A 5MGy γ-dose tolerant ΔΣ Time-to-Digital Converter with 5.6ps resolution for LIDAR application

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Abstract

Time-to-Digital converters (TDCs) are highly demanded in digital PLLs, ADCs, and time-of-flight measurement units, which are widely used for nuclear instrumentation. Demonstrating applications can be found in the ATLAS detector at the Large Hadron Collider (LHC), or in an accelerator driven system like MYRRHA (as shown in the left picture): in the spallation target the position of the liquid lead-bismuth free surface has to be monitored by a light detection and ranging system (LIDAR), which consists of two receiver frontend channels and a TDC. This work presents a radiation tolerant multi-stage delta-sigma TDC. It adopts the noise-shaping technique, and achieves a time resolution of 5.6ps, when the oversampling ratio (OSR) is 250. A radiation assessment up to 5MGy proves its robustness.

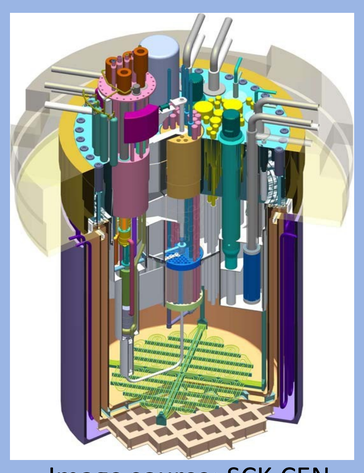
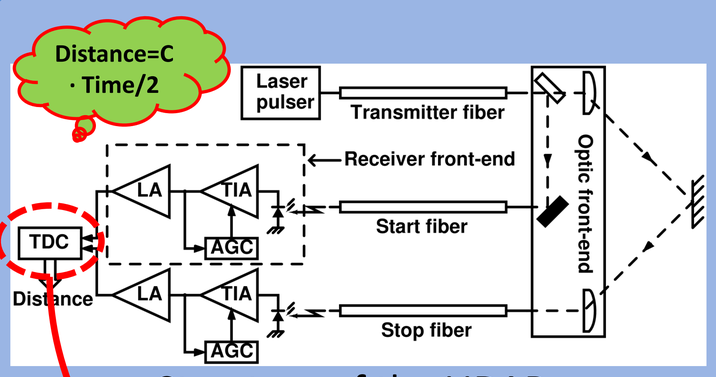


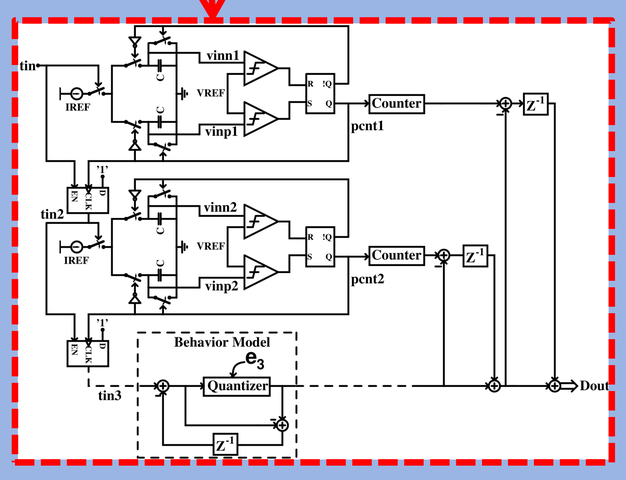
Image source: SCK·CEN

Details of the design



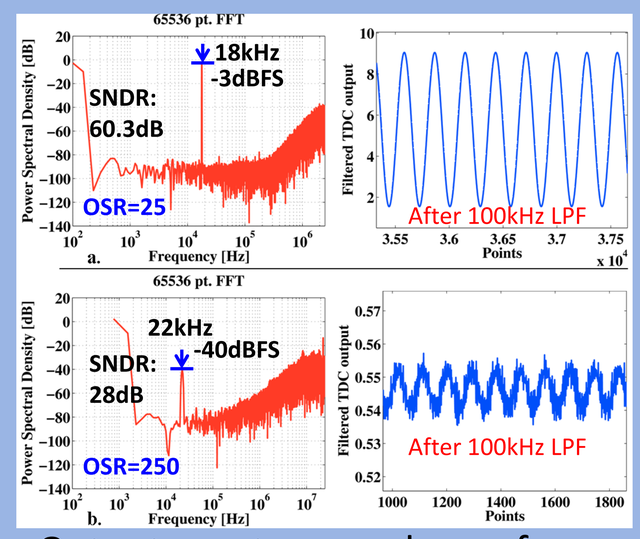
Structure of the LIDAR

1mm distance resolution requires a time resolution of 6.7ps.

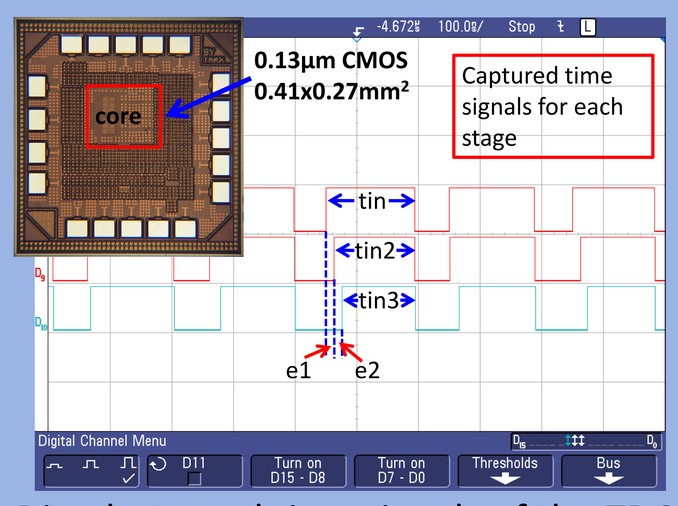


Architecture of the MASH TDC

The 1-1-1 MASH ΔΣ TDC has three stages. Each stage works as a relaxation oscillator, but controlled by the input time signal. The time can be measured by counting the periods of the oscillation clock during the time signal's active phase. By preserving the phase of the oscillation clock between measurements, first-order noise-shaping is obtained. Third-order noise-shaping can be achieved by cascading all three stages.



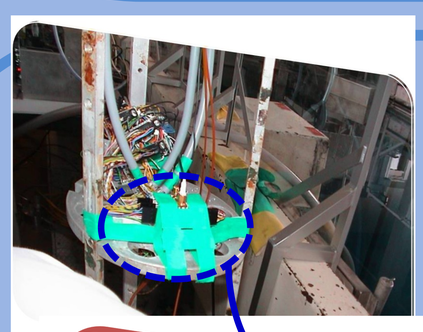
Output spectrum and waveform



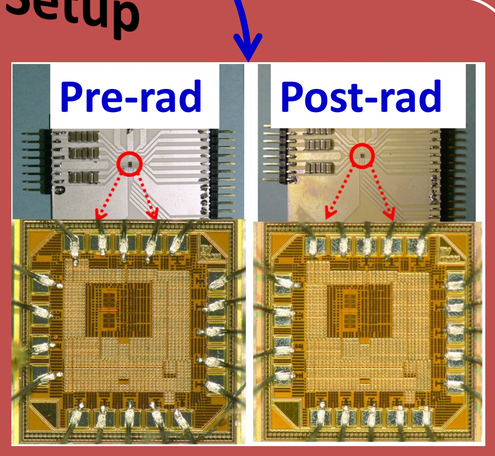
Die photo and time signals of the TDC

The frequency of the oscillation clock can be expressed as 1/(2·RC), which is depending only on passive components. Thus, the TDC exhibits inherent PVT tolerance. Additionally, other hardened-by-design techniques have also been implemented to improve the system's radiation tolerance, such as constant-gm biasing circuit, guard ring, etc. …

Radiation assessment



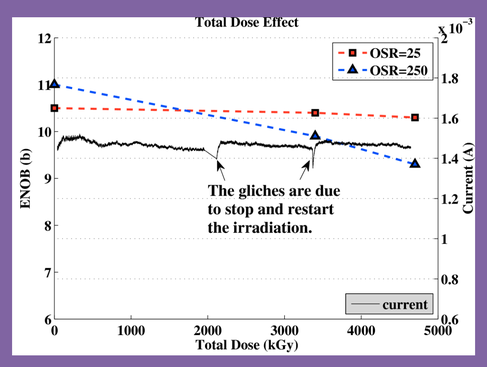
Setup



Irradiation

- Gamma-dose radiation
- Low dose rate experiment: 1.2kGy/h exposure time: 130h
- High dose rate experiment: 30kGy/h exposure time: 165h

On-line test



Conclusion

A radiation tolerant third-order ΔΣ TDC is implemented in 0.13µm CMOS. It consumes only 1.7mW power and achieves an ENOB of 11b. Even after an extremely high radiation dose of 3.4MGy, the ENOB drops only 1 bit and, for an OSR of 250, a 10.5ps time resolution is still achieved.