

A multichannel compact readout system for single photon detection: design and performances

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Abstract

Optimal exploitation of Multi Anode PhotoMultiplier Tubes (MAPMT) as imaging devices requires the acquisition of a large number of independent channels; despite the rather wide demand, on-the-shelf electronics for this purpose does not exist.

A compact independent channel readout system for an array of MAPMTs has been developed and tested.

The system can handle up to 4096 independent channels, covering an area of about $20 \times 20 \text{ cm}^2$ with pixel size of $3 \times 3 \text{ mm}^2$, using Hamamatsu H-9500 devices.

The front-end is based on a 64 channels VLSI custom chip called MAROC, developed by IN2P3 Orsay (France) group, controlled by means of a Field Programmable Gate Array (FPGA) which implements configuration, triggering and data conversion controls.

Up to 64 front-end cards can be housed in 4 backplanes and a central unit collects data from all of them, communicating with a control Personal Computer (PC) using a high speed USB 2.0 connection.

A complete system has been built and tested. Eight Flat MAPMTs (256 anodes Hamamatsu H-9500) have been arranged on a boundary of a 3×3 matrix for a grand total of 2048 channels.

This detector has been used to verify the performances of a focusing aerogel Ring Imaging Cherenkov (RICH) prototype using an electron beam at the Frascati (Rome) INFN National Laboratory Beam Test Facility (BTF) during the last week of January 2009.

Data analysis is ongoing; the first results are encouraging, showing that the Cherenkov rings are well identified by this system.

The Electronic System

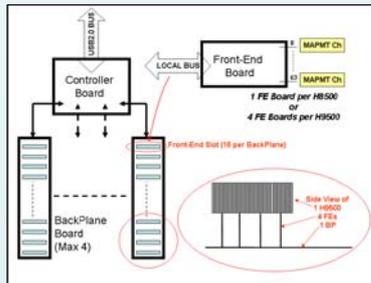
The electronics structure, graphically represented in the figure, is organized according to a hierarchical scheme with a single main board, the Controller Board (CB), and several daughter boards, the Front-End boards (FE). Each FE completely handles 64 pixels or anodes using Flat Panel PMTs (FPMT). In the full configuration the system can handle 64 FEs reading out 4096 channels. The CB and FEs are connected by means of the BackPlane boards (BP) which give the mechanical support to the FEs and provide electrical connectivity. Up to 4 BPs can be connected to the CB. The used H-9500 (256 anodes FPMT) is directly connected to 4 FEs in order to reduce cabling and to optimize signal integrity. In the full configuration 16 H-9500 will cover an area of about $20 \times 20 \text{ cm}^2$ with 4096 pixels.

The CB implements a standard USB 2.0 link to communicate with a PC, running DAQ and analysis code.

The FE is equipped with a VLSI chip called MAROC, developed by IN2P3- LAL institution from Orsay (F), which implements the analog processing of the signals coming from the FPMTs.

A FPGA is used for handling:

- MAROC configuration
- analog data extraction and ADC conversion control
- 1st level trigger
- data transfer to the CB



A complete detector



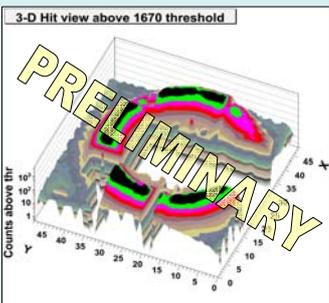
A 3D view of a complete run is shown in the right side picture.

A H-9500 is not working and the data are not equalized; some area show inefficiencies; no pedestal subtraction has been performed. The plotted histogram is built comparing the analog data against a common fixed threshold. Despite the mentioned limitations the ring is well identified, showing the effectiveness of the system in single photon identification.

In the left side picture 8 H-9500 are arranged on a boundary of a 3×3 matrix.

Underneath of them the FE cards connected to the 4 BPs are well visible. The CB is placed at the bottom of this stack (not visible).

This system has been used to collect Cherenkov light coming from an aerogel radiator (COMANCHE project).



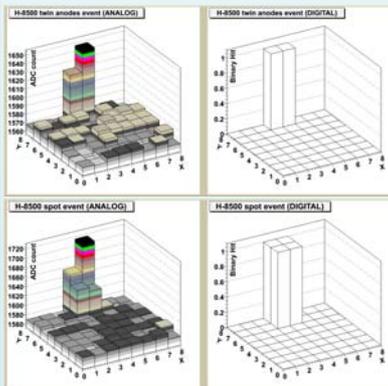
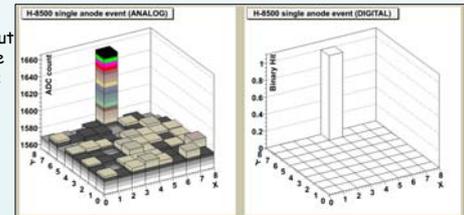
Triggering

The system can be run self triggered or using an external strobe.

The acquisition can be gated thus allowing synchronization with biometrical measurements in case of SPECT detectors.

The MAROC on the FE generates 64 fast digital signals (HITs) if the corresponding anode value is above a common threshold. These information can be used by the local FPGA to strobe the analog signals.

In the simplest scenario a logical OR of the HITs can start an acquisition, but this cannot be efficiently used in single photon applications due to the intrinsic FPMT noise. In the side figure a single HIT (on the right) triggers the analog acquisition (on the left) of a H-8500 FPMT (64 anodes device). This can be considered the 1st level trigger, implemented at FE level.



Once the 1st level trigger has been fired, the HITs information are transferred from all the involved FEs to the CB and a more sophisticated algorithm can be run.

A topological finding algorithm is implemented: the process considers 8×8 (H-8500) or 16×16 (H-9500) matrixes and identifies 2×2 spot in the matrix (bottom figure) or 2×1 spot on the edges (top figure).

The pattern finding process is very fast: 350 ns are needed for HIT transfer (each fired FE) and 100 ns are needed to identify spots on a 16×16 matrix. In case of 16 H-9500 the 2nd level trigger can be computed in about $2 \approx 2.5 \mu\text{s}$.

The rate drops of a factor $\gg 100$ from 1st to 2nd level (strongly depending on application).

Additional improvements will include more sophisticated 1st level trigger (i.e. majority findings) and boundary effects between different sensors at 2nd level.

Applications

The system has been designed to equip detectors for small animal SPECT and for scintimammography.

Have a look at F. Cusanno's poster: "A novel high resolution, high sensitivity SPECT detector for molecular imaging of cardiovascular diseases".

In this case a good 2nd level trigger algorithm is mandatory to efficiently identify interesting events, thus reducing the data rate.

As reported the use in RICH detector is also possible, extending the detection range down to single photons.

The data rate is mainly limited by the MAROC output multiplexer settling time: this gives an acquisition rate in the order of 20-30 kHz, depending on the quantity of information needed to transfer (i.e. occupancy and zero skipping mechanism). In applications requiring binary information only, the analog multiplexing can be disabled to increase readout rate.

Conclusions & Future Work

The system has proved to be effective in a test beam operation for the RICH configuration. SPECT detectors are in advanced realization phase: laboratory measurements are promising and clinical tests are foreseen soon.

MAROC3 chip (the 3rd version) prototypes are ready and will be available to the users later this year, extending the dynamics and including an internal ADC.

Studies are in progress to use this system also for PET: to be efficient the coincidence trigger must be done externally in less than 100 ns, using the total charge information coming out from opposite detectors.

The architecture of the system is consistent also with the new promising photon detectors: silicon photomultipliers (SiPM). These devices can, in fact, be used modifying only the front-end. Part of the project is funded by Filas/Regione Lazio.