Development of a TOF PET prostate probe readout system

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Frontier Detectors for Frontier Physics

Abstract

A compact readout system for a matrix of Silicon PhotoMultipliers (SiPM) has been developed in the framework of the TOPEM (TOf PEt Mri) INFN research program.
The electronic system was designed to completely handle 128 pixels (a SiPM matrix), independently measuring both the arrival time of the incoming photons and the charge of the detected signal.
The design is based on existing ASICs, developed in the framework of high energy physics, achieving a good compromise in compactness, speed and power.
The controller of this system is interfaced to a Linux based PC running the data acquisition and event display code. The communication between the PC and our system is done using the USB 2.0 protocol, which can run up to 25 MB/s.
Moreover in the controller can be realized a coincidence logic with an external detector, thus permitting to trigger the data acquisition, implementing a complete TOF-PET system.
In parallel to this work a dedicated ASIC in under advanced development, implementing all the needed functions and giving a higher compactness, necessary to build a real detector to be used in clinical practice. A prototype with the basic building blocks has been developed and an evolved version is under design.

We report here the design of the system and some laboratory measurements.

Introduction

The Italian Istituto Nazionale di Fisica Nucleare (INFN) funded a R&D program called TOPEM (TOf PEt Mri) [1] to build an endorectal PET probe to be used in multimodality with MRI for prostate cancer diagnosis and follow up. Fully exploiting the Time of Flight capability will allow to increase significantly the SNR/NECR. The probe will be used in coincidence with a dedicated external detector and/or a standard PET.

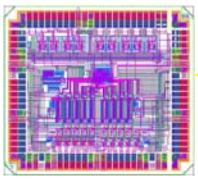
The electronic system is challenging:

- it must measure the coincidence of the γ rays with a precision of about 300 ps (FWHM) or less;
- it must be small enough to be connected directly to the internal detector;
- it must be compatible with the MR environment;
- it must be fast and low power.

A dedicated electronic system using off-the-shelf components has been designed and prototypes are now running in laboratory. In parallel to this work, an ASIC has been also studied to integrate all the main functions, gaining in compactness, speed and power.

The proposed ASIC

The system developed with existing components will be upgraded by using a dedicated ASIC which implements a front end scheme, designed to exploit the specific characteristics of the SiPM and to match its physical parameters (very low output impedance, large gain bandwidth, etc.). A first prototype of the proposed ASIC has been designed in CMOS 130 nm mixed analog-digital technology to satisfy the main requirements such as high density integration (64-128 channels), low power/channel (few mW), flexibility (gain and threshold tuning), energy resolution (8 bit ADC), digital output (LVDS) and taking care of minimization of time jitter and time walk. This release (see Fig. 1) containing only 8-channels of the analog chain, has been designed in order to fully characterize the detector and the very front-end part, while next development will be the integration of a Time-to-Digital converter and serial readout to fully exploit the excellent timing features of SiPM associated with LYSO crystals required in TOF-PET applications. Each channel is based on input current buffer followed by a current discriminator for fast event tagging followed by an LVDS driver. Each channel is also equipped with an 8-bit voltage DAC for the fine tuning of the SiPM bias voltage and a 6-bit current DAC for offset compensation, while a single 8-bit current DAC provides the thresholds to all discriminators. A simple standard cell digital section implements a SPI interface to remotely control the different DACs.
Finally, the logical "OR" of the outputs is provided for triggering purpose.
The test card (Fig. 1 right) is intended to be put in the acquisition system shown, replacing the NINO card.



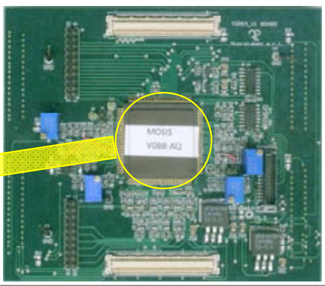


Figure 1

System development

At the beginning we had to choose the main components and we focused on:

- a very fast preamplifier-discriminator with low input impedance and Time Over Threshold (TOT) capability, used as front-end;
- a Time to Digital Converter (TDC) with dual edge measurement capability and resolution ≤ 100 ps.

We found such components at CERN, produced for LHC experiments, but also available to other users.
The preamplifier-discriminator chip is NINO [2]: an 8 channels wide bandwidth fully differential preamplifier-discriminator with 40 Ω input impedance.
The TDC is the HPTDC chip [3]. It measures the timing of both edges of the 32 input pulses with resolution selectable down to 25 ps.
In addition the system needs a controller and a data transfer channel: a FPGA is the natural choice for the logic and USB was chosen for DAQ PC connection.
DAQ code has been developed under Linux with particular care on porting under Windows.

In Fig. 2 the developed system, now under test, is shown.

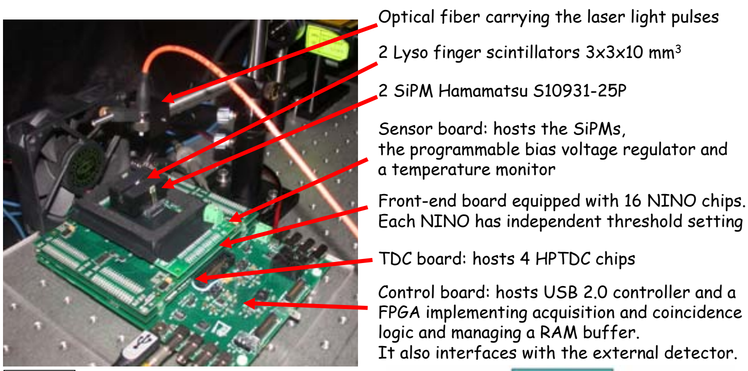


Figure 2

First measure taken with this system.
Working parameters have been determined in a rough and quick way.
The time difference between the 2 SiPMs illuminated by the same light pulse through the Lyso fingers has been recorded.
Lyso-SiPM coupling is not optimized.
TDC measures are not yet corrected for the NINO time walk: improvements are coming.

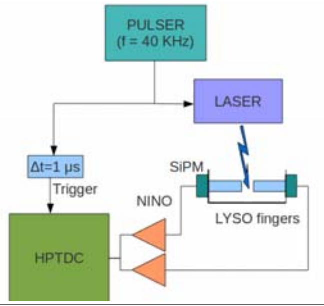


Figure 3

References

1. "TOPEM: a Multimodality Probe (PET TOF, MRI and MRS) for Diagnosis and Follow up of the Prostate Cancer", IEEE 2010 Conference records
2. "NINO: an ultra-fast and low-power front-end amplifier/discriminator ASIC designed for the multigap resistive plate chamber", NIM A 533 (2004) 183.
3. "Design aspects and prototype test of a very precise TDC system implemented for the Multigap RPC of the ALICE-TOF", NIM A 533 (2004) 178

Conclusions

The electronic system is now built and working. The bench measurements are promising a lot of work is still needed but it will be possible to obtain the requested resolution.
This modular system is very flexible: for example to test different sensors only the topmost card of the stack need to be redesigned. A real detector can be built using this device, only modifying the sensor arrangement.
The ASIC development is going in parallel: the 1st release is now working and a test card to put the prototype in the acquisition chain has been built. The next iteration will include the TDC and a larger number of channels.