Experimental results of the pFREYA16 ASIC for x-ray ptychography in continuous wave light sources

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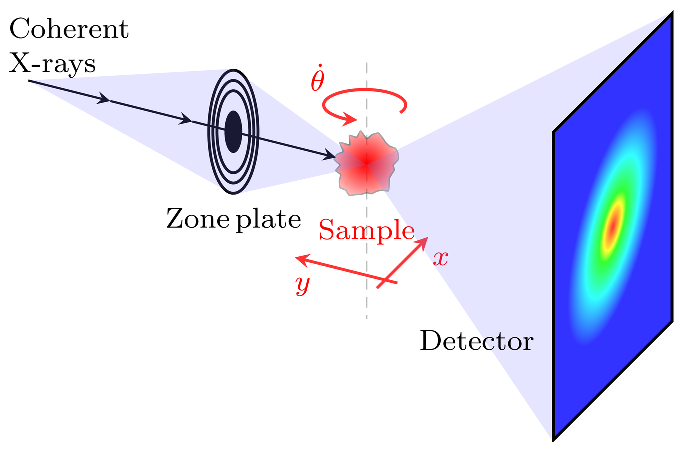
Introduction

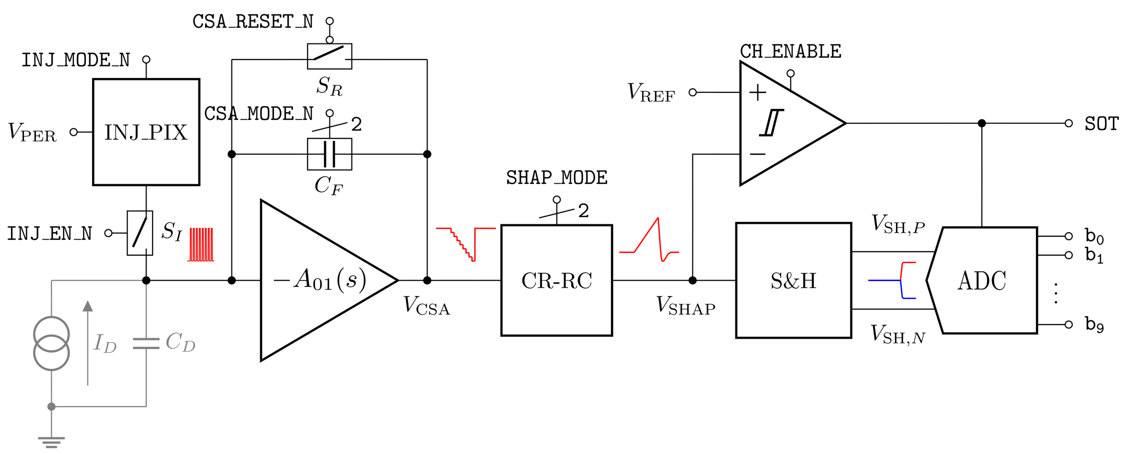
- In the present work the measurements obtained from a **read-out channel for a pixelated detector to be employed in x-ray ptychography**, named **pFREYA16** (prototype Fast Readout for ptYchography Applications with 16 pixels), are reported.
- The target of **FALCON collaboration** (University of Bergamo, University of Pavia, and Argonne National Laboratory) is to develop a low-noise, low-power **128-by-128 hybrid pixel matrix** operating at **1 MHz** conversion rate.

X-ray ptychography



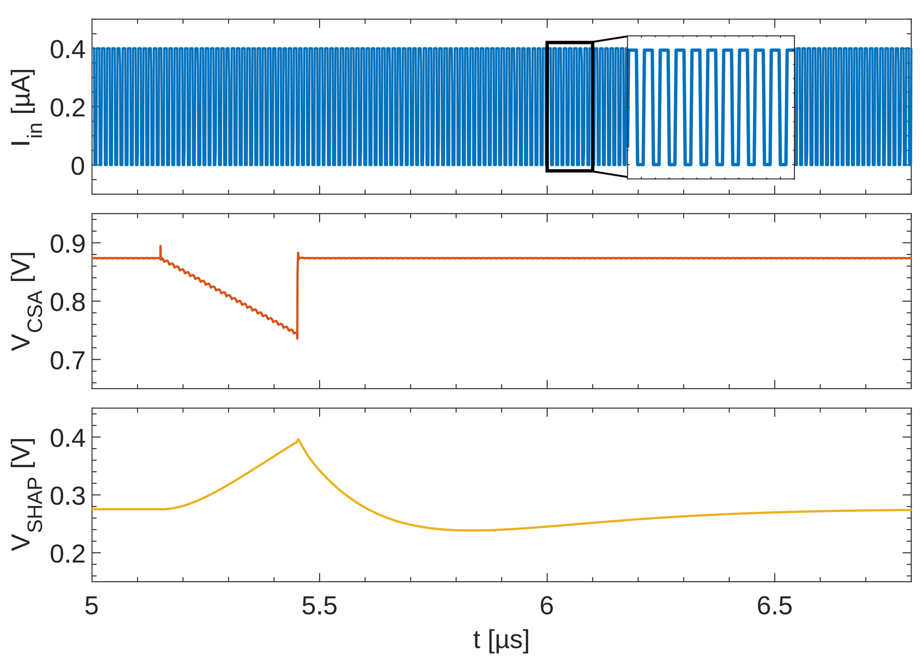
- X-ray ptychography key idea is to collect a **large volume of diffraction patterns**.
- To avoid motor repositioning overhead (>1 ms per sample), diffraction patterns are continuously acquired (**fly-scan ptychography**).
- Typical ptychography throughput is low [1], but can be **sped up by acquiring modest-sized frames**.
- **Iterative phase retrieval** algorithms are applied to the data to **reconstruct the phase** information from the detected amplitude.
- Amplitude and phase information are combined to obtain a **nanometric model** of the specimen, exceeding physical lens limits [2].

pFREYA16 readout channel



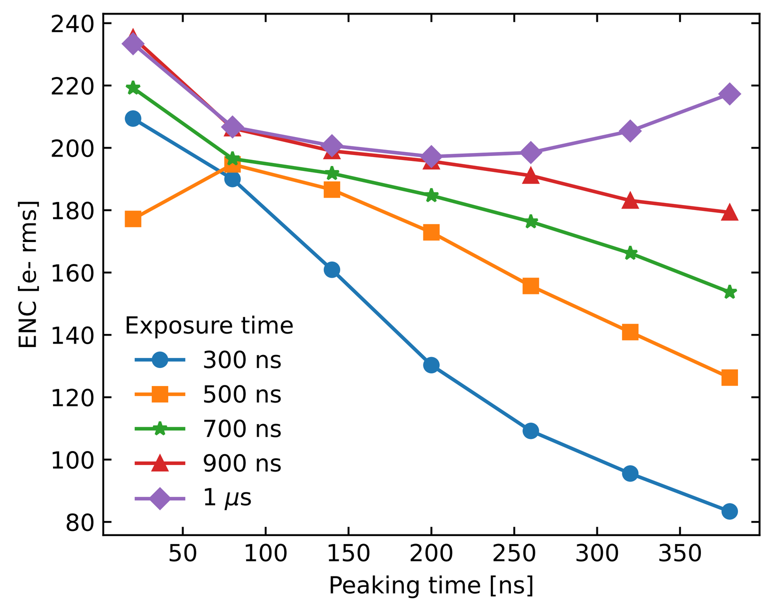
- Developed in a **commercial 65 nm CMOS technology**.
- **Single photon detection**, with an equivalent noise charge of **250 e⁻ rms** at a detector capacitance of 100 fF.
- Adapts to **3 input photon energies**: 5 keV, 9 keV, and 25 keV.
- **Input dynamic range up to 256 photons** for each mode.
- **Unipolar semi-Gaussian RC-CR shaper** with 4 selectable peaking times between 230 ns and 530 ns.
- **Signal-Over-Threshold comparator chain** to reject <1 input photon signals.
- Output digitised by a **10-bit SAR ADC** [3].
- Power consumption of **220 µW**.
- Area occupation of **150 µm × 150 µm**, comprising digital blocks.

Simulated transient signals



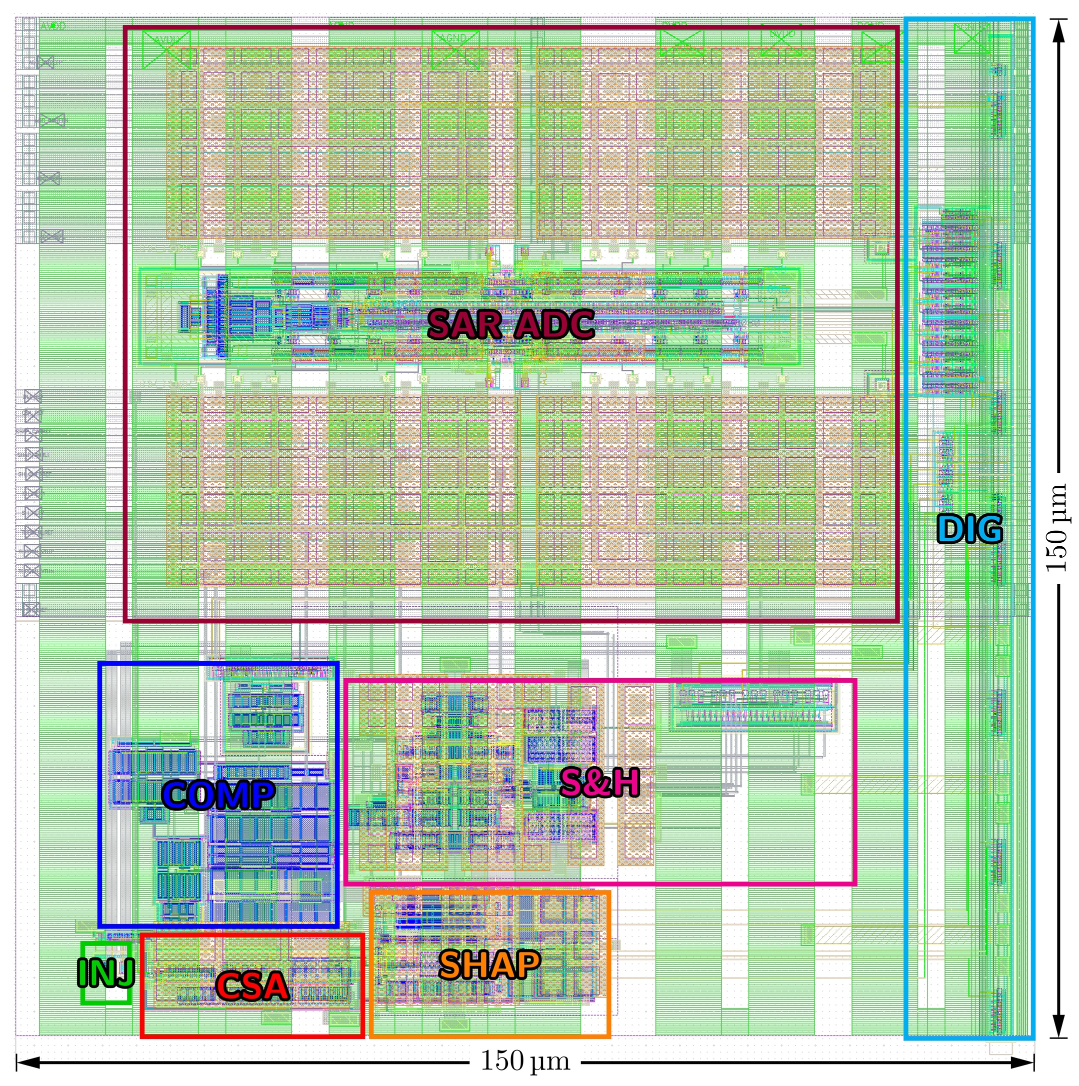
- Transient simulation, reported for t_{exp} = 300 ns and t_p = 450 ns in 9 keV photon mode at half dynamic.

Noise optimisation in simulation



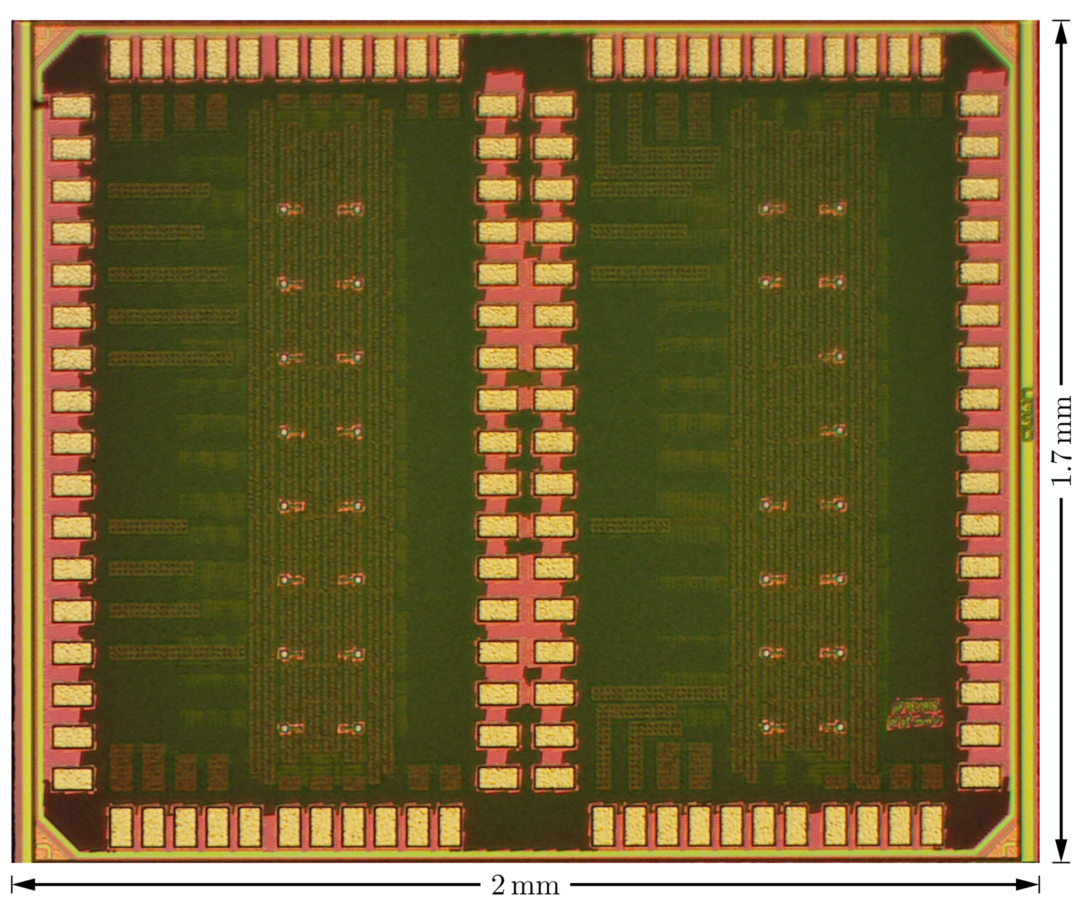
- Transient noise simulations performed on schematic-level CSA and ideal shaper.
- Optimisation study on exposure time t_{exp} and peaking time t_p.
- **The shorter t_{exp}, the better.**
- **The longer t_p, the better.**

pFREYA16 elementary cell



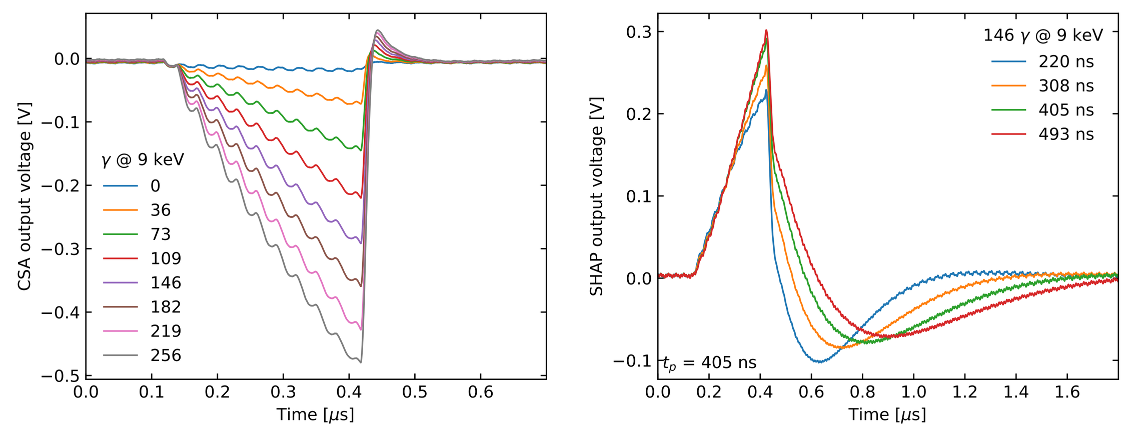
- **Modular layout**, sharing reference tracks and digital buses.
- Channel **current bias shared by 4 adjacent pixels**, not shown.
- Peripheral injection circuit and monitor circuit are not shown.
- 9 metal layers and MIM capacitors over electronics.

pFREYA16 ASIC



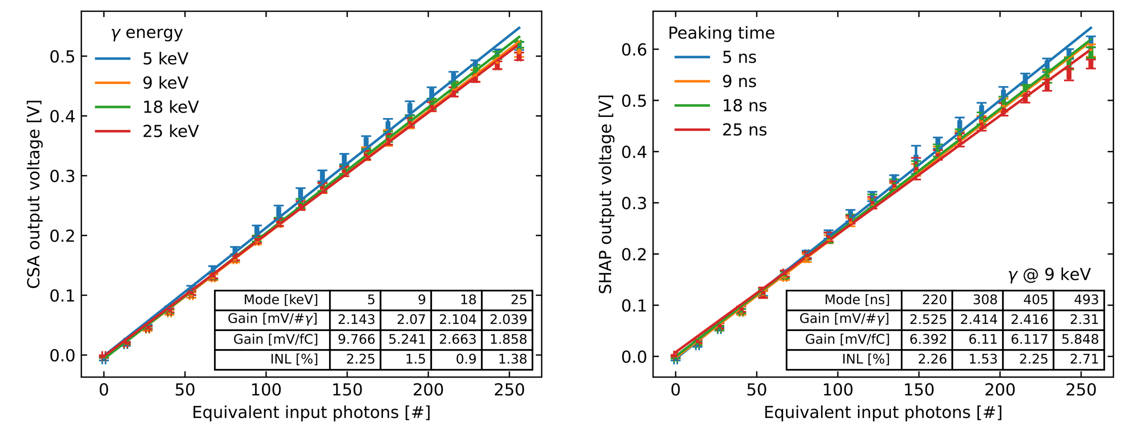
- Area of 1.7 mm × 2 mm.
- CLCC68 package.
- Cells mirrored about vertical axis to isolate analog from digital.
- On the right, pFREYA16, a **prototype 8-by-2 matrix**.
- On the left, pFREYATS, **test structures** arranged in the same 8-by-2 matrix fashion.

Transient measurements



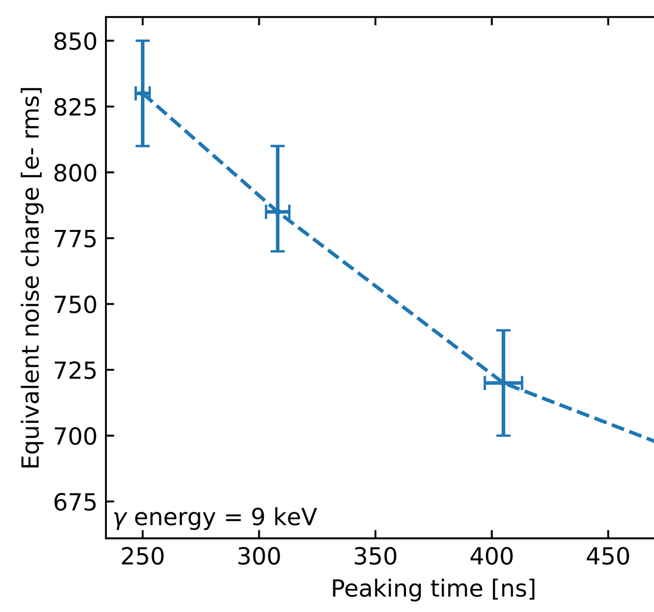
- CSA and shaper **transients as expected**.
- Slower injection strobe used due to test setup limitations.
- Overshoot and artifacts due to test board interface.
- Peaking time 6% shorter than expected but scaling by 100 ns, in accordance with simulations.

Transcharacteristic measurements



- CSA and shaper **transcharacteristics are in line with simulations**.
- Input and output dynamic range as expected.
- Gain 4% higher than expected.
- Linearity improved with respect to simulation.

ENC results



- ENC measurements performed on the shaper waveform obtained through an oscilloscope.
- The results are **higher than expected**, with an optimal ENC of about 670 e⁻ rms.
- The optimum is obtained for the longest peaking time.
- Source of the higher noise can be an instability on the shaper baseline not foreseen in simulations.

Conclusions

- A **prototype readout channel to be employed in x-ray ptychography** has been designed and developed.
- The core analog blocks, namely the **CSA** and the **shaper**, have been **thoroughly tested**.
- **Channel performance are in line with simulation**, exception made for **noise which seems to be higher** than expected, currently under investigation
- The mixed-signal section of the channel is currently under test.
- **New version with faster digital backend** is envisioned in the near future.

References

[1] C. Jacobsen, J. Deng, and Y. Nashed, "Strategies for high-throughput focused-beam ptychography," *Journal of Synchrotron Radiation*, vol. 24, no. 5, pp. 1078–1081, Sep 2017. [Online]. Available: https://doi.org/10.1107/S1600577517009869

[2] X. Huang, K. Lauer, J. N. Clark, W. Xu, E. Nazaretski, R. Harder, I. K. Robinson, and Y. S. Chu, "Fly-scan ptychography," *Scientific Reports*, vol. 5, p. 9074, Mar. 2015.

[3] P. Lazzaroni, M. Hammer, M. Manghisoni, A. Miceli, L. Ratti, and V. Re, "FALCON readout channel for X-ray ptychography applications," in *2022 17th Conference on Ph.D Research in Microelectronics and Electronics (PRIME)*, 2022, pp. 193–196.