10µm Global Shutter Pixel for Radiation Tolerant CMOS Image Sensors

Presenter: Pedro Sants

Authors: P. Santos, I. Hafizh, P. Leroux, G. Meynants

20/11/2024

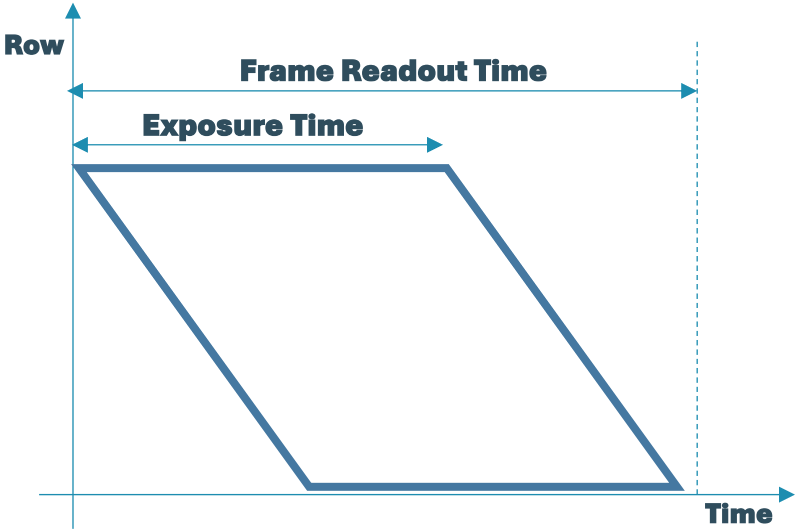
Agenda

- Motivation and Global Shutter operation introduction;
- CDS in Image Sensors;
- Radiation Effects on MOSFET devices;
- CMOS Radiation tolerant techniques;
- 10µm Global Shutter CMOS Radiation Tolerant Pixel;
- Experimental Results;
- Conclusions;
- Q&A

Geel Campus
Faculty of Engineering Technology

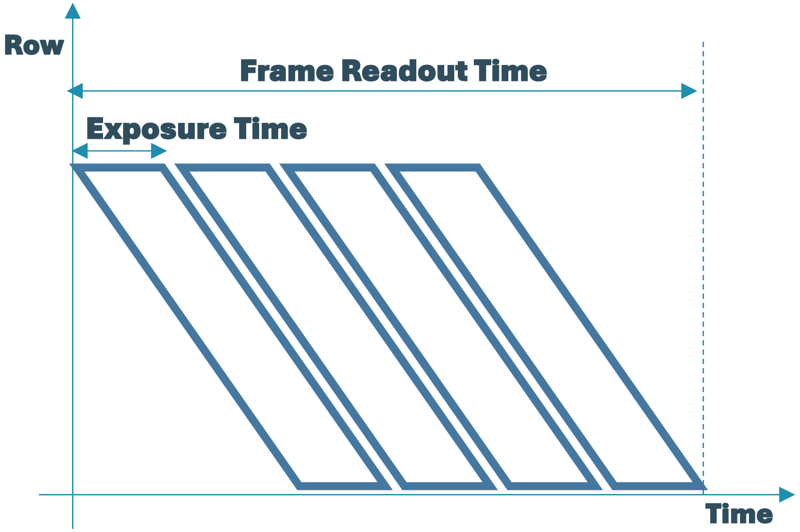
Rolling Shutter vs Global Shutter pixels

Rolling shutter



Challenges:
- Motion artifacts – skew
- Speed limitation

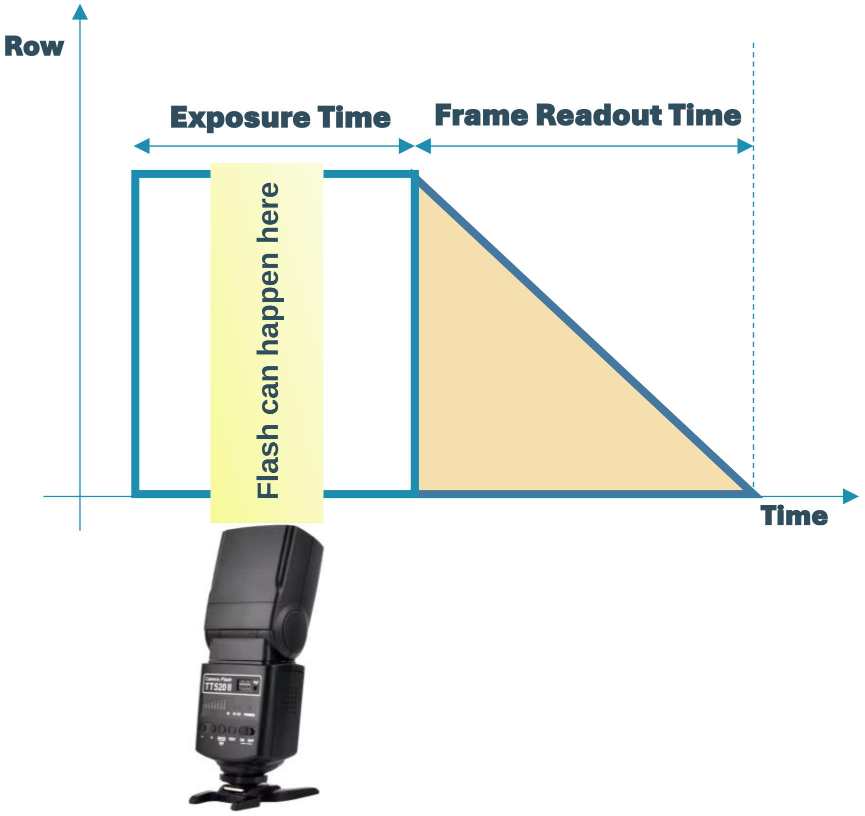
Readout at higher speed



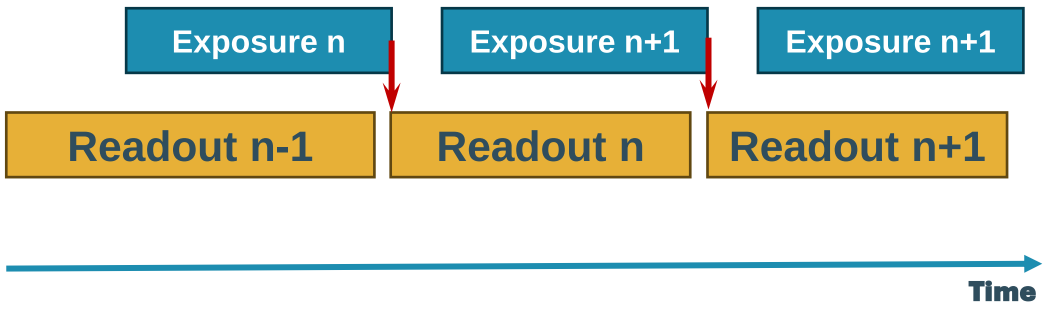
4x lower skew but:
- 4x less signal per exposure
- No synchronization -> Flash

Rolling Shutter vs Global Shutter pixels

Global Shutter



Pipeline operation:

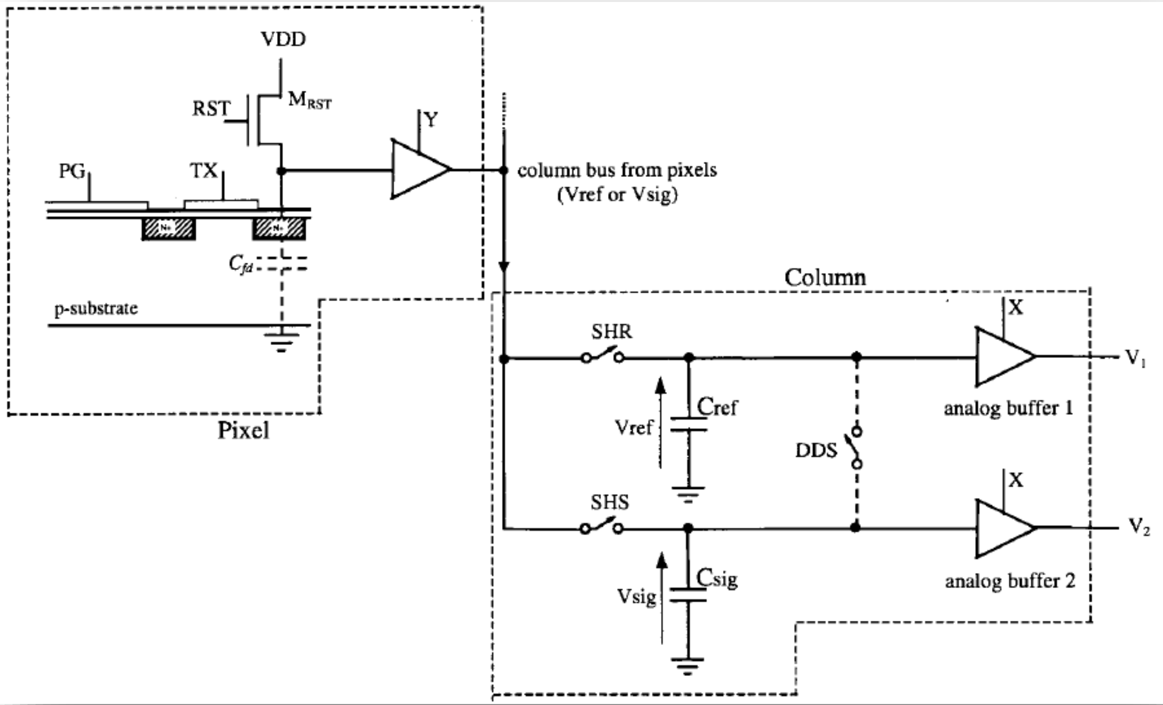


Applications:

- Snapshot and short exposure time;
- Structured light projection => depth;
- Background subtraction;

CDS in image sensors

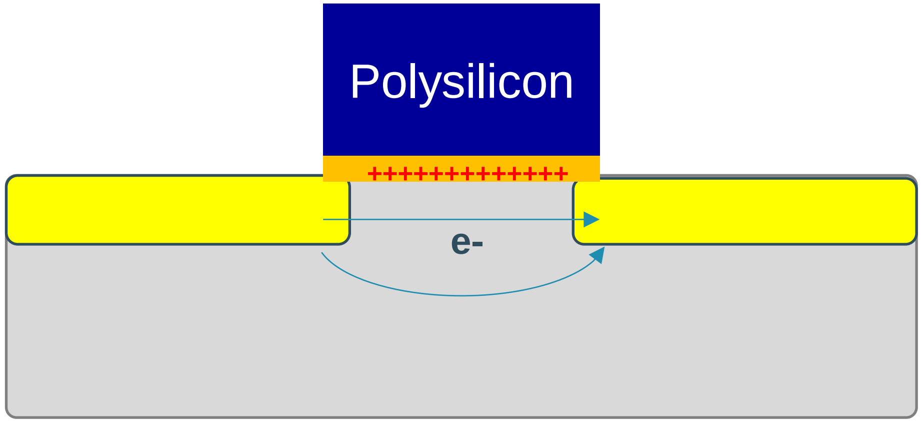
- Cancels or reduces some noise (kTC, 1/f and offset).
- Pixel reset and pixel signal are stored;
- Difference is computed – the result is the elective number of generated e-;
- Extracts the background noise from the radiation sources;
- CDS can either be analogue, digital or both processes combined.



[Degerli Y. et al.]

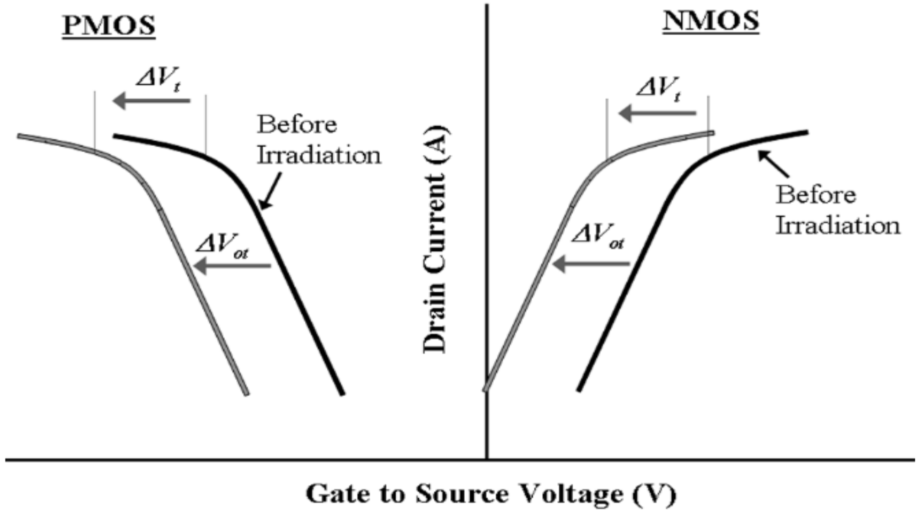
Radiation effects in MOSFETs

TID effects on MOSFET devices.



TID effects in MOSFET’s:

- Vth shift in NMOS;
- Vth shift in PMOS;
- Increase of leakage currents;
- Degradation of µ;
- Increase of 1/f noise;



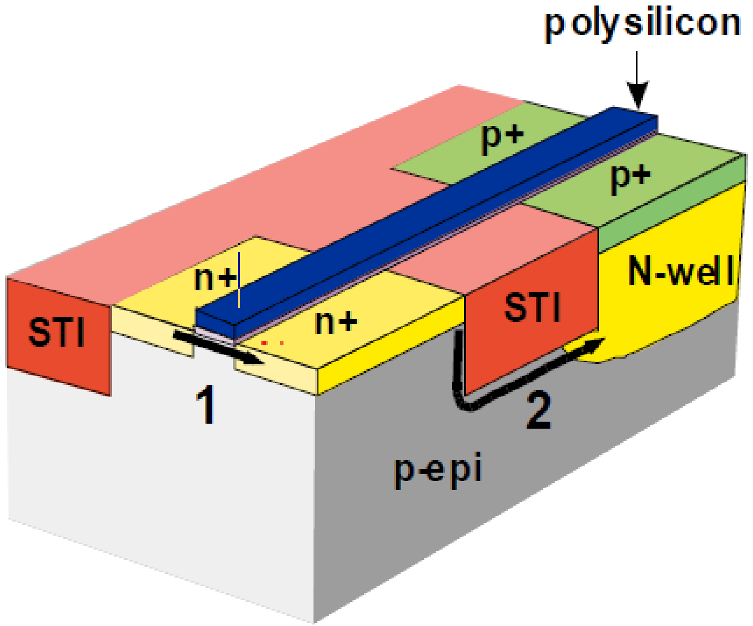
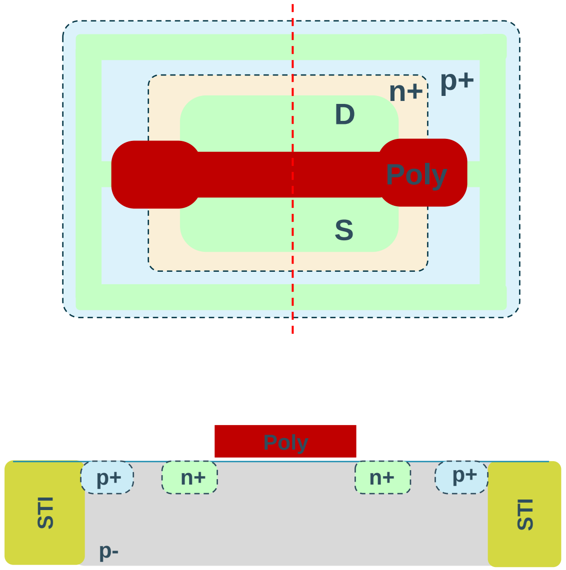


Figure 1: [1] As indicated by the arrows, two possible leakage paths in a shallow-trench isolation technology.

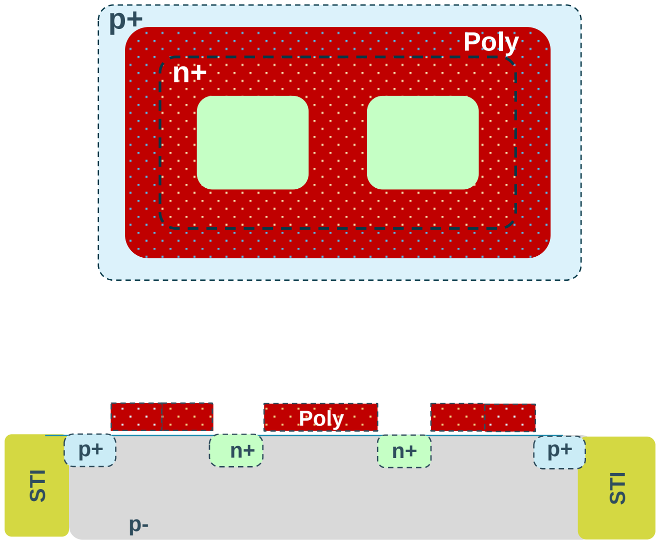
CMOS devices under radiation

- RHBD FET designs to mitigate the TID effects

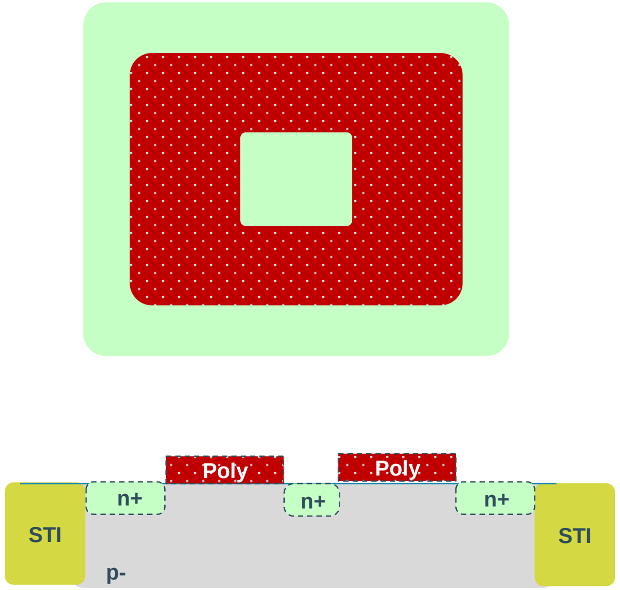
H MOSFET [2]



ButterFly FET [3][4]

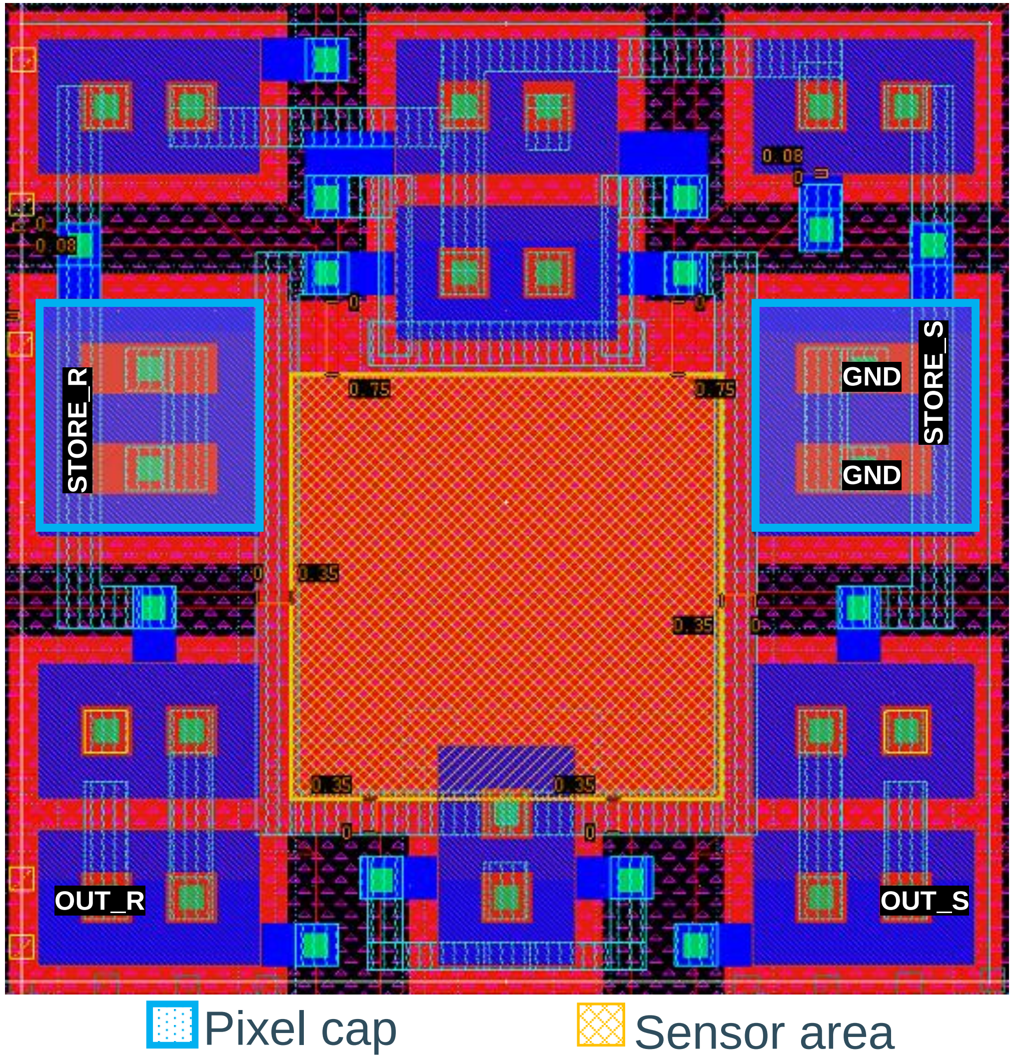


ELT FET [3][4]

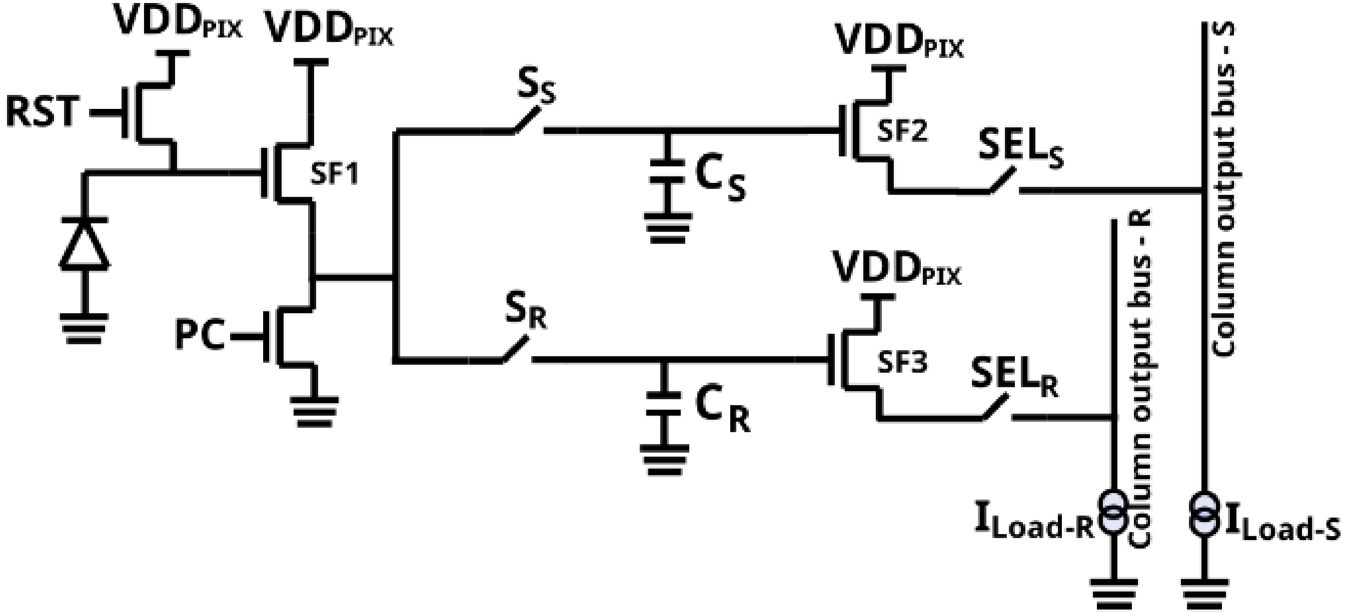


10µm Global shutter pixel design

a)



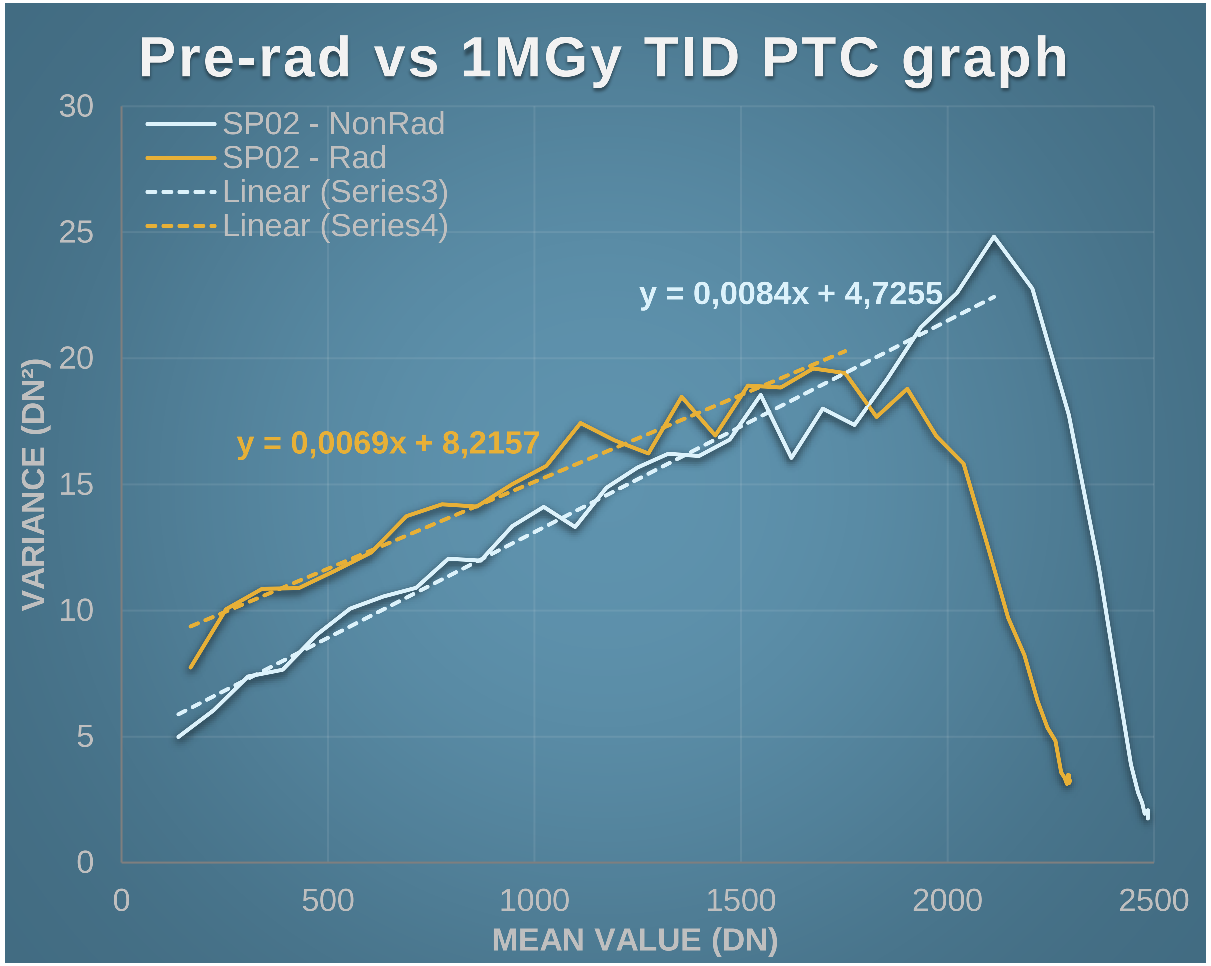
b)

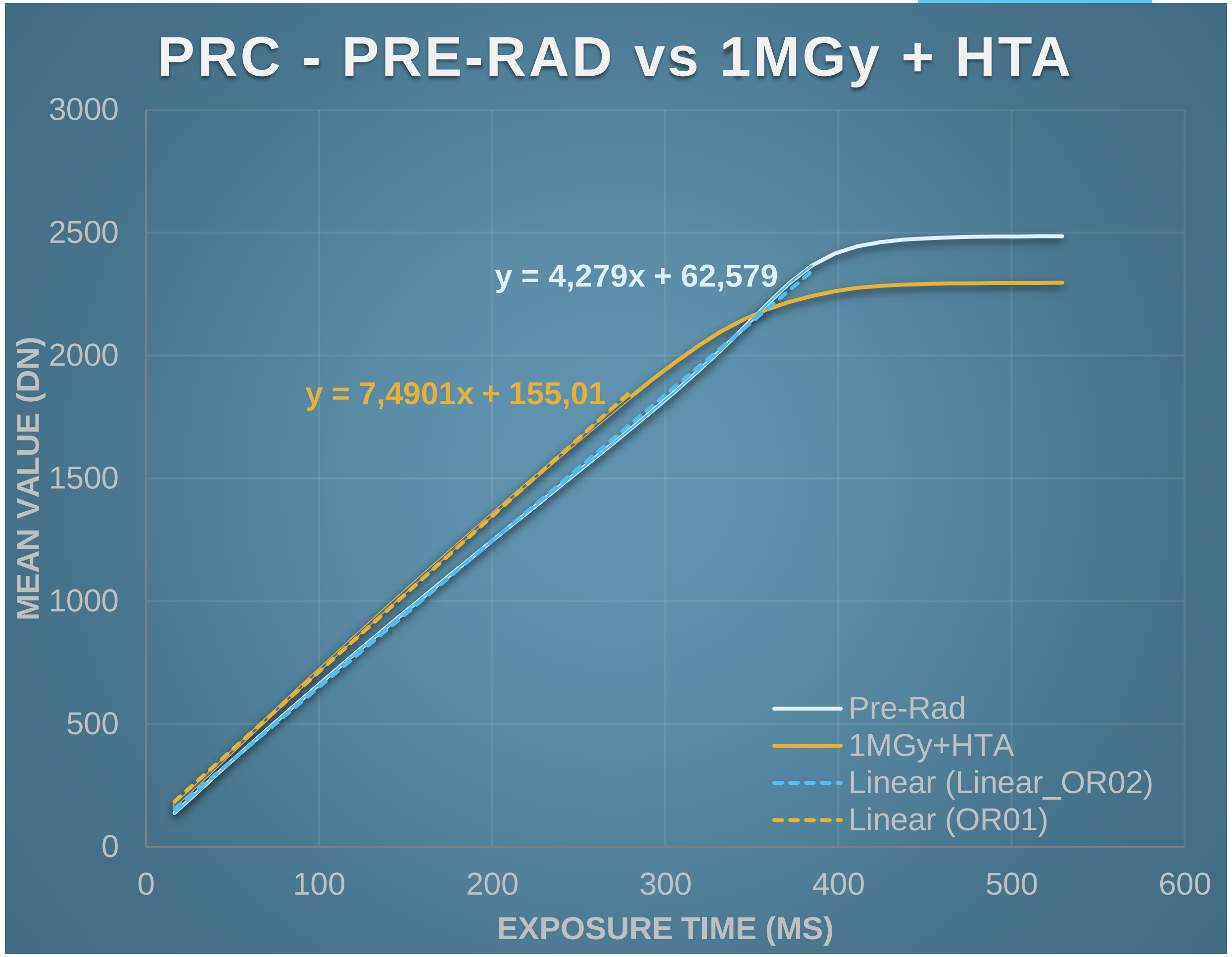


Voltage Domain Global Shutter Pixel: a) Schematic and b) Layout

Experimental Results

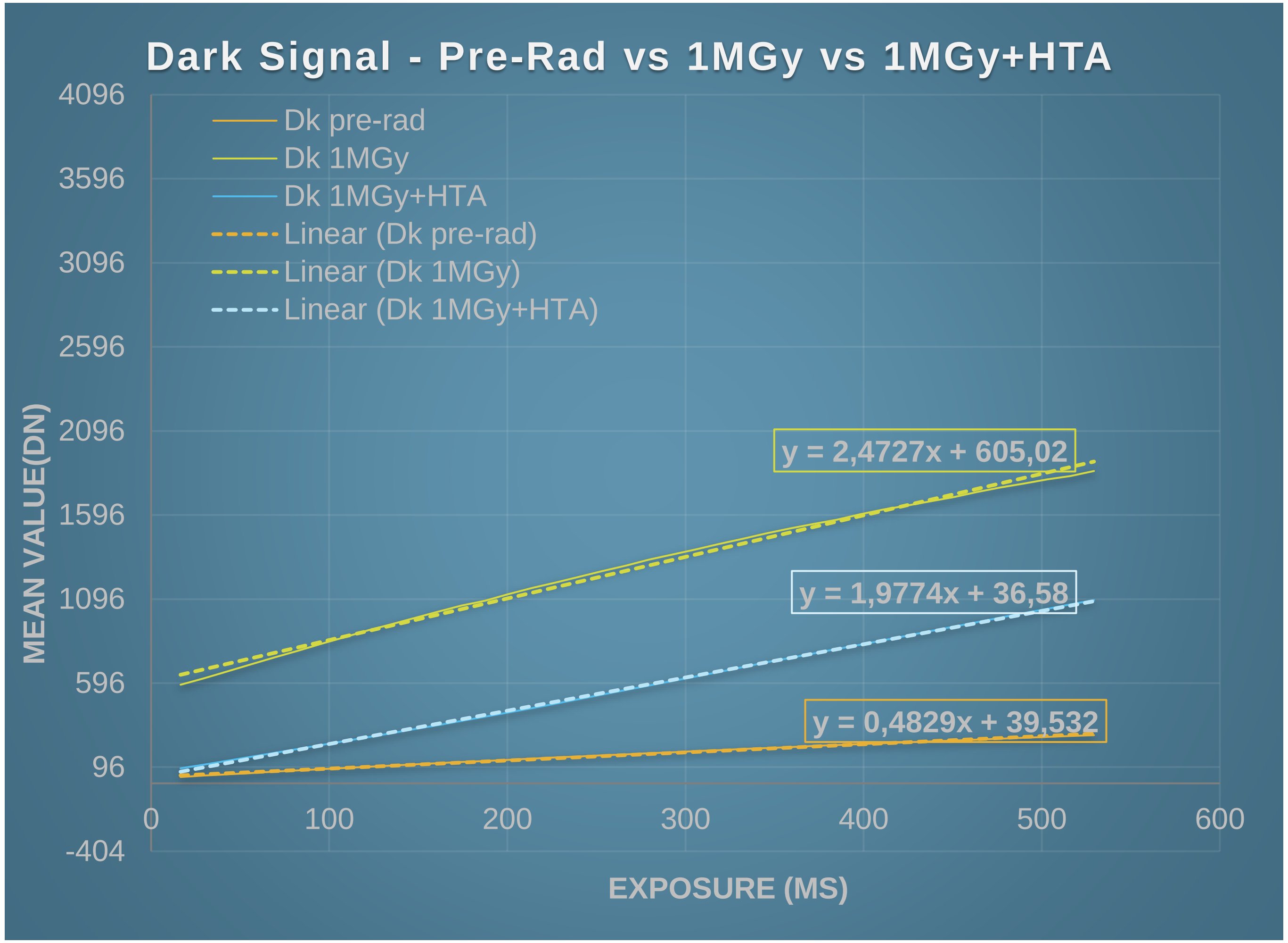
Experimental results





Geel Campus
Faculty of Engineering Technology

Experimental results (2)



TID Level	*DN*
Pre-Rad	168
150 kGy	205
250 kGy	253
500 kGy	347
1 MGy	445
1 MGy + HTA	188

Pixel Performance

Parameter	Pre-Rad	1 MGy + HTA	Unit
Conversion Gain (K)	5,034	4,13	µV/e-
Dark Current[1]	57,5	286,6	e-/s
Dynamic Range	49,3	43,4	dB
Temporal Dark noise	59,6	74,2	e-
FWC	17444	10981	e-

[1]at room temperature – 20C

Conclusion

- The presented Voltage Domain Pixel design can withstand TID effects up to 1MGy (SiO_2).
- The noise performance is yet to be improved;
- Dark current increases but is significantly mitigated by the RHBD techniques implemented;
- Pixel timing optimisation yet to be concluded;
- Integrated electronics (RHBD ADC's and readout electronics) can improve even further the pixel performance.
- Charge Domain Pixel designs suffer from the same issues, being expected similar degradation;

References

[1] M. R. Shaneyfelt, P. E. Dodd, B. L. Draper, and R. S. Flores, “Challenges in Hardening Technologies Using Shallow-Trench Isolation,” IEEE Trans. Nucl. Sci. vol. 45, no. 6, pp. 2584-2592, Dec. 1998.

[2] B. Dierickx, “Radiation hard design in CMOS image sensors,” Conference: CPIX Workshop, Bonn (DE) September 2014

[3] W W. J. Snoeys, et.al., “A new NMOS layout structure for radiation,” IEEE Transactions on Nuclear Science, pp. vol. 49, no. 4, pp. 1829-1833, Aug. 2002.

[4] Dewitte, Hugo et. al., “Ultra-High Total Ionizing Dose Effects on MOSFETs for Analog Applications,” IEEE Transactions on Nuclear Science, pp. vol. 68, no. 5, pp. 697-706, March May 2021.

[5] M. H. White, D. R. Lampe, F. C. Blaha and I. A. Mack, “Characterization of surface channel CCD image arrays at low light levels,” IEEE Journal of Solid-State Circuits, Vols. vol. 9, no. 1, no. doi: 10.1109/JSSC.1974.1050448, pp. pp. 1-12, Feb. 1974.

Thank you