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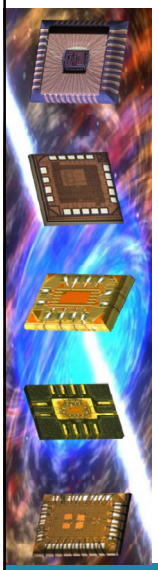
Research on radiation tolerant integrated circuits

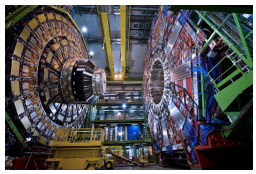
Prof. dr. ir. Paul Leroux

Outline

- **Situation**
- Radiation tolerant ICs developed in our group
- Collaborations with CERN

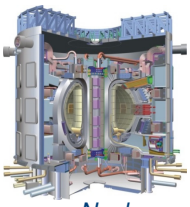
Radiation tolerant integrated circuits





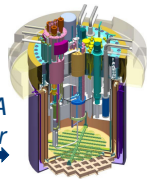
CERN – LHC

Our radiation tolerant chips



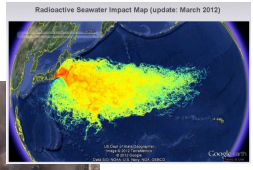
Nuclear fusion

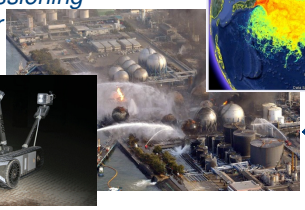
MYRRHA reactor



Deep space missions

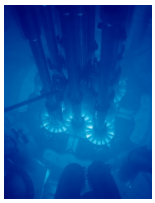
Robotic decommissioning of nuclear reactors





Robotic intervention i.c.o. nuclear accident

PWR safety



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Problem statement
Current radhard systems are inadequate

Leap beyond…

Feasible with…

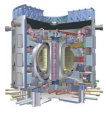
100 Gy COTS

space grade

10 kGy

…current technology

…current limits



10 MGy
2.10^{16} n/cm²
10^{7} ion/cm²
60 MeVcm²/mg

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KU Leuven in Flanders

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Paul Leroux – 10/09/2014

Department of Electrical Engineering (ESAT)

Outline

- Situation
- **Radiation tolerant ICs developed in our group**
- Collaborations with CERN

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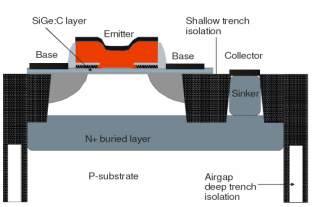
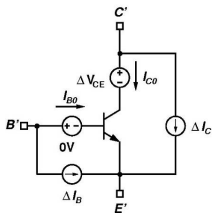
Research activities in radiation tolerance since 2004

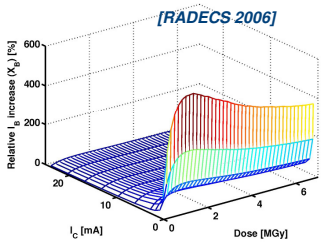
- Modelling of radiation effects in semiconductor devices



[IEEE TNS 2009]



[RADECS 2006]



- **Design of radiation tolerant ICs**
  - System architectures
  - Circuit topologies
  - Device-level

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Radiation-Hardening-by-Design

System-level RHBD
Selection of robust structures

Circuit-level RHBD
Techniques for mitigating radiation effects

Transistor-level RHBD
Enclosed-layout, guarding ring

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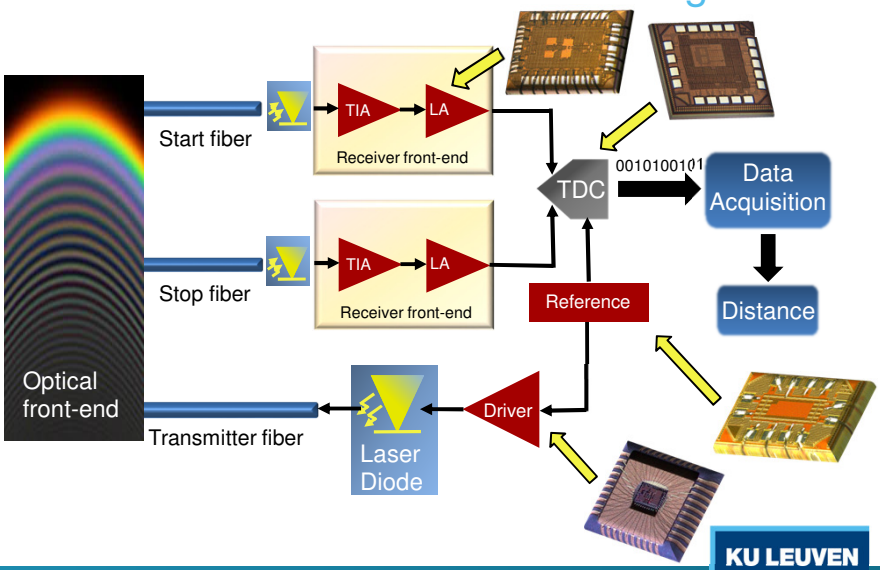
Optical radar or LIDAR
Distance measurement via time-of-flight



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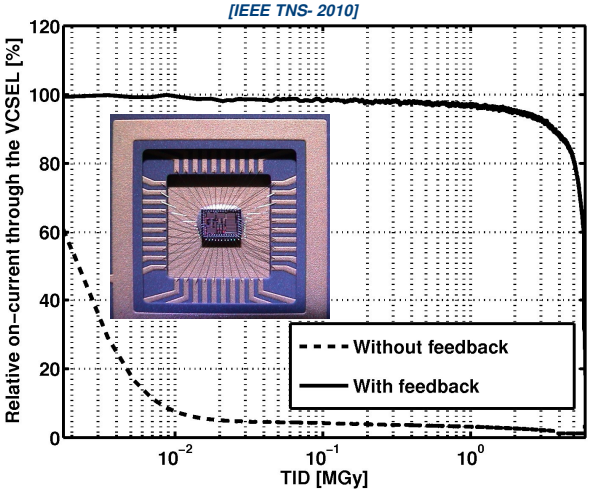
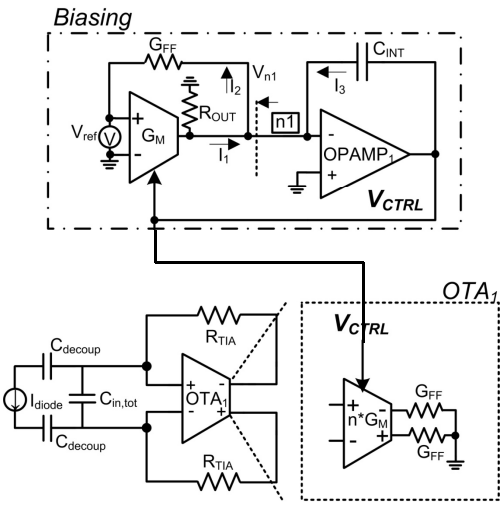
MGy tolerant VCSEL driver

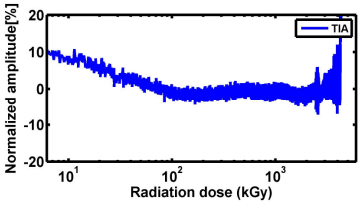
- With feedback:
  - Current drops by 10% after 3.5 MGy
- Without feedback:
  - Current drops by 90% after 10 kGy

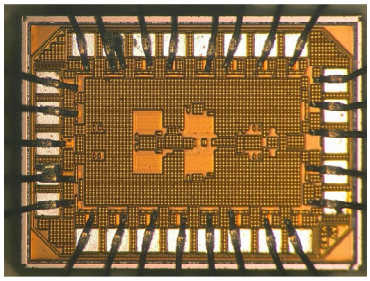
[IEEE TNS- 2010]



Radiation tolerant TIA (up to 4 Mgy)

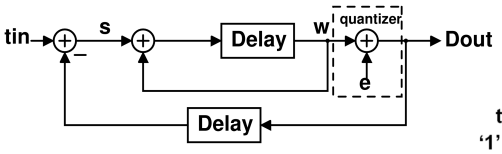




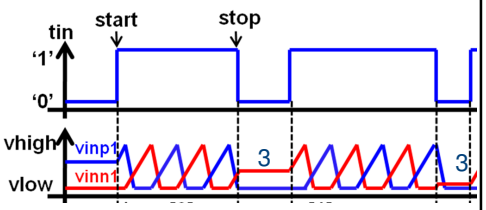


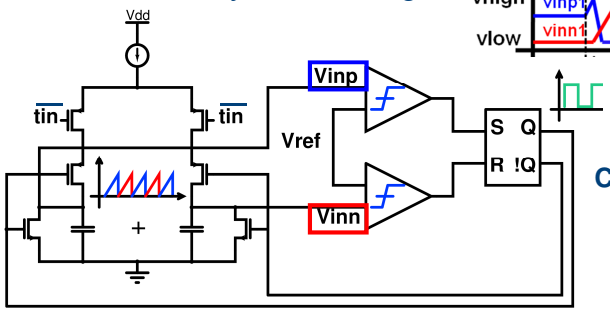
[IOP JINST-2012]

Single-loop first order ΔΣ TDC: Time integration and error feedback



Relaxation oscillator controlled by the time signal





Counter

$$T_{OSC} = 2\frac{CV_{REF}}{I_{REF}}$$

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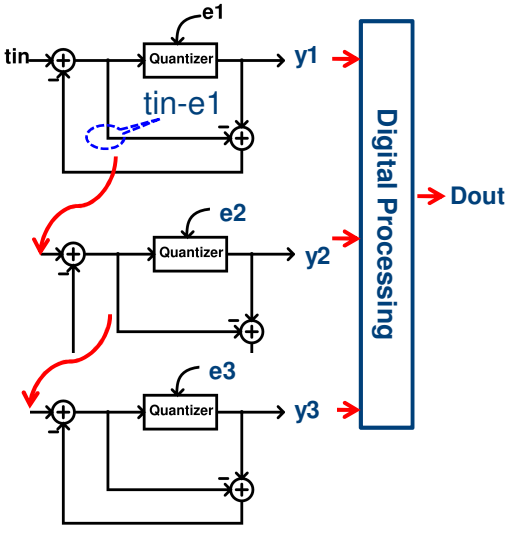
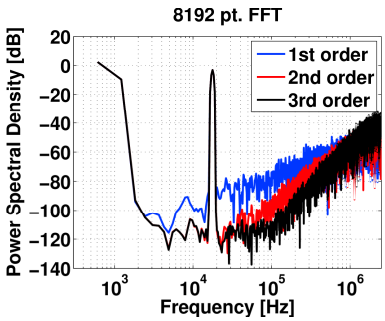
3rd order 1-1-1 MASH ΔΣ-TDC: Multi-stage Error Feedback:



$$\text{Dout} = y1\cdot z^{-1} + y2\cdot z^{-1}\cdot(1-z^{-1}) + y3\cdot(1-z^{-1})^2 = \text{tin} + e_3\cdot(1-z^{-1})^3$$



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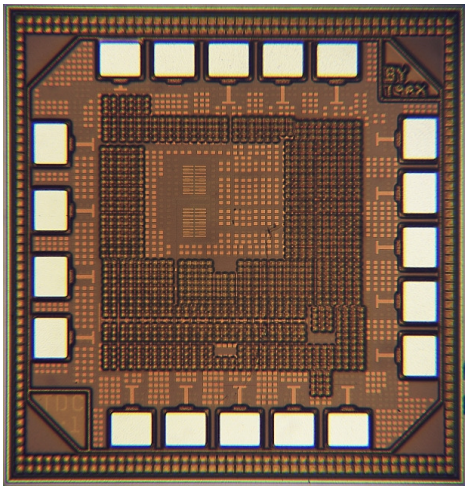
3rd order 1-1-1 MASH ΔΣ TDC: Measurement results

- **Resolution: 5.6 ps**
- Number of bits: 11
- Power: 1.7 mW
- Range: 20 ns
- Area: 0.11mm^2
- 130nm CMOS
- **Radhard: 5MGy (10.5ps)**

[ISSCC-2011]



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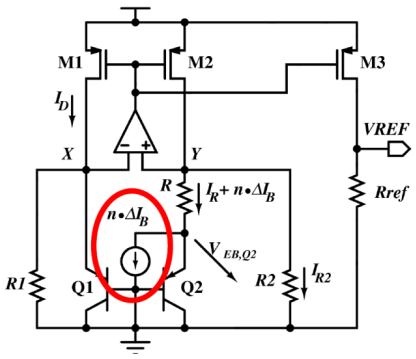
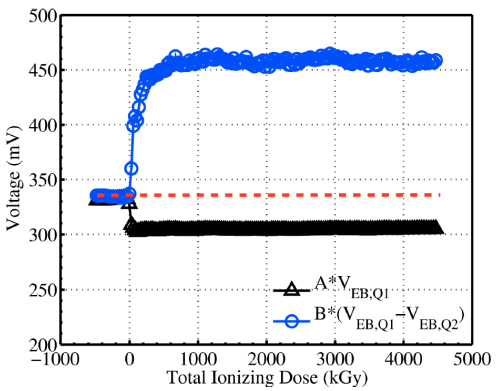
Conventional bandgap reference: Radiation assessment

$$V_{BG} = A \cdot V_{EB,Q1} + B \cdot (V_{EB,Q1} - V_{EB,Q2}), \quad \text{where} \quad A = \frac{Rref}{R2}, \quad B = \frac{Rref}{R}.$$





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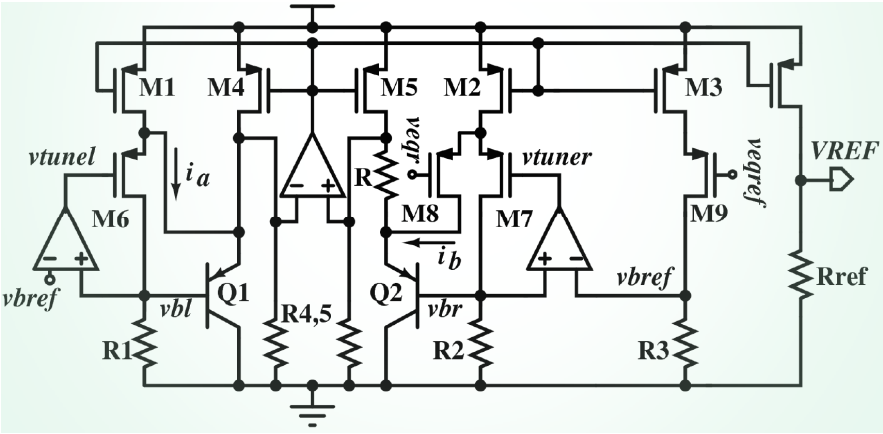
Radhard bandgap reference: DBLC circuit concept

DBLC = Dynamic Base-current Leakage Compensation



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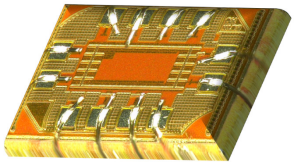
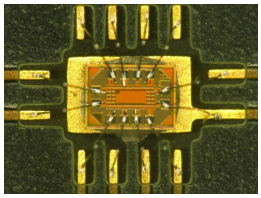
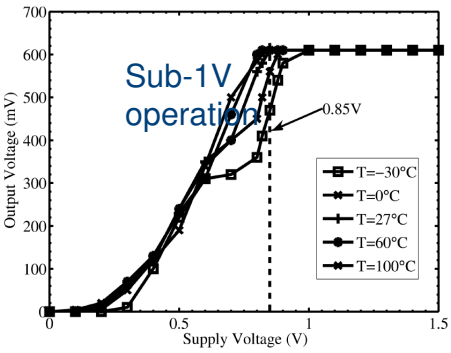
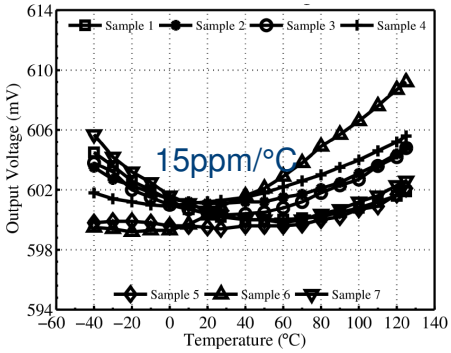
Radhard bandgap reference: Measurement before irradiation









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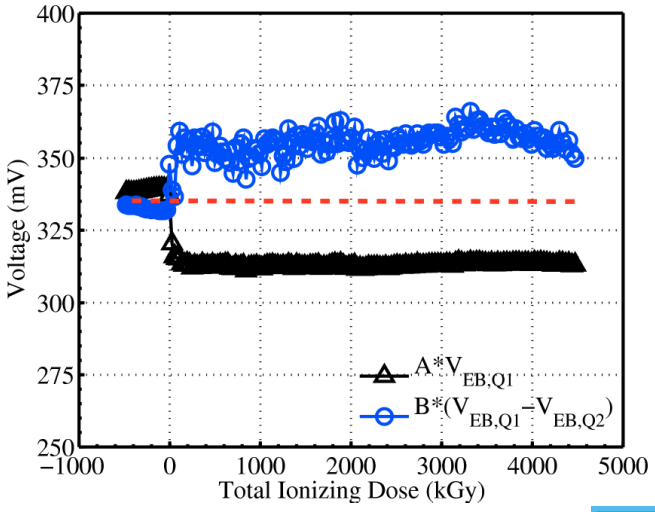
Radhard bandgap reference: Radiation assessment



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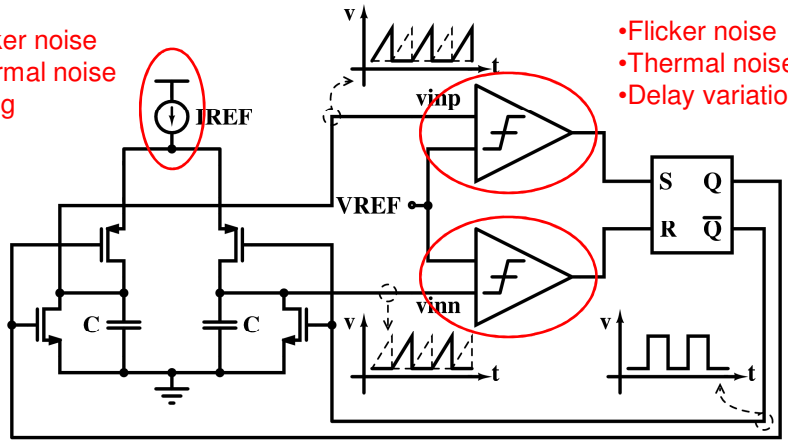
Relaxation Oscillator: Noise sources

Current Source

- Flicker noise
- Thermal noise
- Aging

Comparator

- Flicker noise
- Thermal noise
- Delay variation



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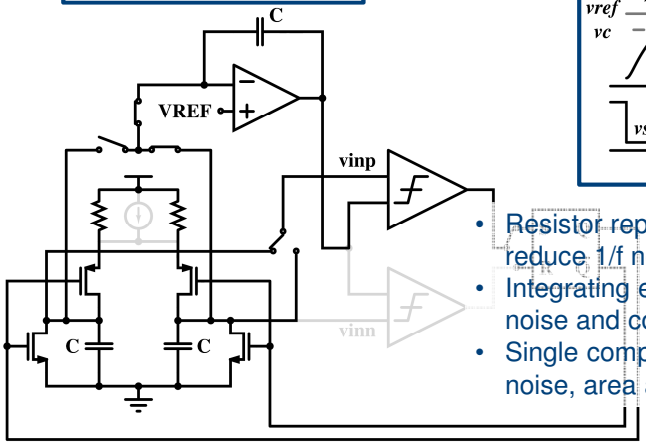
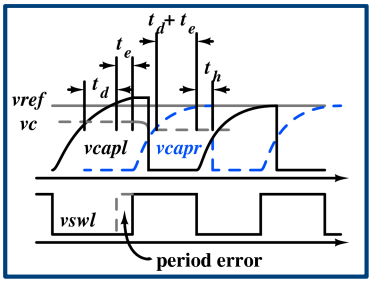
High-Q robust relaxation oscillator

$$T_{OSC} = 2RC\ln\left(\frac{V_{DD}}{V_{DD}-V_{REF}}\right)$$





- Resistor replaces current source to reduce 1/f noise
- Integrating error feedback avoids 1/f noise and comparator delay variation
- Single comparator allows further noise, area and power reduction

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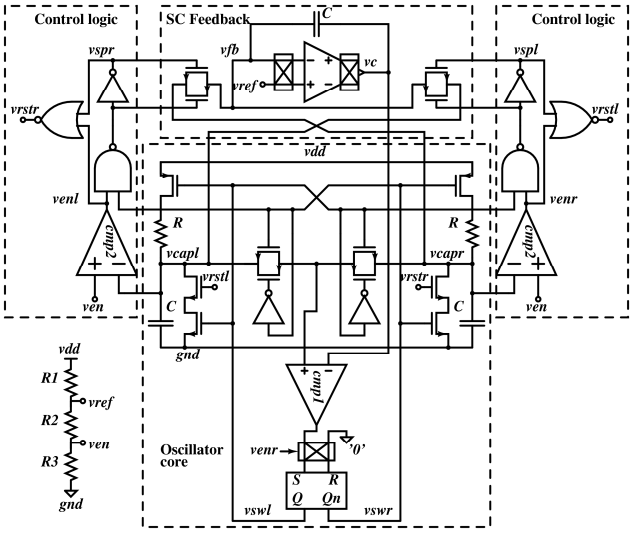
Relaxation Oscillator: More detailed schematic



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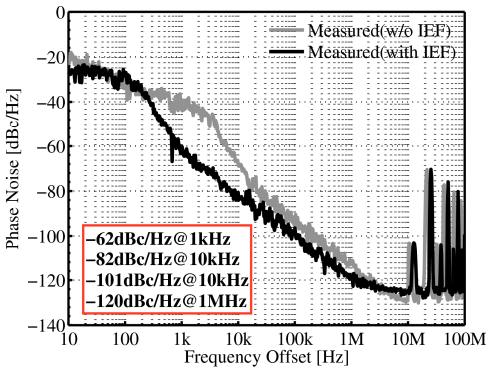
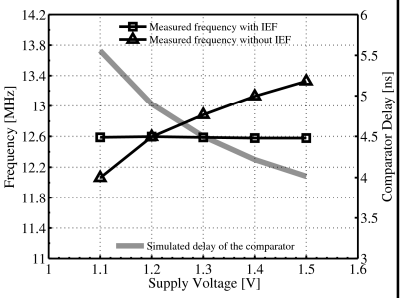
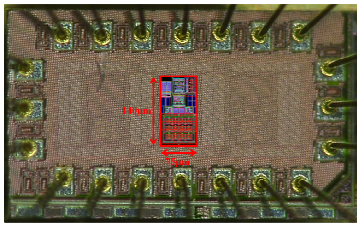
High-Q robust relaxation oscillator: Measurements







[ISSCC-2013]

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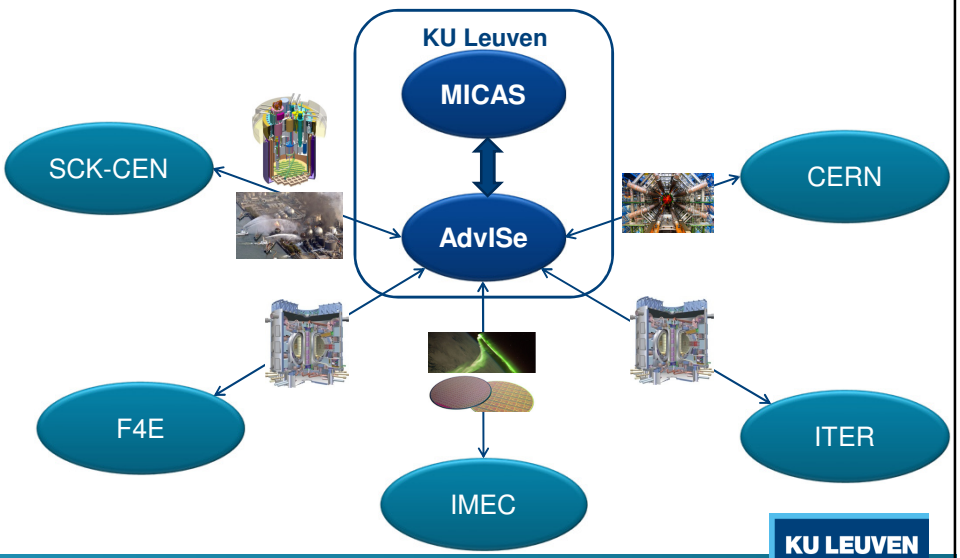
Most relevant collaborations



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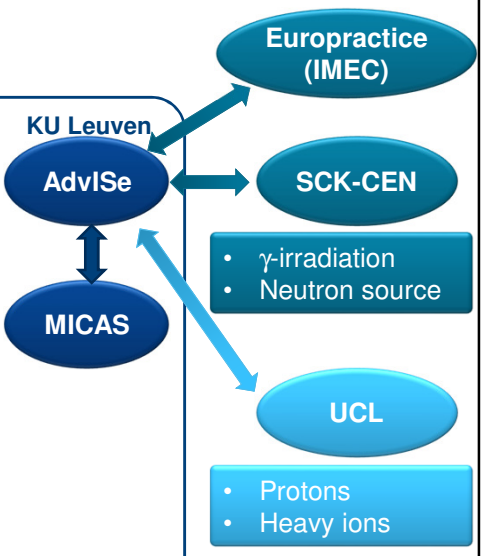
Available resources

- Chip bonding and packaging
- Focused ion beam
- Thick-film fabrication line
- ESAMAT laboratory:
  - Agilent E8257D PSG Analog Signal Generator
  - Tektronix DPO72004B 20GHz Oscilloscope, 50GS/s, 4 ch, 200M
  - Europtest PN9000 Phase Noise measurement
  - …



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Outline

- Situation
- Radiation tolerant ICs developed in our group
- **Collaborations with CERN**

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Collaborations with CERN
PLL for clocking TDCs

- Collaboration with Jorgen Christiansen (CERN PH-ESE-ME)
- TDC previously developed by Lukas Perktold
  - 5 ps resolution
  - IBM 130 nm CMOS
- Migration to TSMC 65 nm CMOS
- Need for accurate time reference PLL
  - KU Leuven PhD student Jeffrey Prinzie
- Applications:
  - Low resolution (~1ns): CMS and ATLAS muon detectors
  - High resolution (10ps – 100ps): ALICE TOF, CMS HPS, ATLAS FP420, LHCb Torch, Totem, Fast forward detectors, etc.
  - Non HEP: Laser ranging, Radar, On chip instrumentation, Imaging systems (PET, 3D imaging), etc.

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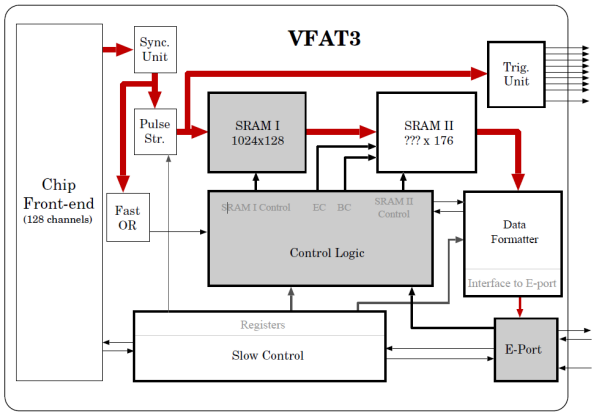
Collaborations with CERN
Front-end for VFAT3 readout of GEM detectors

- Collaboration with Paul Aspell (CERN PH-ESE-ME)
- PhD-student: Mieczyslaw Dabrowski



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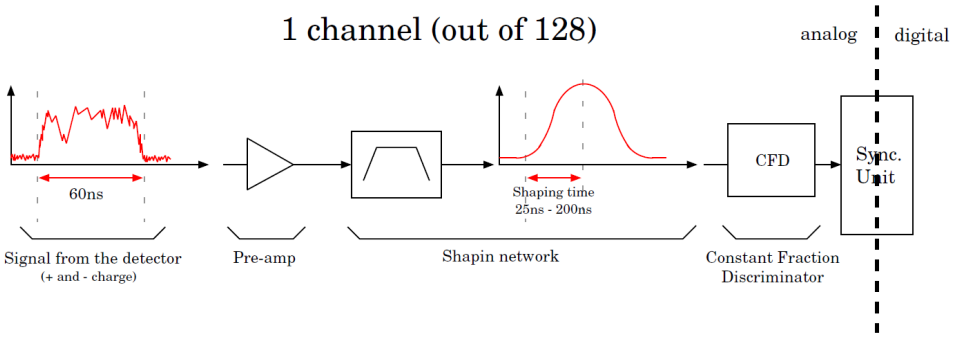
Collaborations with CERN
Front-end for VFAT3 readout of GEM detectors



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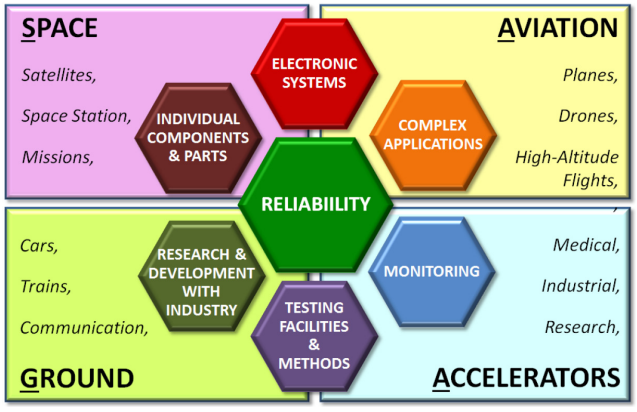
Collaborations with CERN:
MC ITN proposal RADSAFE-SAGA

- Initiators: CERN (Markus Brugger) and Univ. Monpellier II
- KU Leuven role: Design of radiation hardened ASICs



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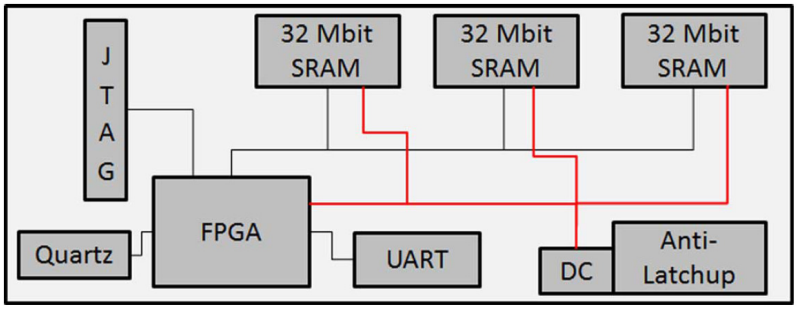
Further possible collaborations with CERN: SRAM-based radiation detector

- Bit upsets in SRAM memory allows to measure (charged) particle flux
- Custom ASIC to improve sensitivity, replace older SRAM modules



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CMS (associate) membership

- Why?
  - Access and share information with other partners, interesting for the PhD students working with CMS
  - New and challenging and interesting collaborations, joint PhD's
  - RD53 group and work on pixel detector front-end
  - Grow network in the community
- How?

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Thank you!

Acknowledged PhD students:

- Dr. Sofie Put
- Dr. Ying Cao
- Jens Verbeeck
- Maarten Strackx
- Marco Mercuri
- Jeffrey Prinzie
- Bram Faes
- Robin Theunis
- Jurgen Vanhamel
- Mieczyslaw Dabrowski

More info: **http://www.kuleuven.be/advise**
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