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A High Dynamic Range ASIC for Time of Flight PET with monolithic crystals

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The HRFlexToT is a 16-channel ASIC for SiPM anode readout designed for Positron Emission Tomography (PET) applications that features high dynamic range (>8 bits), high speed and low power (˜3,5 mW/ch). The ASIC has been manufactured using XFAB 0,18 µm CMOS technology. Initial measurements show a linearity error below 3%. Single Photon Time Resolution (SPTR) standard deviation measurements performed using a Hamamatsu LCT4 MPPC (3x3 mm2, 75 µm cell) shows 40% improvement with respect to the previous version of the ASIC, setting this specification in the order of 60 ps and reducing 3 times power consumption.

Summary

Positron Emission Tomography (PET) is a well-established nuclear medicine technique for visualization and quantification of metabolism and different biological processes at the cellular level. The technological implementation of PET requires fast and efficient detectors coupled to fast readout electronics.

This paper presents HRFlexToT (High Resolution Flexible Time-over-Threshold) which is a new version of the FlexToT ASIC designed with an extended dynamic range suitable for readout of pixelated and monolithic scintillator crystals in Time-of-Flight PET applications. It features 16 channels, high dynamic range, high speed, low input impedance stage based on a MOSFET current mirror with double feedback loop, common cathode connection, directly coupled input with common mode voltage control and separated timing and energy measurement signal output.

The time stage is composed of a fast comparator which outputs the width of the input signal using a non-linear ToT. A fast OR between all timing channels can be readout using a differential LVDS output and individual time readout is also provided in single-ended output.

The energy measurement block is the main difference between the HRFlexToT and its predecessor, which is conceptually similar to a Wilkinson ADC. This redesigned energy path provides a linear ToT output encoding the collected charge in the binary pulse width with an extended dynamic range and allowing a resolution higher than 8 bits. The energy measurement in obtained in four stages. The first stage is a Gaussian Pole Zero cancellation of the SiPM recovery time constant, which can be configured to cope with different scintillators and sensors. Secondly, a ramp generator starts a ramp after detecting the incoming signal. Thirdly, the peak is sampled by a peak detector that can be also configured as a track and hold. Lastly, a rail to rail comparator generates a linear ToT energy pulse using the peak detected and the ramp signal as a threshold. Individual control of the threshold at the comparator is also available.

Different triggers can be used for the energy measurement: a low level trigger for signals above 10 photoelectrons that allows to filter Dark Count events; the timing signal of the input stage for trigger levels close to the first photoelectron; a cluster high level trigger in case the signal is spread among several channels; an external trigger for pedestal calibration. The control of the system is performed by an asynchronous Finite State Machine, which reduces drastically cross talk interference of digital signals on the analog circuitry.

A considerable reduction in power consumption, from 10mW/ch to 3,5mW/ch, is partly achieved by using XFAB 0,18 µm CMOS technology instead of AMS 0,35 µm HBT BiCMOS technology as was utilized in the FlexToT. Electrical injected signal shows a linearity error of the energy measurement around 3%. SPTR (Single Photon Time Resolution) standard deviation measurements performed using a Hamamatsu LCT4 MPPC

(3x3 mm2, 75 µm cell) shows 40% improvement with respect to the previous version of the ASIC, setting this specification in the order of 60 ps. Coincidence Resolving Time measurements are expected to be performed during spring 2018.

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