Because of the modularity and flexibility of the hardware and especially the software, the extensions will smoothly fit into the existing design.

Acknowledgment

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