



Science & Technology Facilities Council

Technology

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CMOS Active Pixel Sensors for space radiation monitoring

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- CMOS Sensor for radiation detection
 - A 16Megapixel sensor for
Transmission Electron Microscopy (TEM)
 - A CMOS image sensor for the Highly
Miniaturised Radiation Monitor (HMRRM)
 - Conclusions
-

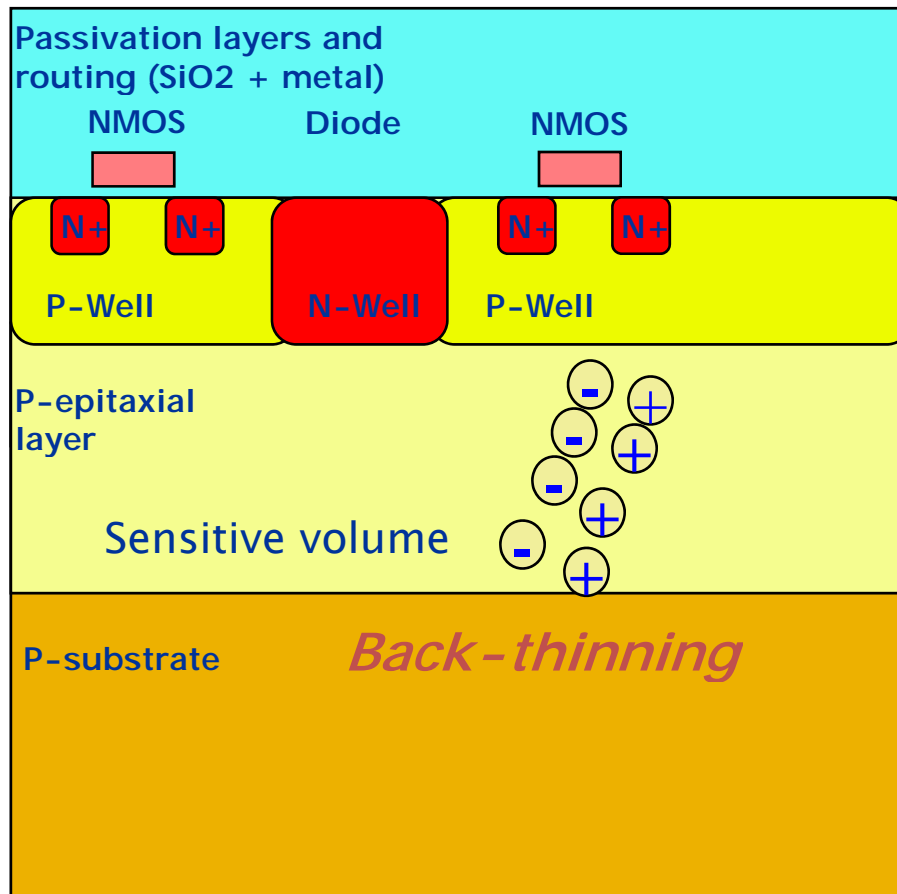


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Detection of particles in CMOS sensors

Highly integrated sensor
Radiation hardness
Low power



A few μm

$\sim 1 \mu\text{m}$

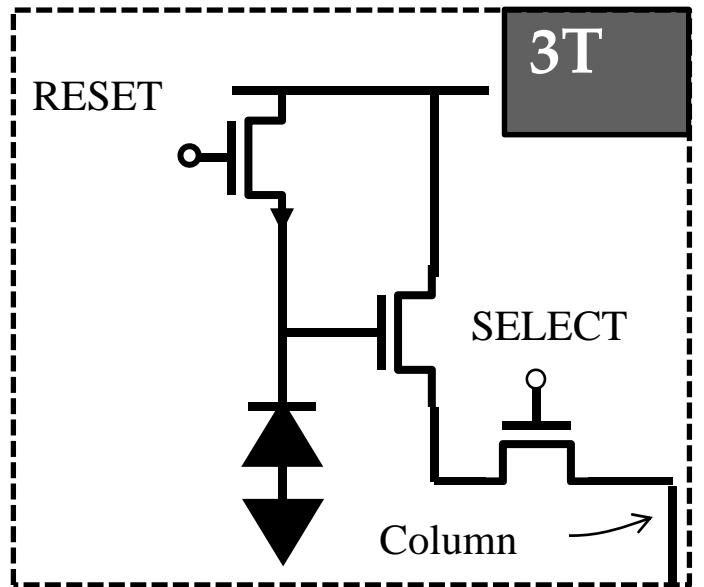
Up to tens of μm

A few tens of μm

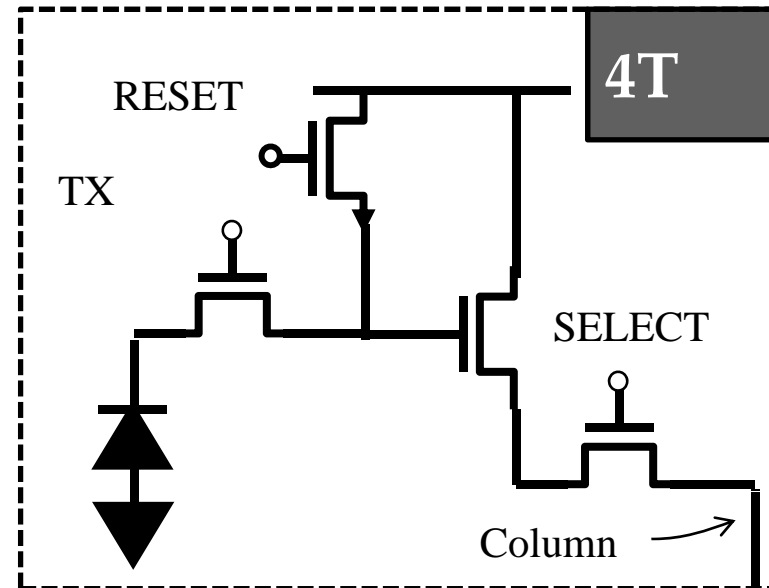
R. Turchetta, M. Prydderch, G. Villani,
*Accelerated particle and high energy
radiation sensor*, WO/2004/099740



Pixel choice. Integrating sensors



Simplest active pixel
Higher noise
Well proven, high radiation
tolerance



Most popular active pixel
today
Low noise
Good radiation tolerance



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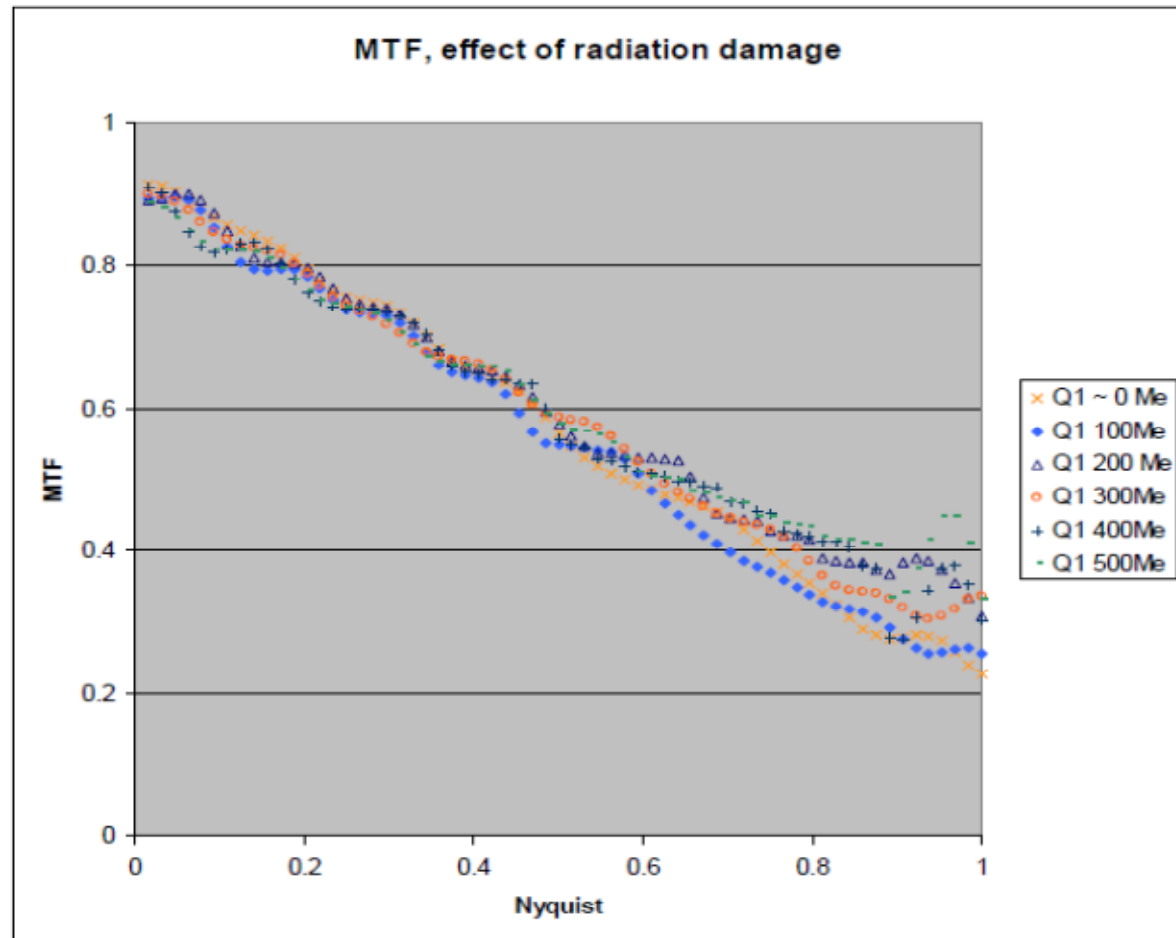


A 4kx4k sensor for Transmission Electron Microscopy

- Electrons accelerated at 100keV – 1MeV. Most typical energy: 300 keV
 - Single electron sensitivity
 - Pitch = 14 μm \rightarrow 56mmx56mm focal plane \rightarrow sensor > reticle \rightarrow stitching
 - Radiation hardness \rightarrow Enclosed geometry layout and guard ring rules
 - Off-chip control and analogue output
 - 0.35 μm CMOS
-



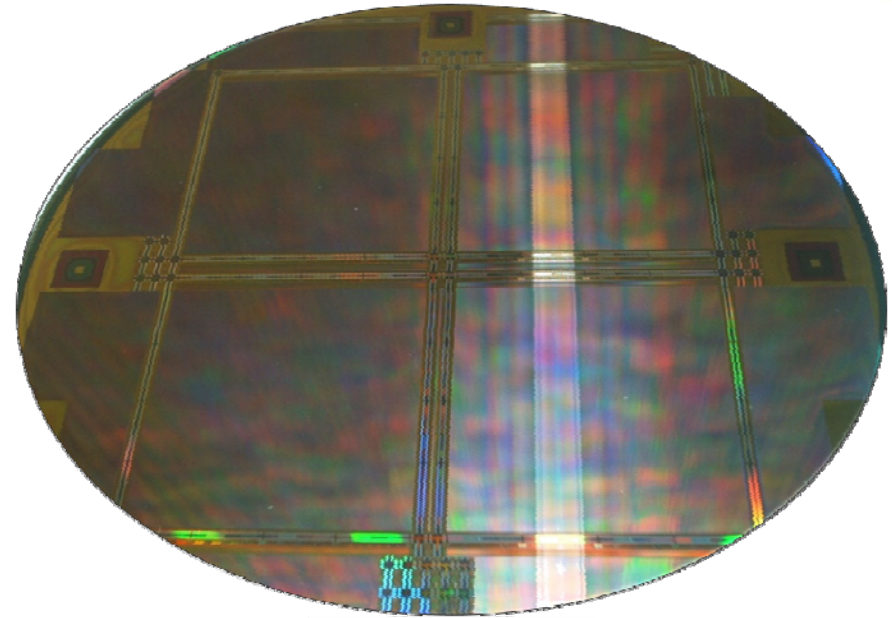
- Little variation in MTF
- Similar results for DQE





A 16Mpixel sensor for TEM

- 61x63 mm² silicon area (4 dies per 200mm wafer)
- 0.35μm CMOS
- 16 million pixels, 4Kx4K array
- 14 μm pixels
- Radiation hardness of >500 million of primary electrons/pixel (>20 Mrad)
- Backthinned
- Readout noise = 83 e- rms
- 40 fps



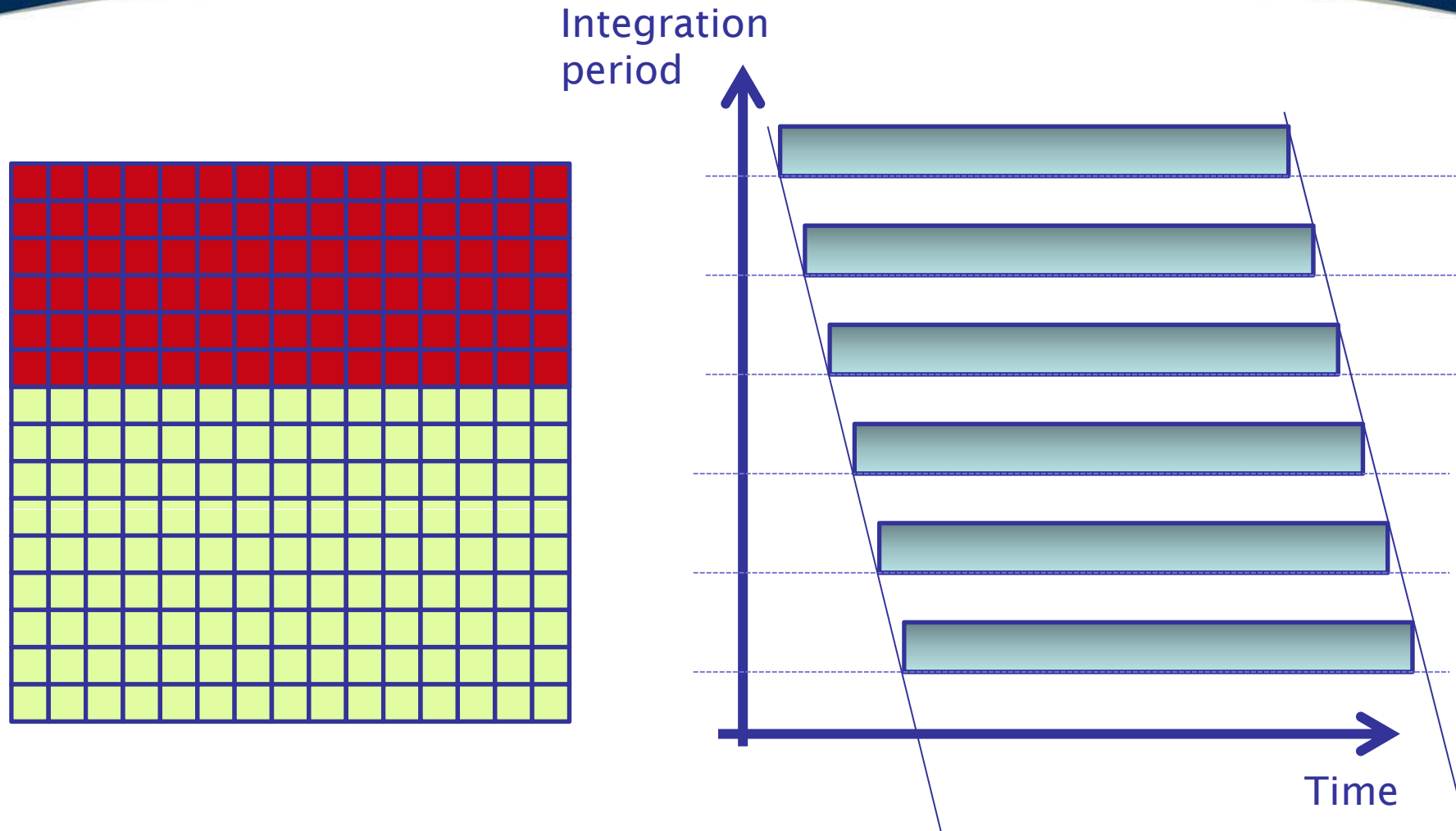
- 32 analogue outputs
- Pixel binning
- Region Of Interest readout
- Binning 1X, 2X and 4X
- External 16 bit ADCs

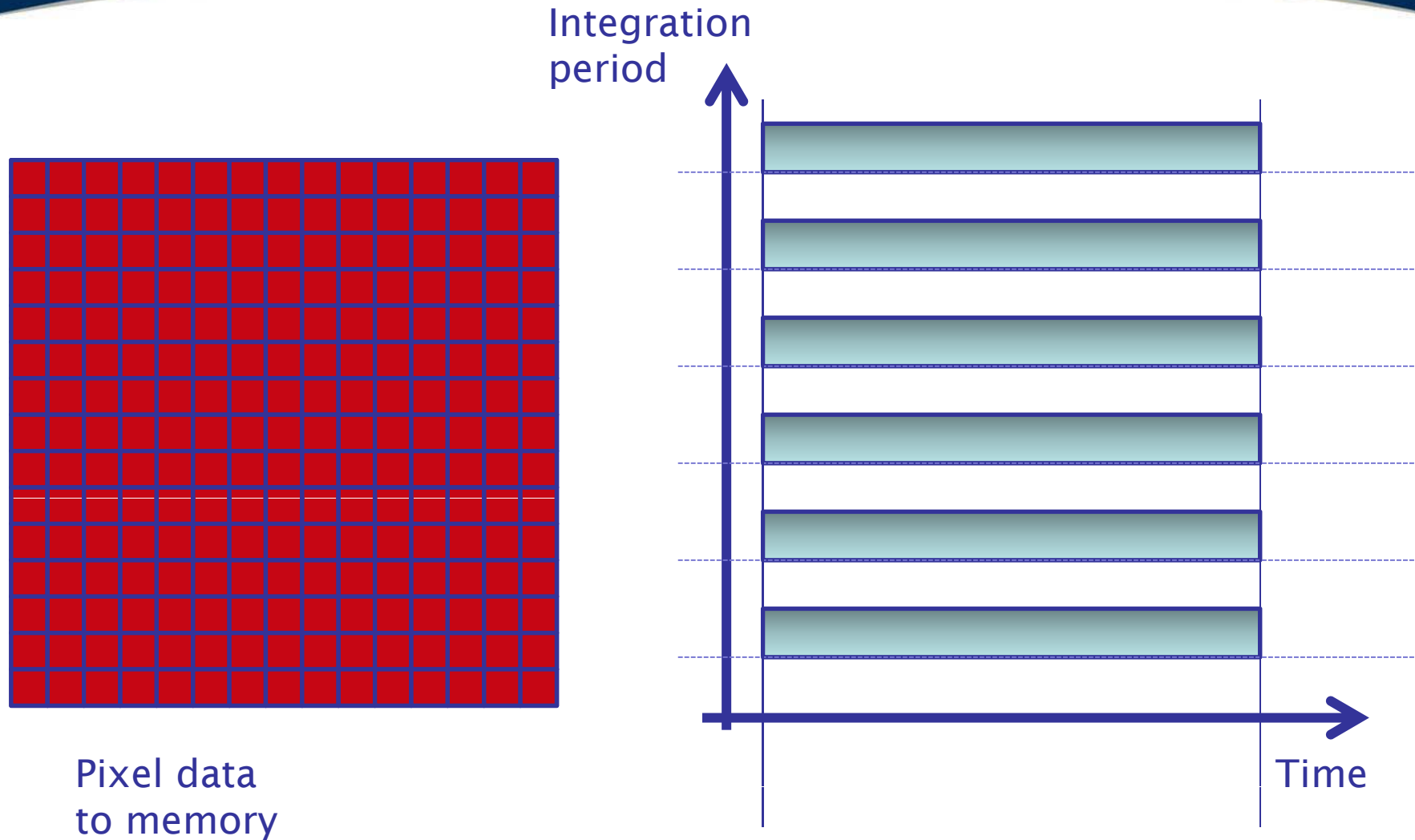


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Rolling shutter



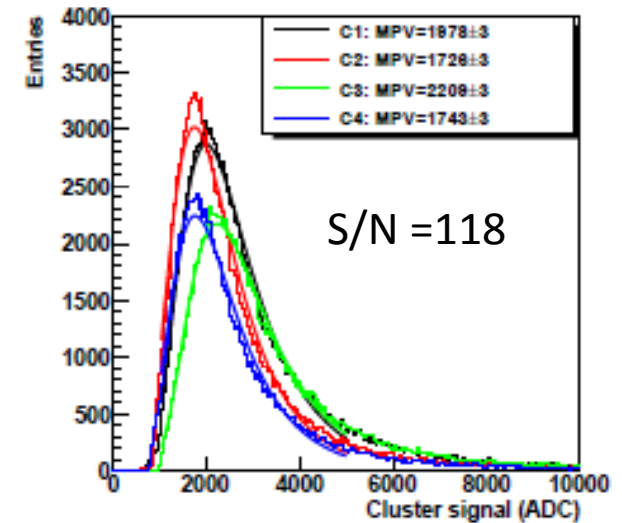
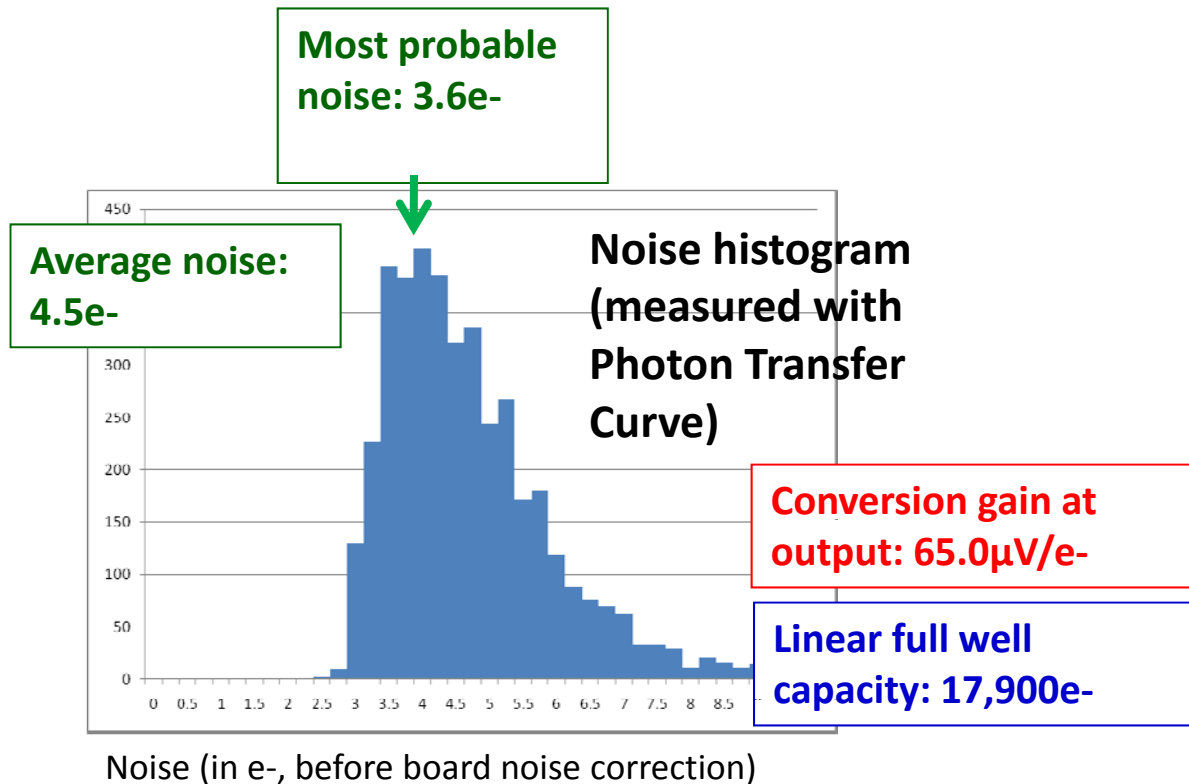
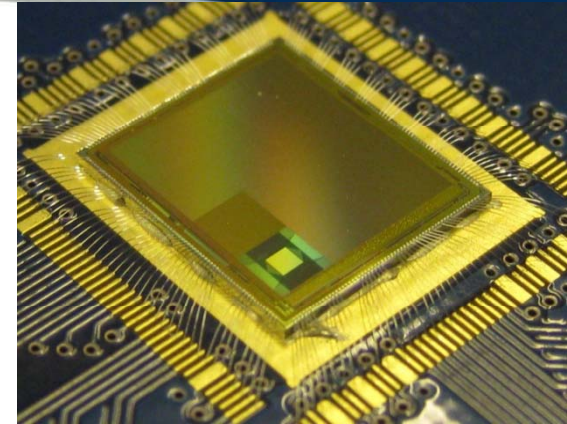




CMOS 0.18 μm – 4T sensor

12 μm epi thickness with 1kohm cm resistivity

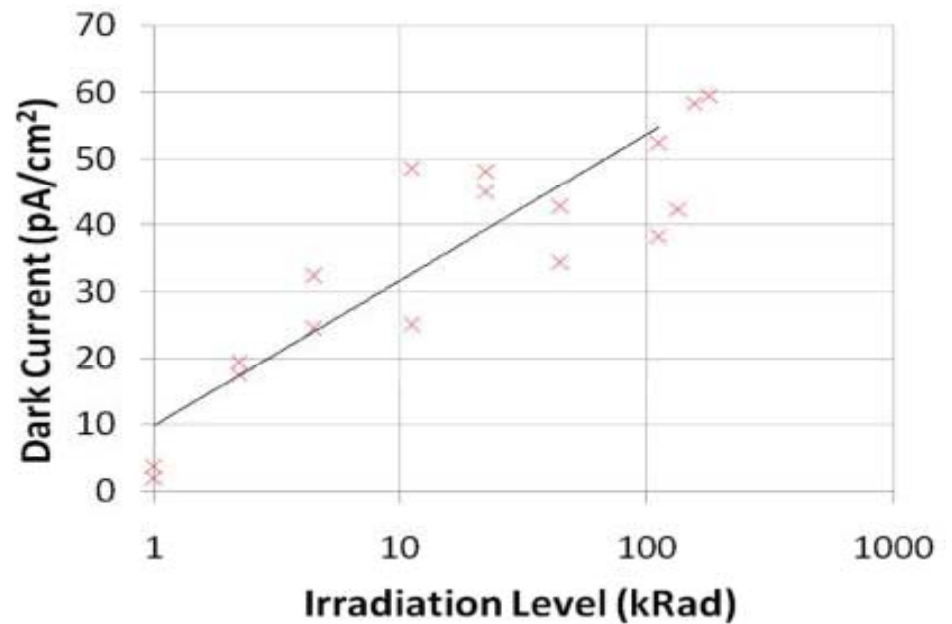
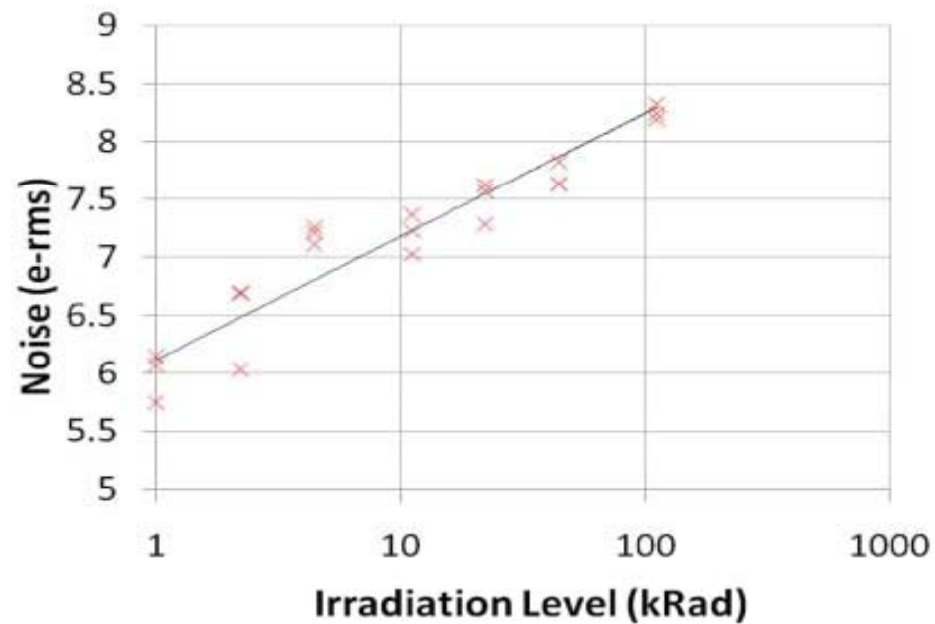
15 μm pixel



Landau distribution
(from beam test results)

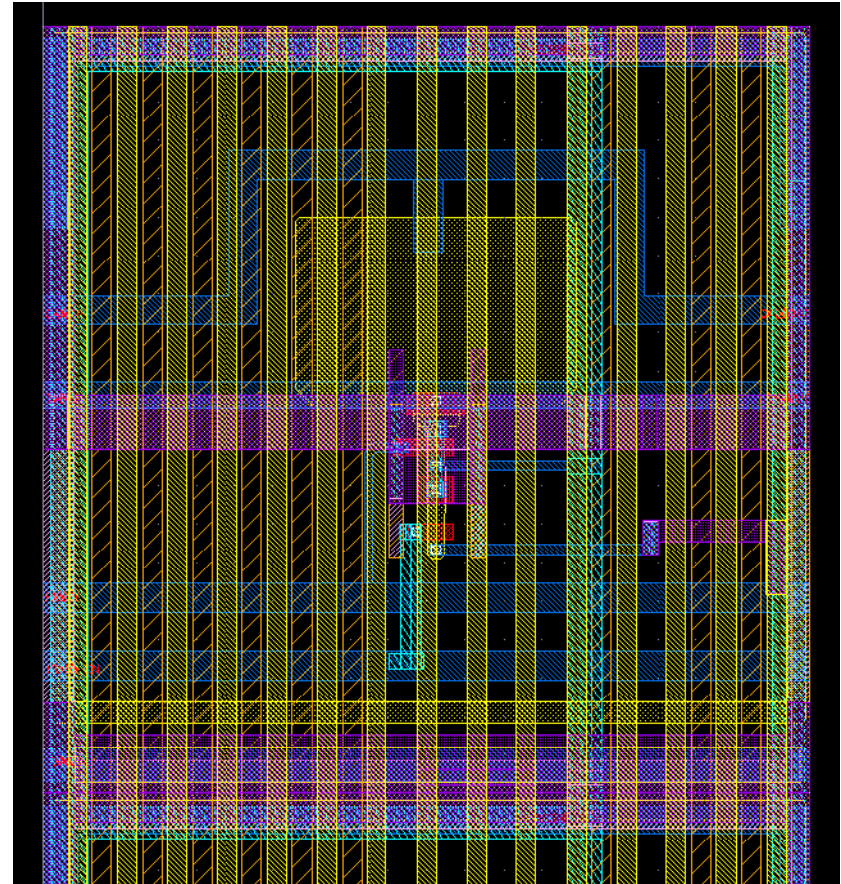


4T pixel. Radiation tolerance.

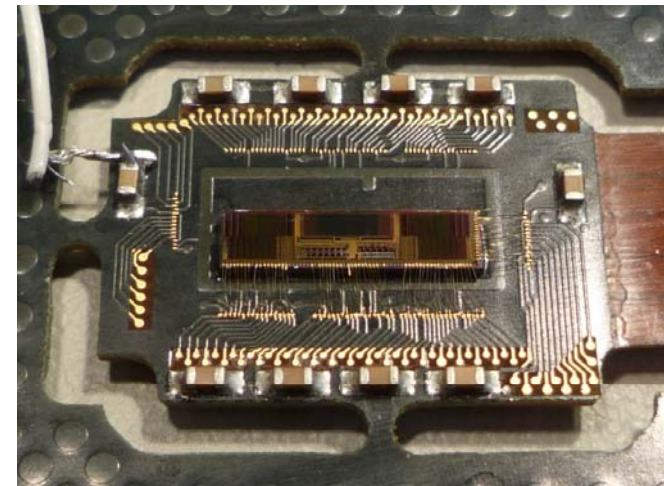
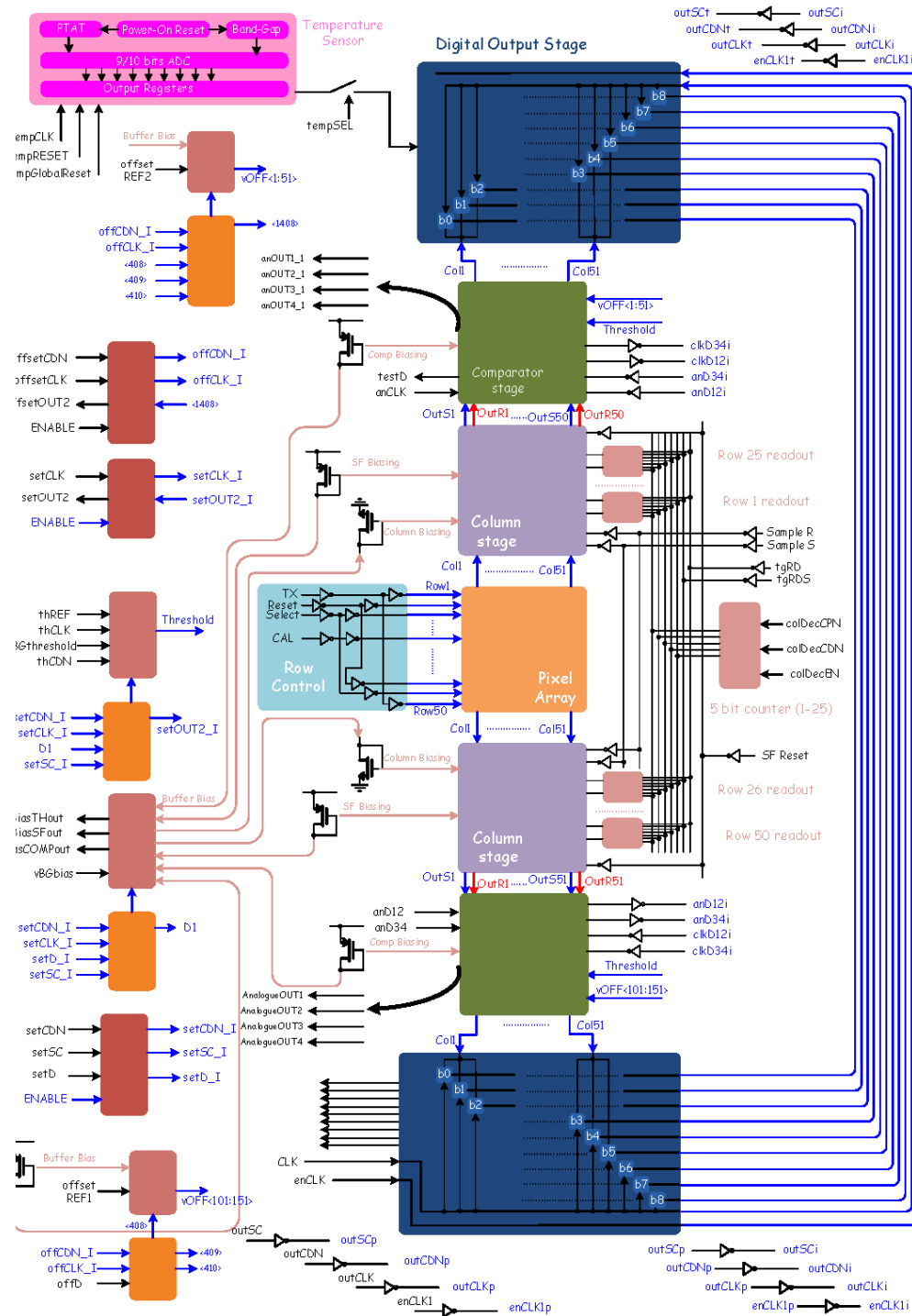


A CMOS sensor for a Highly Miniaturised Radiation Monitor (HMRM). Main specifications.

- 0.18 μm CMOS Image Sensor technology
- 20 μm 4T-pixels in a 50 x 51 array
- Snapshot and correlated double sampling (CDS)
- Frame rate up to 10,000 fps
- Column-parallel 3-bit single-ramp ADC, with in-column trimming
- Digital readout, plus analogue readout for debugging
- Integrated DAC for voltage/current generation
- Band gap
- Temperature sensor



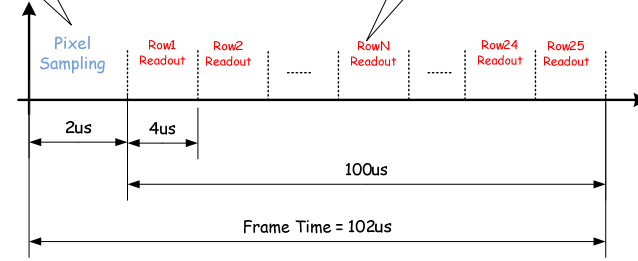
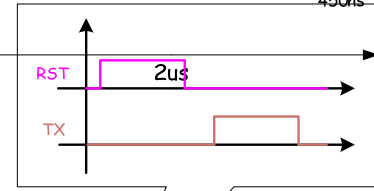
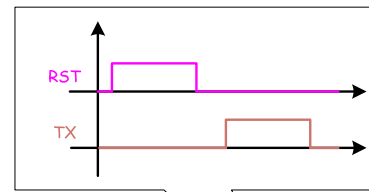
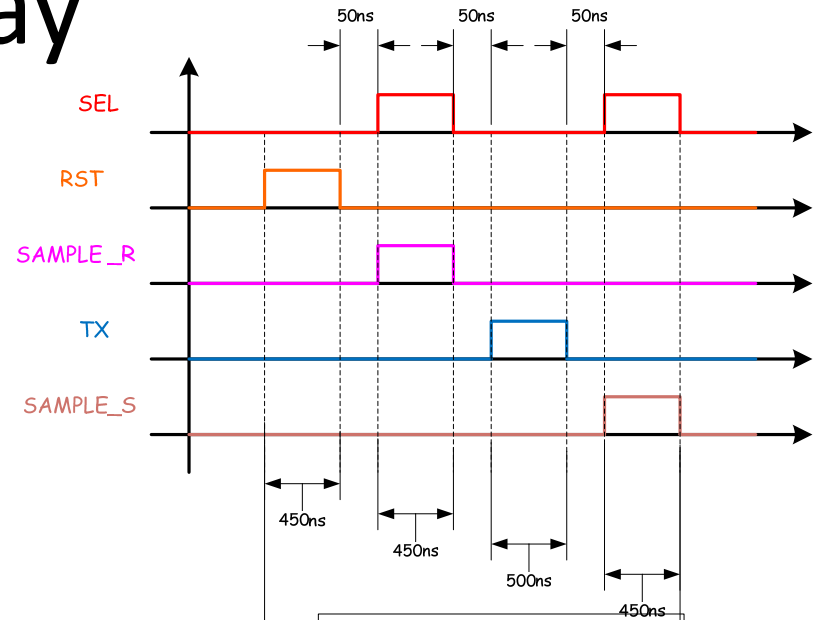
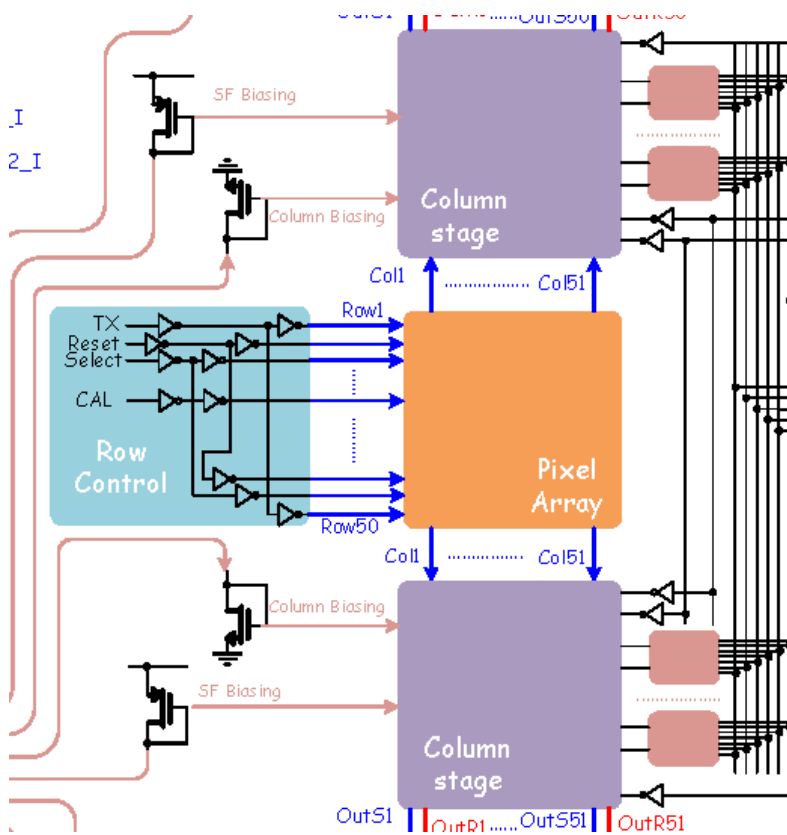
Sensor floorplan



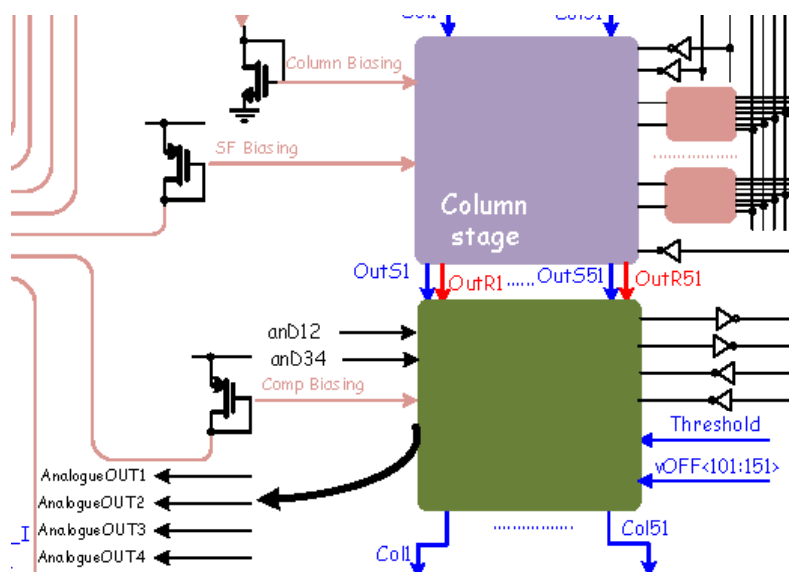
- 60 sensors manufactured on 12 μm , low resistivity epitaxial substrates
- 60 sensors manufactured on 12 μm , high resistivity ($>1\text{k}\Omega\text{cm}$) epitaxial substrates

Design for radiation tolerance:
 -Total dose
 -- single event upset immunity

Pixel array



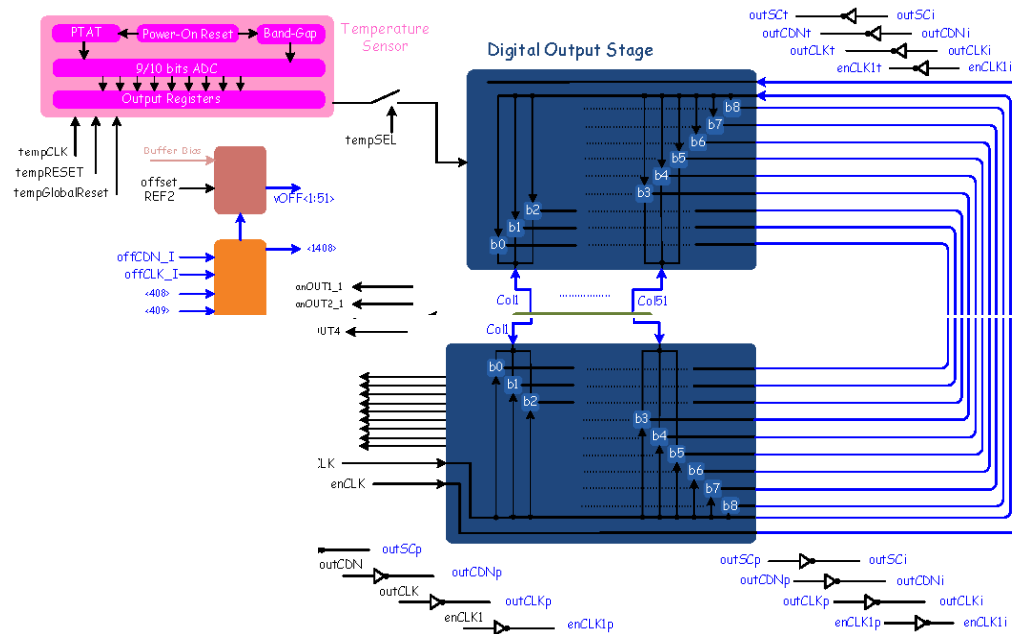
Analogue-to-Digital Conversion



- 1 comparator per column (readout on both sides)
- Seven 7-bit programmable thresholds → 49 bit shift register for programming
- One 8-bit DAC for each comparator trimming adjusting → 816 bits shift register for programming

- Threshold 1 : 0 to 673e- (40.3mV) STEP 5.3e-
 - Threshold 2 : 0 to 673e- (40.3mV) STEP 5.3e-
 - Threshold 3 : 0 to 1346.2e- (80.77mV) STEP 10.6e-
 - Threshold 4 : 0 to 2688e- (161.3mV) STEP 21.16e-
 - Threshold 5 : 0 to 4762e- (285.75mV) STEP 37.5e-
 - Threshold 6 : 0 to 9419e- (565.15mV) STEP 74.2e-
 - Threshold 7 : 0 to 18753.6e- (1.125V) STEP 147.6e-
- 1 e- = 60 μ V; 7-bit DAC to generate thresholds

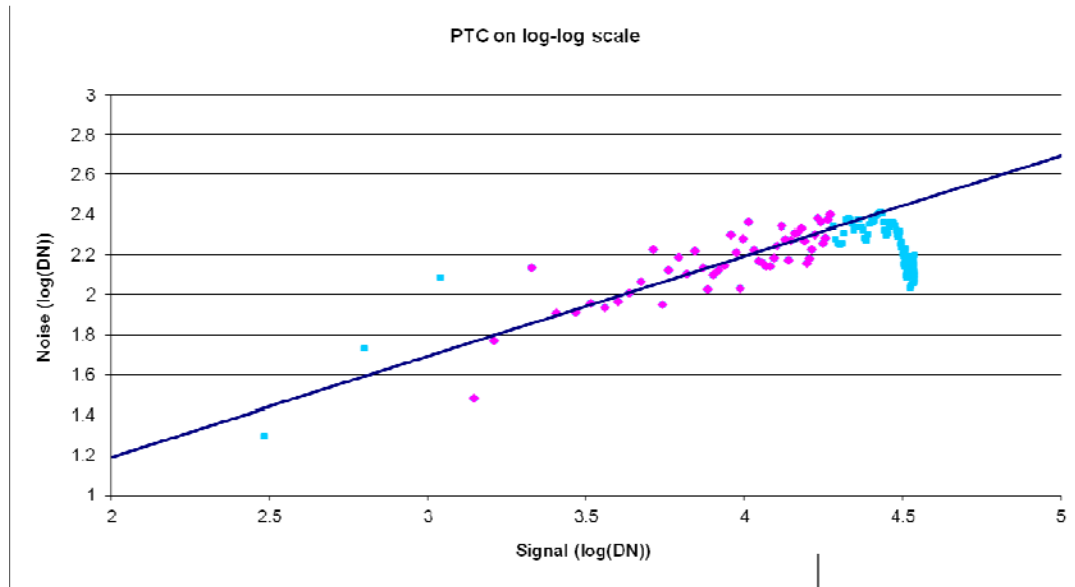
Output data path



- 3-bit encoder per comparator
- Data read on a 9 bit bus → $2 * 17 = 34$ clock cycles for readout
- plus one clock cycles for temperature sensor data (9-bit)
- Test input to the entire shift register

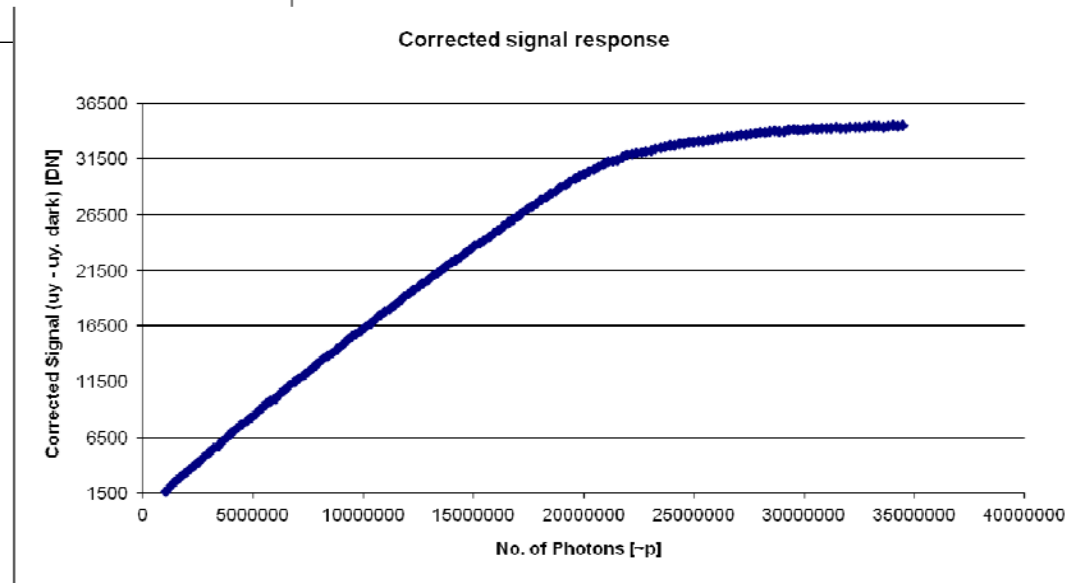
- Triple majority voting (TMV) system for single event upset immunity
- TMV used for programming and readout shift registers, except in shift register controlling the analogue readout
- Enclosed geometry layout for total dose tolerance (entire chip)

Results. CDS



- Photon Transfer Curve method, measured through analogue test output
- Gain = 59.9 $\mu\text{V} / \text{e}^-$ (exp. 51.2)
- Noise = 16.8 e^- rms (exp. 13.5)
- C_{in} = 2.1 fF (exp 2.3)
- Full well = 14,600 e^-
- Full well (lin) = 6600 e^-

- Expected performance on data path
- Gain = 40.3 $\mu\text{V} / \text{e}^-$
- Noise = 13.9 e^- rms
- S/N (m.i.p.) = 69





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- CMOS image sensors provide new solutions to radiation detection
- 16 Mpixel sensor for TEM already in the market (Falcon camera, by FEI)
- High radiation tolerance
- Highly Miniaturised Radiation Monitor (HMRM) based around a CMOS image sensor now in development
- 1st iteration 90% functional
- Measured noise = 16.8 e- rms →
S/N (m.i.p.) = 69
- HMRM instrument about to be tested with sources
- 2nd iteration on its way with reduced power consumption and improved cross-talk and reliability





Questions?

www.dsc.stfc.ac.uk/cmossensors
