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Characterization of a readout integrated circuit with in-pixel time measurement

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Single-photon counting (SPC) hybrid pixel detectors (HPDs) have brought a new quality to the detection of low- and medium- intensity X-ray radiation. Due to the rapid development of CMOS technology, it is now possible to include much more functionality in each pixel without increasing its dimensions. This opened up new possibilities for SPC readout integrated circuits (ROICs). Counting photons whose energy exceeded one or several thresholds is accompanied by or replaced by energy measurement and/or precise timestamping. The main interest of the project described in this abstract is in-pixel time measurement, which allows either timestamping by means of time-of-arrival (ToA) measurement or extracting information about the energy of the photon from time-over-threshold (ToT) measurement. Chips capable of doing this have been used in a wide range of experiments, including fields such as 3D and 4D tracking and reconstruction, antimatter research, electron microscopy and others \[1-3\]. Current state-of-the-art ROICs include Timepix4 \[2, 4\] and Timespot1 \[3, 5\]. Timepix4 has been used in the tracker consisting of 4 detector planes to reconstruct high-energy hadrons, achieving track resolution equal to (350 ± 5) ps \[2\]. Timespot1 has been used to build a demonstrator of a system for 4D particle tracking with a resolution of approximately 200 ps \[3\].

This abstract is a continuation of work carried out in the Department of Measurement and Electronics at AGH University of Krakow, which focuses on the development of fast, low-noise SPC ROICs and the extension of their capabilities beyond SPC \[6-8\].

Recently we presented a prototype chip in 28 nm CMOS technology (Fig. 1), consisting of a 8×4 pixel matrix. Each pixel consists of an analog front-end (AFE) and time-to-digital converters (TDCs) with ring oscillators, and its schematic and layout are shown in Fig. 2 and Fig. 3, respectively. Preliminary results of AFE characterization, oscillator frequency correction and ToT measurement are presented and discussed in \[7, 8\]. The frequency mismatch between the in-pixel ring oscillators can be corrected with satisfactory effect (Fig. 4). The ToT measurement capability has also been demonstrated (Fig. 5). Current work is focused on finishing the characterization of more samples and modes of operation, (ToT, ToA, SPC) with emphasis on improving time measurement resolution, investigating factors that limit the performance, and finding solutions to mitigate them.

\[1\] R. Ballabriga *et al.* "ASIC developments for radiation imaging applications: The Medipix and Timepix family". In: *Nucl. Instruments Methods A* 878 (2018), pp. 10–23.
\[2\] K. Akiba *et al.* "Reconstruction of charged tracks with Timepix4 ASICs". In: *J. Instrum.* 18.02 (Feb. 2023), P02011.
\[3\] A. Loi *et al.* "A prototype 4D-tracking demonstrator based on the TimeSPOT developments". In: *J. Instrum.* 19.02 (Feb. 2024), p. C02069.
\[4\] R. Ballabriga *et al.* "The Timepix4 analog front-end design: Lessons learnt on fundamental limits to noise and time resolution in highly segmented hybrid pixel detectors". In: *Nucl. Instruments Methods A* 1045 (2023), p. 167489.
\[5\] S. Cadeddu *et al.* "Timespot1: a 28 nm CMOS Pixel Read-Out ASIC for 4D Tracking at High Rates". In: *J. Instrum.* 18.03 (Mar. 2023), P03034.
\[6\] R. Kleczek *et al.* "Single Photon-Counting Pixel Readout Chip Operating Up to 1.2 Gcps/mm2 for Digital X-Ray Imaging Systems". In: *IEEE J. Solid-State Circuits* 53.9 (Sept. 2018), pp. 2651–2662.
\[7\] L. Kadlubowski and P. Kmon. "Recording channel design for time-based measurements in 28 nm CMOS" . In: *J. Instrum.* 18.10 (Oct. 2023), P10028.
\[8\] L. Kadlubowski and P. Kmon. "Multichannel integrated circuit for timebased measurements in 28 nm CMOS". In: *J. Instrum.* 19.02 (Feb. 2024), p. C02004.

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