Design and Performance of an ASIC for TOF applications

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Abstract—A low power SiPM readout ASIC for Time of Flight applications, targeting 25 ps r.m.s intrinsic resolution, has been developed in the framework of the EndoTOFPET-US collaboration. In this work, we present preliminary results of electrical characterization of this ASIC, along with preliminary results with SiPM arrays coupled to LYSO crystal matrices.

Index Terms—Time-of-flight, PET, Medical Imaging, SiPM, IC Readout Electronics.

I. INTRODUCTION

THE EndoTOFPET-US system[1] is a multi-modal tomograph which includes a 200x200 mm² pixelated PET detector, based on 4096 3x3 mm² SiPMs coupled to LYSO scintillation crystals. The TOFPET ASIC (figure 2) is a 64 channel mixed-mode chip designed in 130 nm CMOS technology targeting 25 ps r.m.s intrinsic resolution and low power consumption, and featuring fully digital output.

The readout architecture is based on a dual-threshold technique (figure 1). A low-noise front-end amplifier delivers replicas of a fast signal to two voltage mode discriminators, with independently set thresholds (on a per channel basis). The discriminator outputs are fed to a mixed mode dual TDC which provides a time measurement (50 ps binning) of the rising edge of DO_T and the falling edge of DO_E. Events which do not activate DO_E (dark counts) are rejected.

TDC data is extracted by a global controller and output using dual LVDS links. The maximum output event rate is 6 M event/s. A detailed description of the circuit design and chip floorplan can be found in [2].

Fig. 1: Simplified channel diagram.

Fig. 2: TOFPET ASIC die.

Fig. 3: ASIC mezzanine.

II. TEST SYSTEM

THE TOFPET ASIC’s performance was evaluated with the bare die directly bonded on the test board. Two mezzanine boards (figure 3), each with one ASIC and up to 4 SiPM arrays of 16 channels each, are plugged to a carrier board which provides power, reference clock source, FPGA interface and individually adjustable bias voltage for each SiPM array. A low jitter clock is provided to the ASIC, which in turn forwards it to an FPGA. The FPGA handles ASIC configuration and data reception. It also generates a test pulse with an adjustable, but synchronous to the reference clock, timing which is delivered to the ASIC or to a pulsed laser driver for testing purposes. A programmable HV source is used to bias the SiPMs. All measurement reported here were performed with the SiPM devices of type MPPC S12643-050CN

III. ELECTRICAL CHARACTERIZATION OF THE FRONTEND

CHANNEL noise was estimated by plotting the number of events as function of threshold (with both thresholds set to the same value) and then fitting to a cumulative probability distribution function, yielding a noise level of $\sigma=2.5$ mV.
which matches the simulation estimates. The expected average pulse amplitude for one photo-electron signal is 40 mV (see figure 6).

Time-over-threshold (ToT) as function of input charge is a non linear function. Power consumption is 8-11 mW per channel, depending on the operation settings.

IV. TDC CALIBRATION AND CHARACTERIZATION

The TDC calibration procedure consists of triggering the TDCs with the test pulse and varying the test pulse delay over a period (typically 50 ns) in fine steps (typically 510 ps). After calibrating and compensating for TDC non linearity, we measure the time difference between two channels triggered simultaneously by the test pulse. The difference between the two measurements removes the common mode test pulse jitter. We obtain a distribution with $\sigma=29$ ps (see figure 7), corresponding to a per channel sigma of $\sigma=21$ ps.

V. SINGLE PHOTON TIME RESOLUTION

Single photon time resolution was measured by setting both thresholds at the 1 photon level and exciting the SiPM with a pulsed laser set such that the SiPM is hit, most of the time, by a single photon. The laser was triggered, at a rate of 80 kHz, by a test pulse generated by the FPGA, thus giving the laser pulse a known time. The ToT distribution of events within $\pm 0.5$ ns of the expected laser pulse time shows the 1 photon and 2 photon peaks (see figure 8). The r.m.s. of the time distribution of events with ToT corresponding to 1 photon provide a measurement of the Single Photon Time Resolution (SPTR). After optimization of the SiPM bias voltage we obtained a SPTR of $\sigma=110$ ps (see figure 9). When the SiPM was excited with large laser pulses we observed a time distribution with $\sigma=32$ ps (see figure 10).

VI. COINCIDENCE TIME RESOLUTION

Coincidence time resolution was measured with $3.1\times3.1\times15$ mm$^3$ LYSO crystals optically coupled to SiPMs and a $^{22}$Na point source. Two MPPC S12643-050CN arrays of 16 SiPM were biased and connected to the ASIC, but only one pixel in each had a crystal. Selecting events within $1\sigma$ of the photopeak, a coincidence time resolution of $\approx 116$ ps has been obtained. The result does not depend on the threshold applied to the other channels. For energy calibration, data was acquired with different emission sources ($^{22}$Na, $^{176}$Lu, $^{137}$Cs). Fitting the known peak positions to an exponential function, the spectrum can be corrected. A preliminary energy resolution of FWHM=17% at 511 keV was obtained.
Fig. 8: ToT distribution.

Fig. 9: SPTR vs bias voltage.

Fig. 10: Time distribution for a large laser pulse.

Fig. 11: Distribution of the time difference of two 511 keV photons.

Fig. 12: Average ToT versus the energy of different photopeaks used for energy calibration.

REFERENCES
