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XXXII Cycle

Versatile digital readout for radiation-sensing electronic devices

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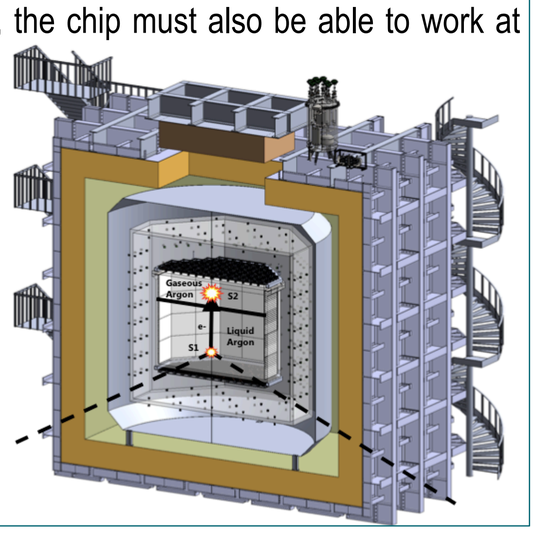
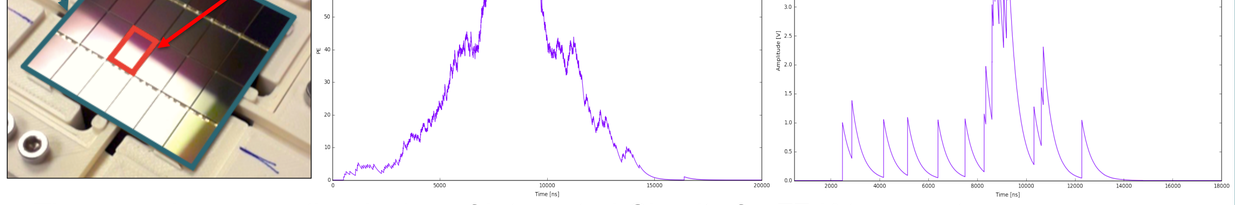
Research context and motivation

- The aim of the research is to design a digital readout **ASIC** able to read large area Silicon photomultiplier (**SiPM**) sensors. The adopted methodology is a binary readout that generates data packets containing the arrival time of the event and the position where the event is detected on the sensor. ***These information allow to reconstruct the original position of the event***. The ASIC must implement a radiation hardening technique in order to prevent errors from Single Event Effects (**SEE**).
- One of the possible application of the ASIC can be in the DarkSide-20k experiment. In order to meet the requirements of this experiment, the chip must also be able to work at cryogenic temperature (**77 K**).
- DS-20K is an experiment for dark matter research at *Laboratori Nazionali del Gran Sasso* (**LNGS**), upgrade of the experiment Darkside-50.
- DS-20K experiment uses a Liquid Argon Dual Phase Time Projection Chamber (**LAr TPC**), able to detect both scintillation and ionization light produced by recoiling nuclei.
- Top and bottom of the TPC are covered by *8280* Photo detector modules (**PDM**). Each **PDM** has 24 rectangular **SiPM** sensors of 11,7 x 7,9 mm.



Addressed research questions/problems

- In DS-20k experiment, the photon-electrons (**p.e.**) generated inside the TPC are collected by the SiPMs in two phases S1 and S2. The resulting signal at the output of the SiPM is a pile-up of several p.e. signals.
- Further pixel segmentation allows for a single photon counting and time stamp readout architecture.
- Analogue readout of large **SiPM** tiles and signal transmission for digitization (with warm electronics) is very challenging in terms of signal integrity.
- An alternative is to use a cold integrated electronics for **SiPM** readout and single-photon time-tagging.



- There are issues on the design of Integrated Circuits for 77 K temperature.
- Hot carrier channel degradation at low temperature: CMOS lifetime decrease and threshold voltage increase.
- No for cryogenic temperature model provided by the silicon foundry for standard cells.

Adopted methodologies

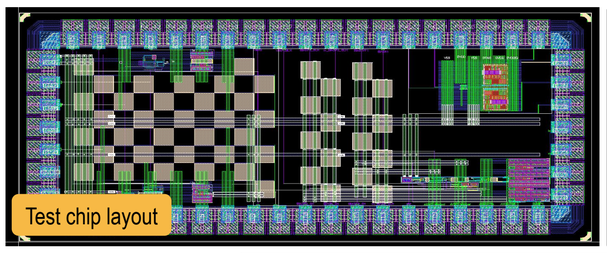
- Python simulations of input signals.
- Test structures to asses the behavior of significant digital circuit at 77K.
- Design and implementation of ALCOR using Cadence tools.
- Protection from SEE: only the configuration registers and FMSs are protected using respectively Triple Modular Redundancy and Hamming encoding techniques.

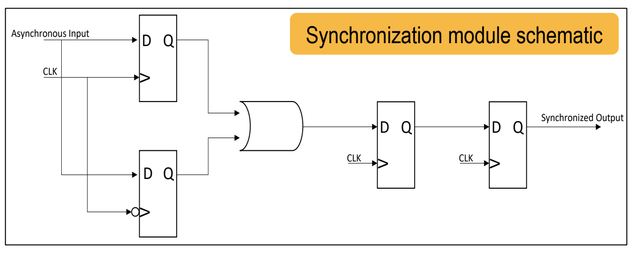
List of attended classes

- 01RISRV – Public speaking (16/02/2017, 1 CFU/5 hours)
- 02LWHRV – Communication (16/02/2017, 1 CFU/5 hours)
- 01PJMRV – Etica informatica (05/05/2017, 4 CFU/20 hours)
- 08IXTRV – Project management (12/09/2017, 1 CFU/5 hours)
- 01QTEIU – Data mining concepts and algorithms (27/02/2017, 4 CFU/20 hours)
- 02RHORV – The new internet society (19/09/2017, 1 CFU/5 hours)
- 01RPQIW – Turbolenza atmosferica (14/06/2018, 3 CFU/15 hours)
- 01LCPIU – Experimental modeling (25/06/2018, 6CFU/30 hours)
- 03QRHRV – Microelectronics for radiation detection II (03/06/2019, 4 CFU/24 hours)
- Barcelona Technoweek, Course on semiconductor detectors (02/07/2018, 35 hours)
- Comprehensive digital IC implementation & sign-off (22/01/2018, 30 hours)
- SQAD 2017: advance school on quantum detectors (16/10/2018, 12 hours)
- VII international course, Detectors and electronics for high energy physics (03/04/2017, 27 hours)

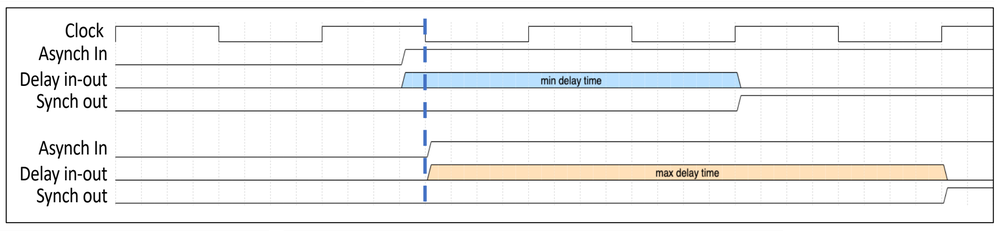
Novel contributions – Test chip

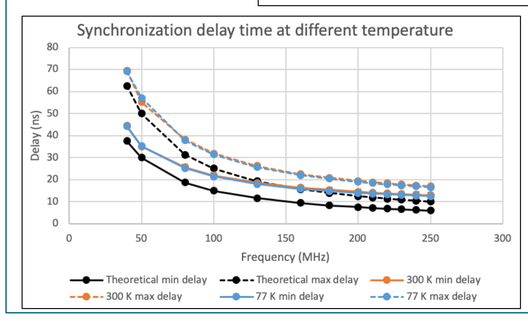
Test chip, designed in UMC 110 nm, embeds digital synchronization module.

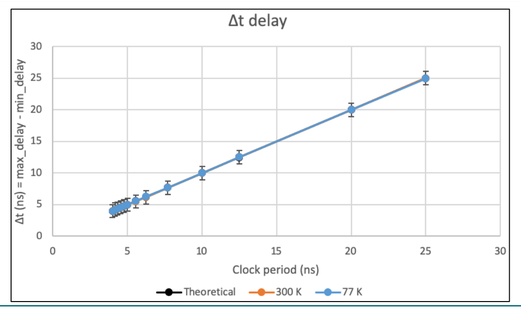




Synch. module Time diagram



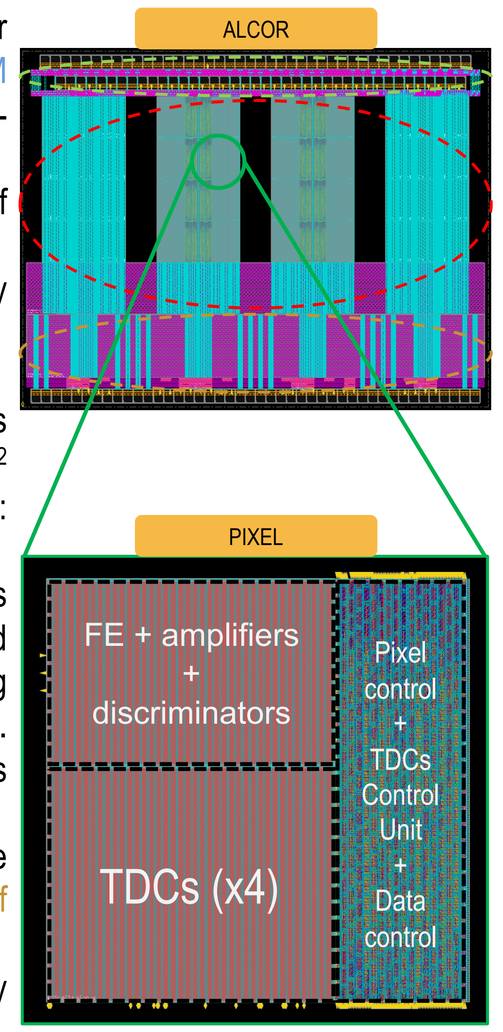




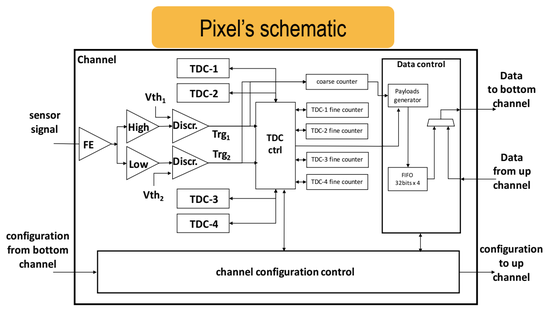
Synch. module results at 300 K and 77 K

Novel contributions - ALCOR

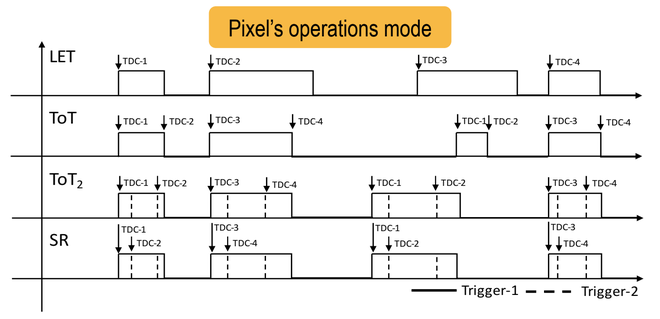
- **ALCOR** (A Low-power Chip for Optical sensor Readout) is a 32-channel prototype to read SiPM sensors. The aim of this chip is to perform single-photon time-tagging.
- ALCOR is designed to work at 77K, at a max freq. of 320MHz.
- This ASIC is designed using UMC 110nm technology and has a dimension of 4,95x3,78mm^2.
- SiPMs are connected to the pads placed in the top.
- The pixels are combined in a matrix structure, 4 rows per 8 columns. Each Pixel occupies 440 x 440 µm^2 and performs a binary read-out of one SiPM sensor: generates a timestamp when detecting a p.e. signal.
- The pixel has two amplifiers and two discriminators (double-trigger). It is able to perform a time-based readout (LET) and charge measurement (ToT) using 4 low-power TDCs based on time interpolation. Furthermore, slew rate (SR) measurement is possible using a double trigger.
- The generated timestamp is passed through the Pixels in the column, until it reaches the End of Column (EOC).
- The EOC reorganizes the data it receives from every column and serializes it outside the chip.



Pixel's schematic



Pixel's operations mode



Future work

- ALCOR submission by the end of October 2019.
- Test of ALCOR at 300 K and 77 K.

Submitted and published works

- Kugathasan, R., et al., "Cryogenic Characterization of FBK RGB-HD SiPMs", accepted by Journal of Instrumentation (2017)
- Kugathasan, R., "A low-power mixed-signal ASIC for readout of SiPM at cryogenic temperature", conference proceeding TWEPP (2019)
- Kugathasan, R., "Integrated front-end electronics for single photon counting in cryogenic dark matter detectors", conference proceeding LIDINE (2019)
- Kugathasan, R., "A low-power mixed-signal ASIC for SiPM readout at low temperature", accepted by IEEE transaction on NSS (2019)

POLITECNICO DI TORINO

PhD program in
Electrical, Electronics and Communications Engineering