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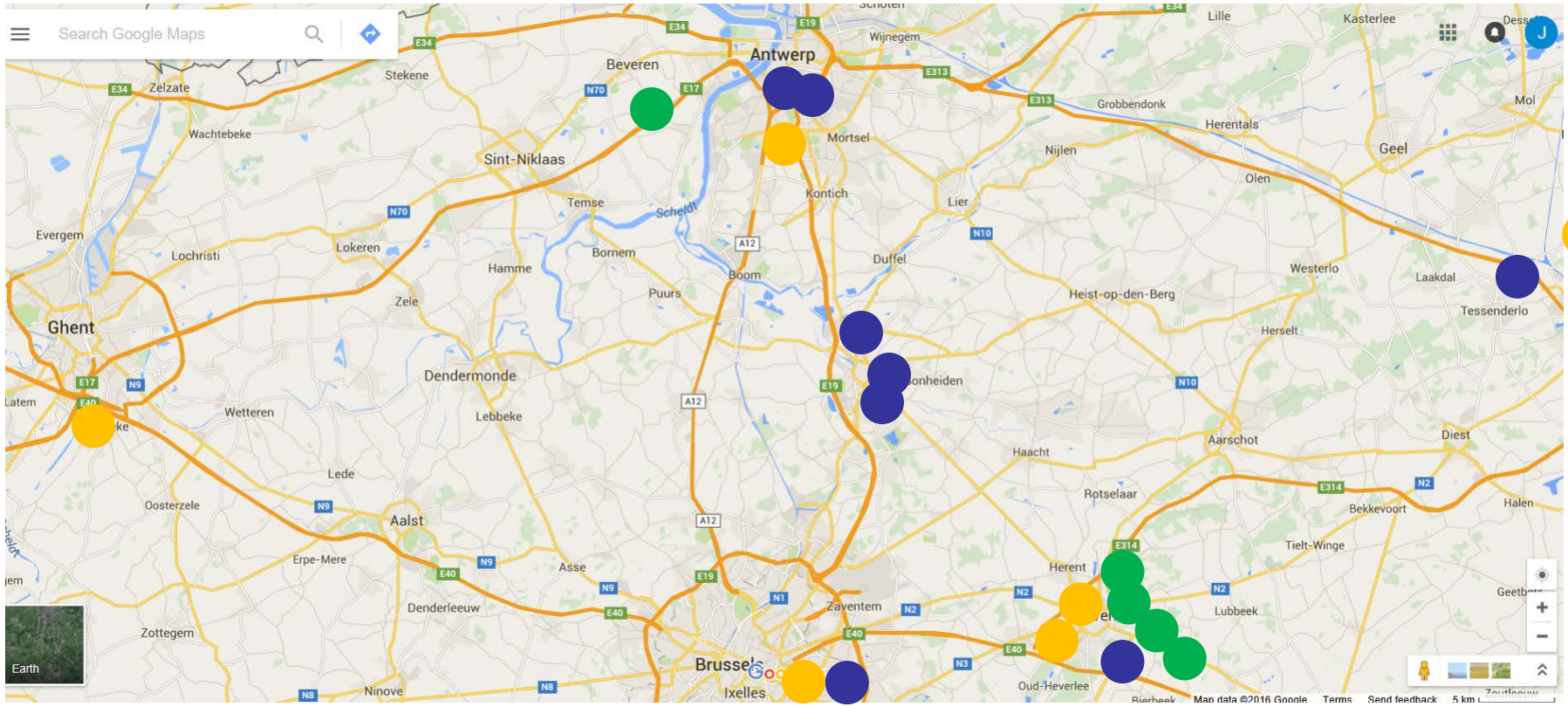
The European Low Flux Image Sensor (ELFIS)

Bart Dierickx, Ajit Kalgi, Alexander Klekachev, **Jan Vermeiren**

Outline

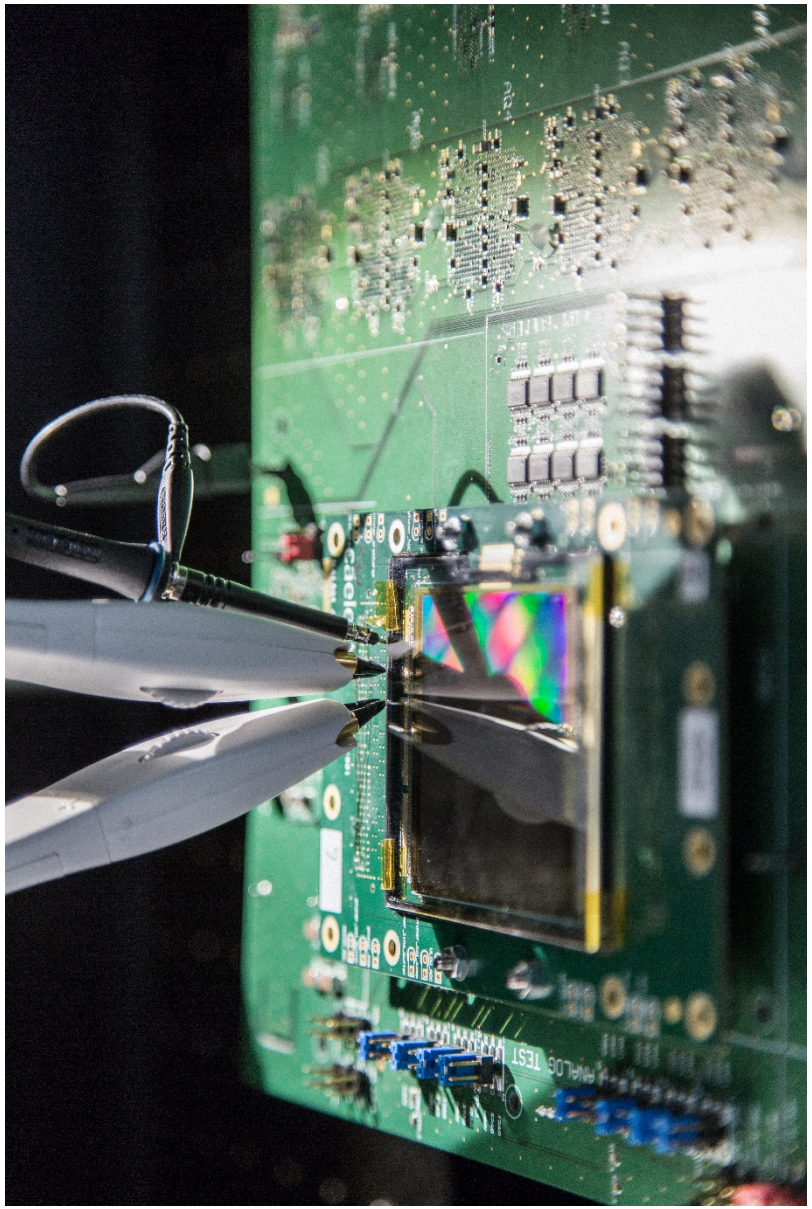
1. Short company introduction
2. ELFIS Key features
3. High Dynamic Range (HDR) images
4. HDR movie
5. HDR + Global Shutter operation
6. Conclusions

Image sensor landscape



- R&D center imaging
- Image sensor design & manufacture
- Image application

Caeleste's Mission



Be the supplier

of

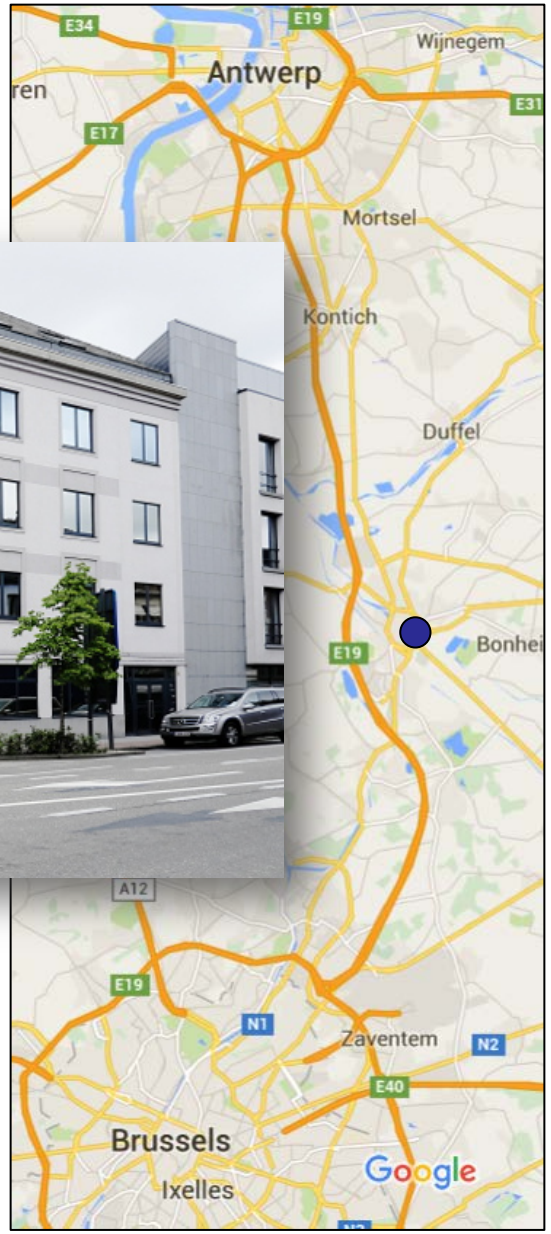
beyond state-of-the-art

custom-designed

CMOS image sensors

Who we are

- **Address**
  - Hendrik Consciencestraat 1b, 2800 Mechelen, Belgium
- **Representation**
  - Europe
    - D + A + CH: EURECA Messtechnik GmbH
    - UK + Ireland: Alrad
    - F + E + I: ATD
    - Russia: NPK Photonica, St. Petersburg
    - Israël: Kedem Technologies
  - America
    - USA: RA Paramount LLC
  - Asia
    - China: Luster Lighttech
    - India: ATOS – Instruments marketing Services
    - Japan: Kiyoshi Tabata
    - Korea: SOLTRON, Seoul



Business focus

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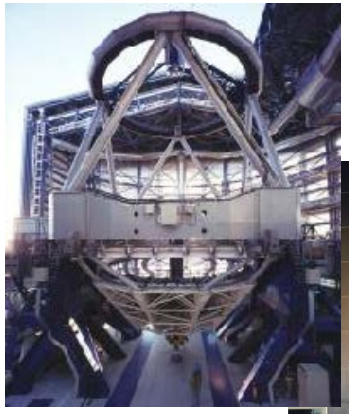
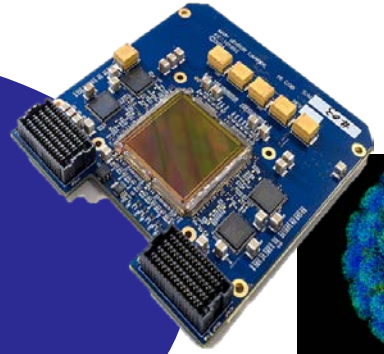
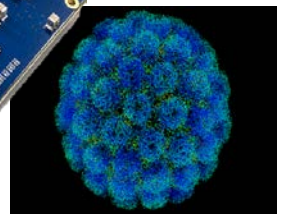
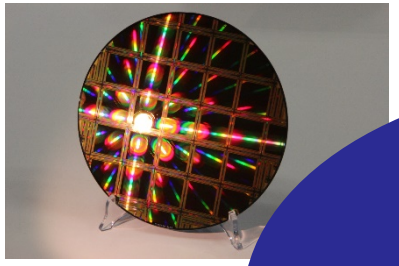


Scientific & Space

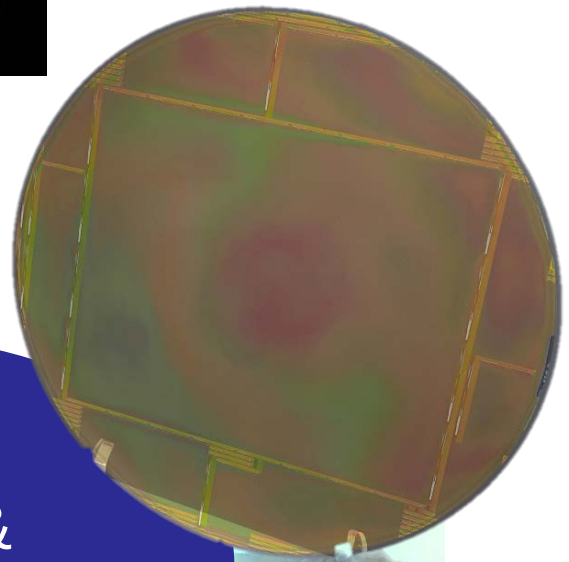




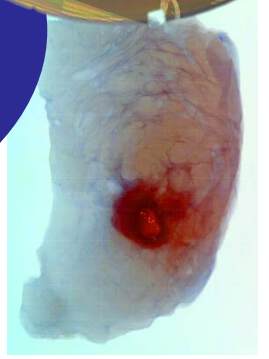
Caeleste's custom-designed differentiation

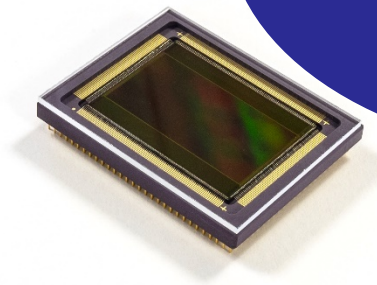


Industrial & Professional Imaging



Medical & Life Science

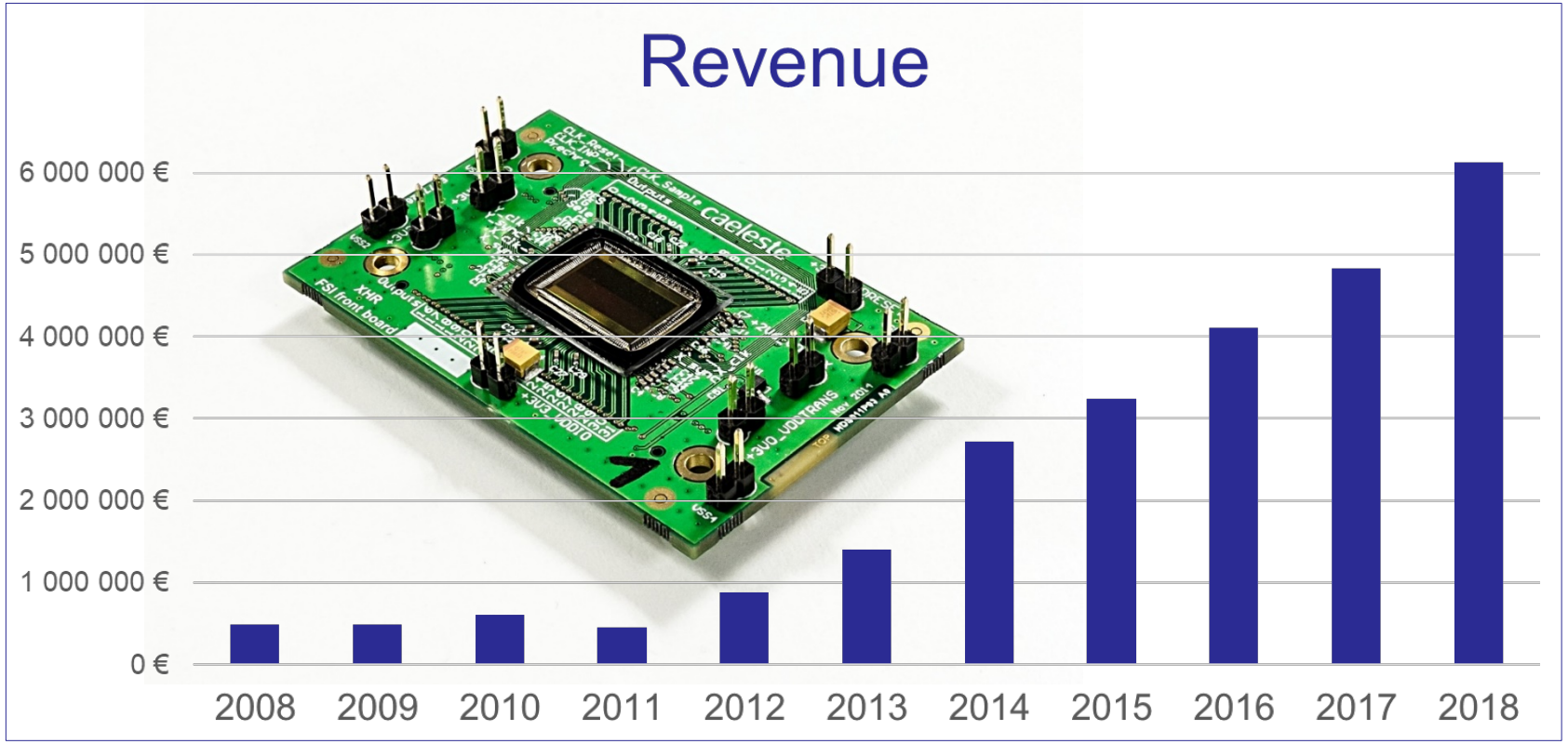




Military

Growing the Business

- **From Consultant to full turn-key Supplier**



2016 Fastest Growing Hardware Company in our region

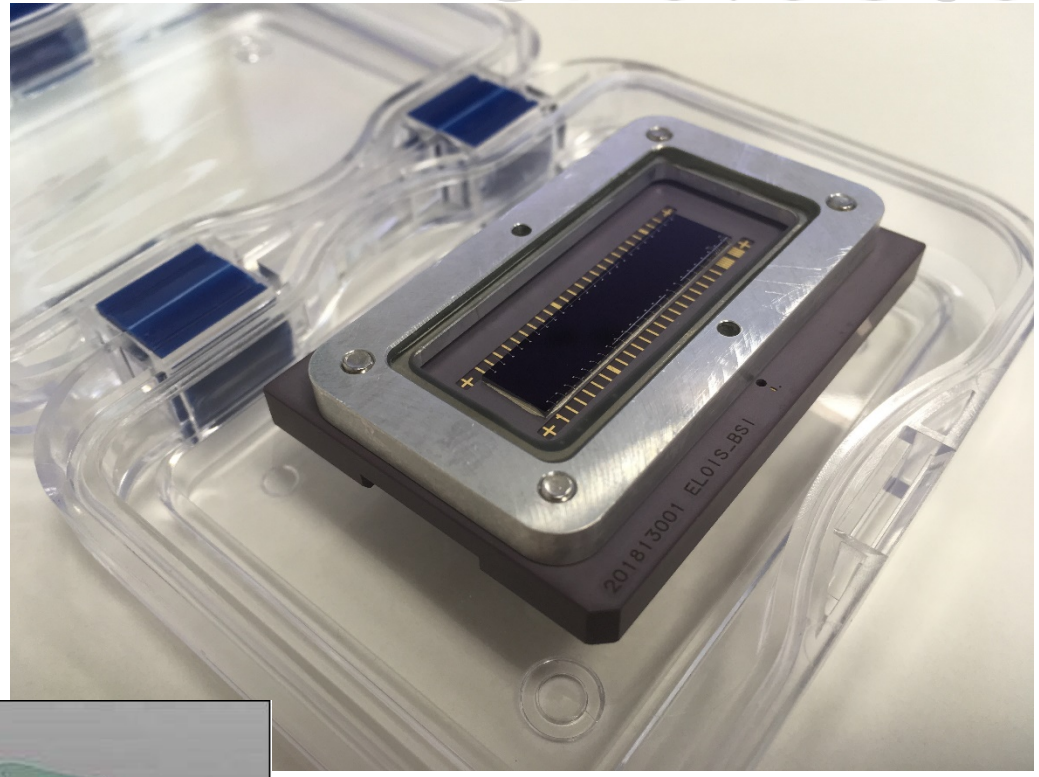
- **Company owned by founders/personnel, no external capital**
  - No exit scenarios; long term view and continuity
  - Allows strong focus on company's DNA: custom, high-end imaging

2.
ELFIS - Key features

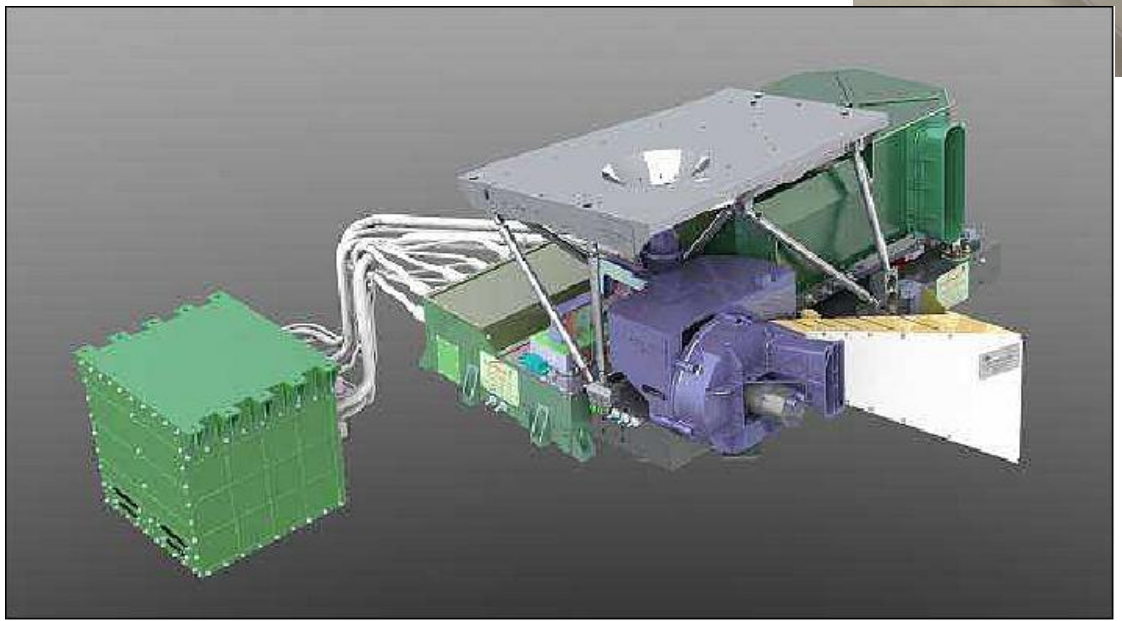
A sensor (system)

Satellite as a sensor

Instrument as a sensor



Integrated sensor



Introduction

- The image sensor – together with the optics - are the key elements of a remote sensing instrument.
- What you loose in noise or resolution, you never gain back

Original

Low resolution

High Noise

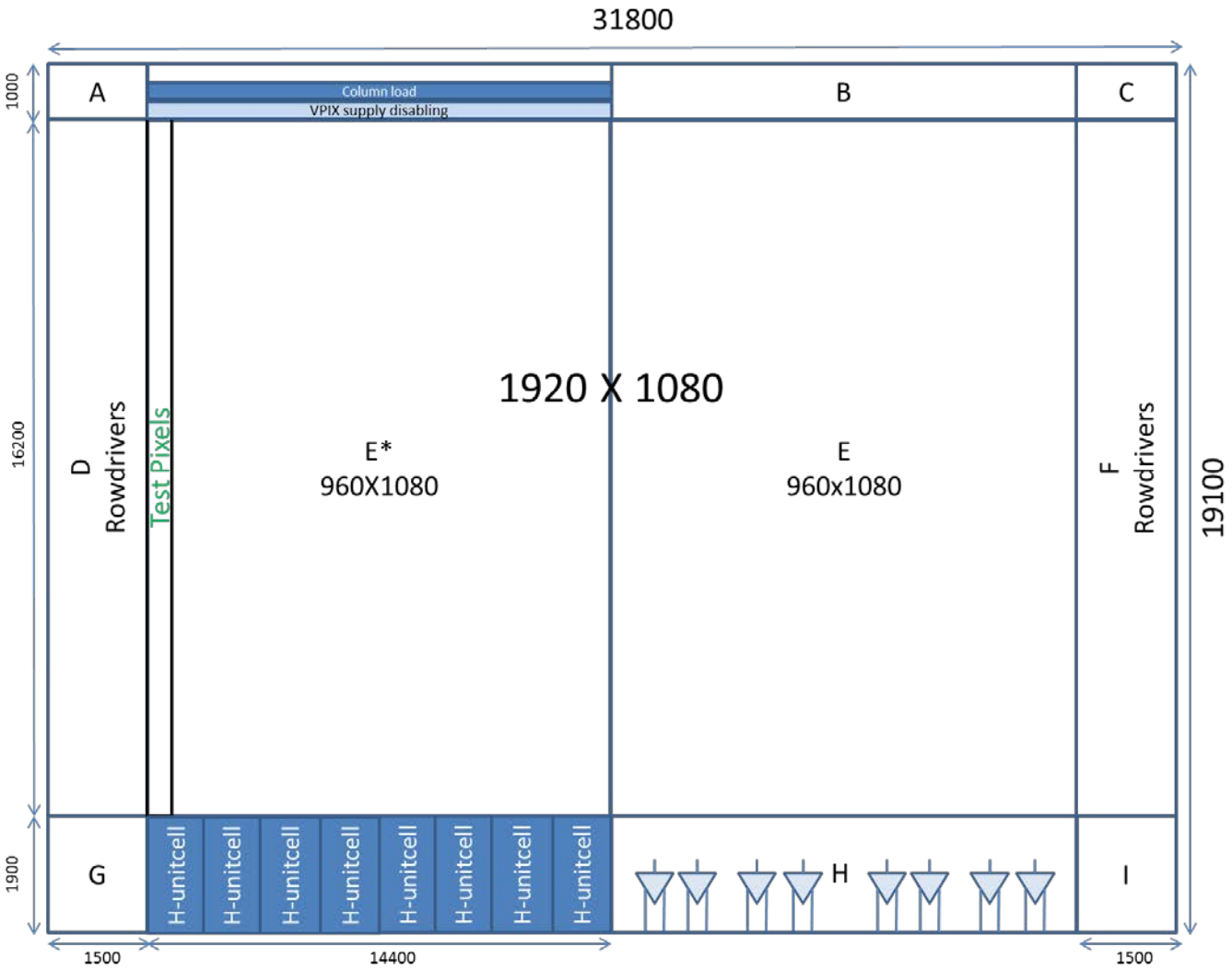
Justification

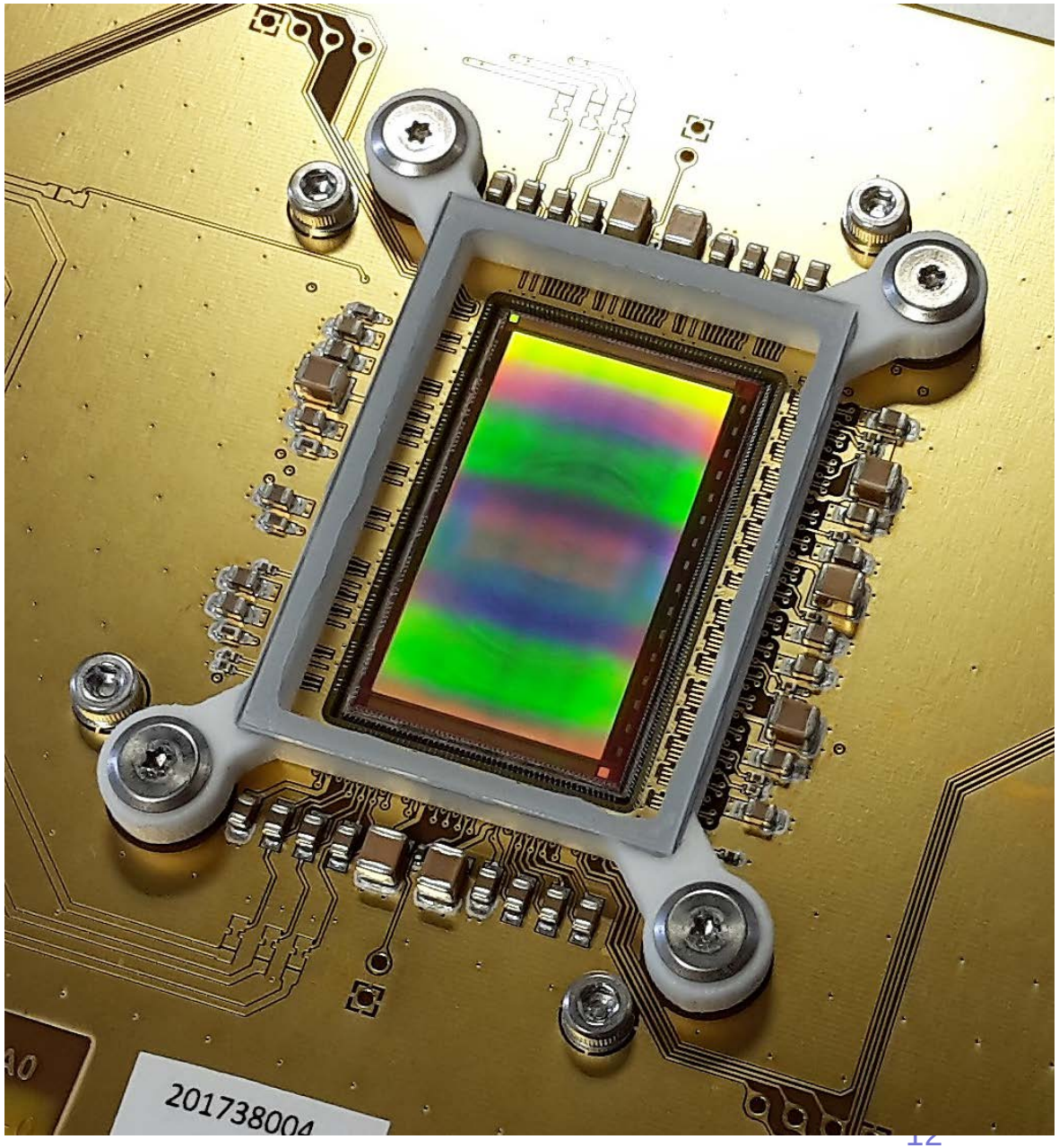
The ELFIS imager is the **first image sensor ever** combining following features

1. True HDR or “MAF HDR” (Motion Artifact Free High Dynamic Range)
2. IWR Global shutter using GS CMOS technology, which
   ⇒Allows low noise readout by the use of on-chip CDS (correlated double sampling)
   ⇒Enabling Global Shutter without dark current penalty
3. BSI (Backside illumination) realizing near 100% QE (quantum efficiency) x FF (fill factor)
4. TID (total ionizing dose) radiation hard design

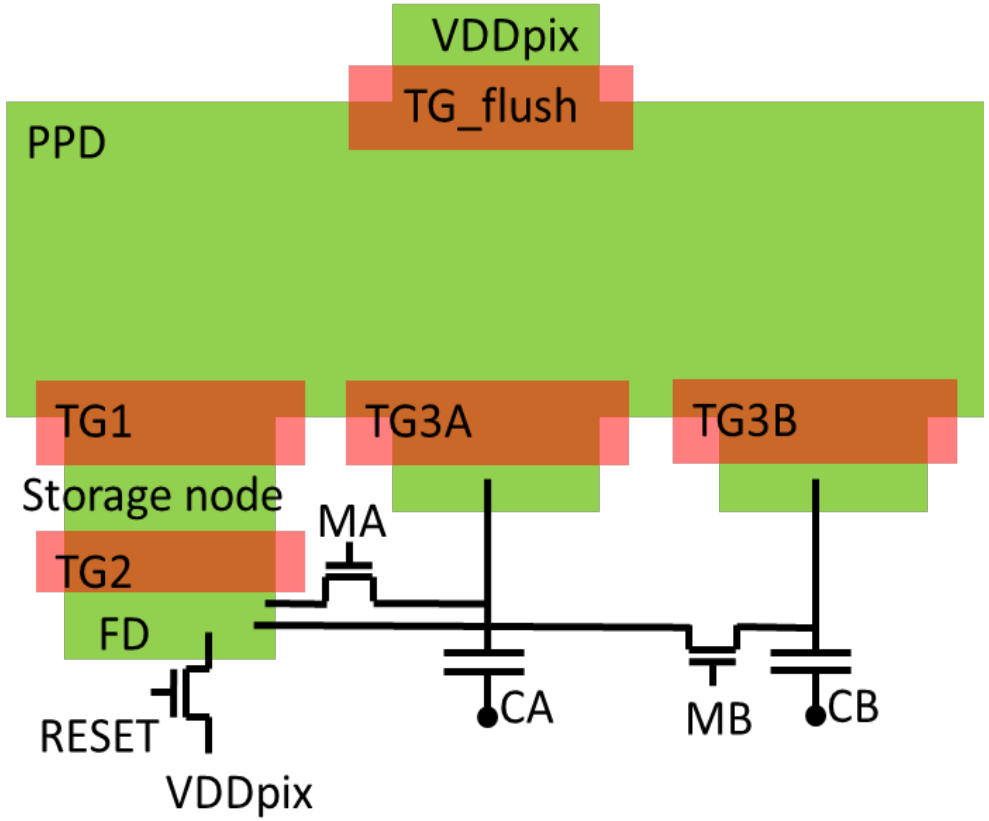
It is developed under ESA contract 4000116089 “European Low Flux Image Sensor”, in collaboration with LFoundry (It) and Airbus (Fr)

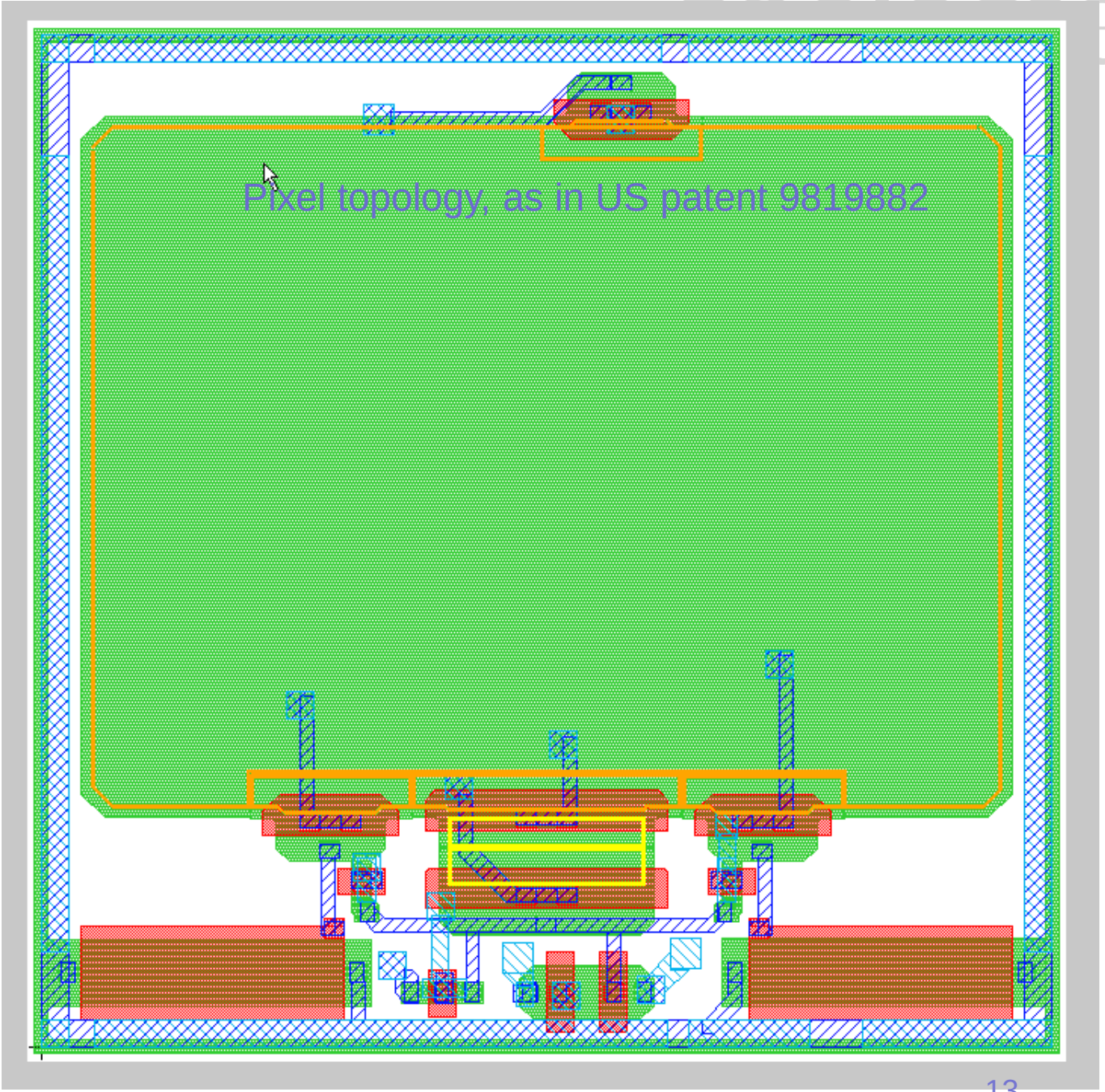
ELFIS Architecture





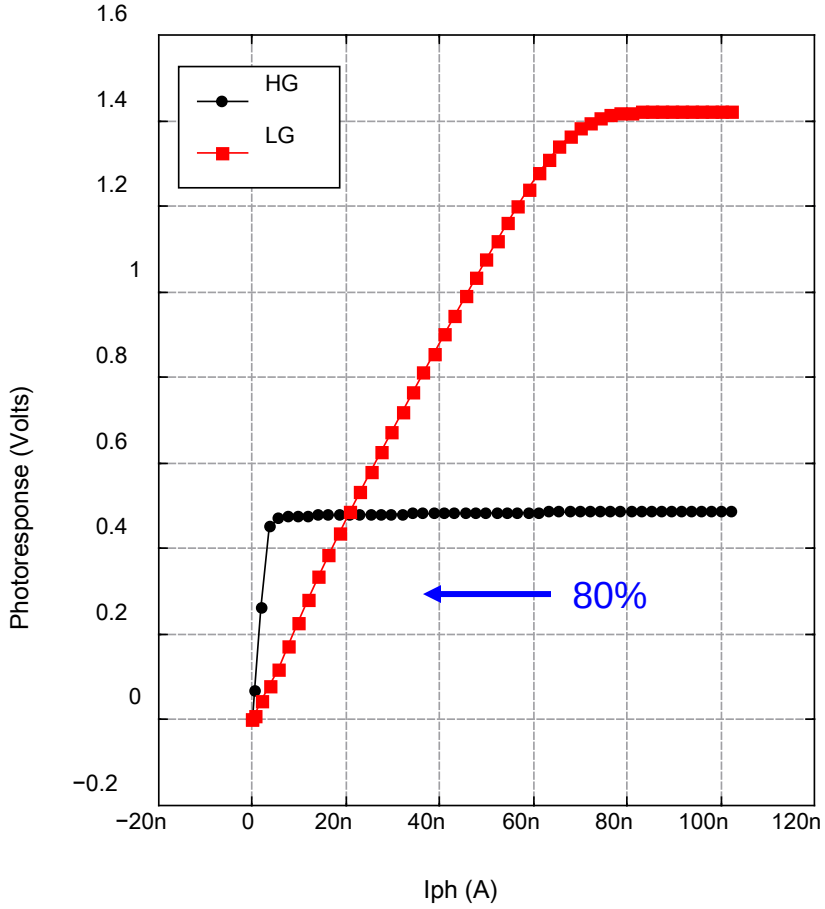
ELFIS pixel


VDDpix
TG_flush
PPD
TG1
TG3A
TG3B
Storage node
MA
TG2
FD
RESET
VDDpix
CA
MB
CB

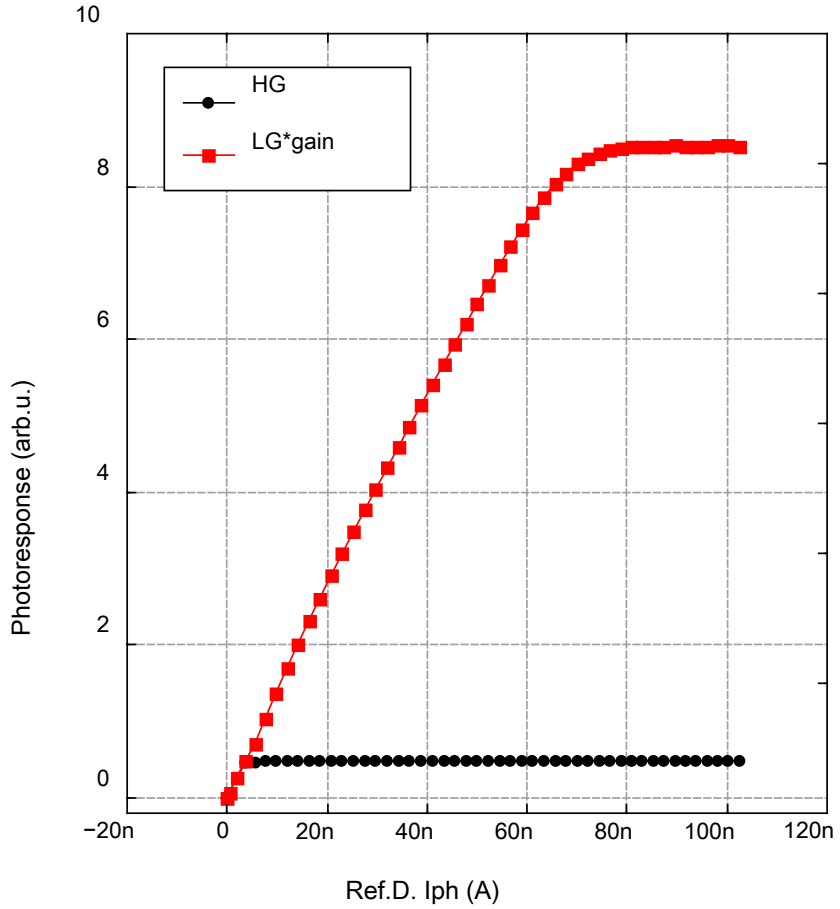

Pixel topology, as in US patent 9819882

ELFIS photo response of HG and LG signals

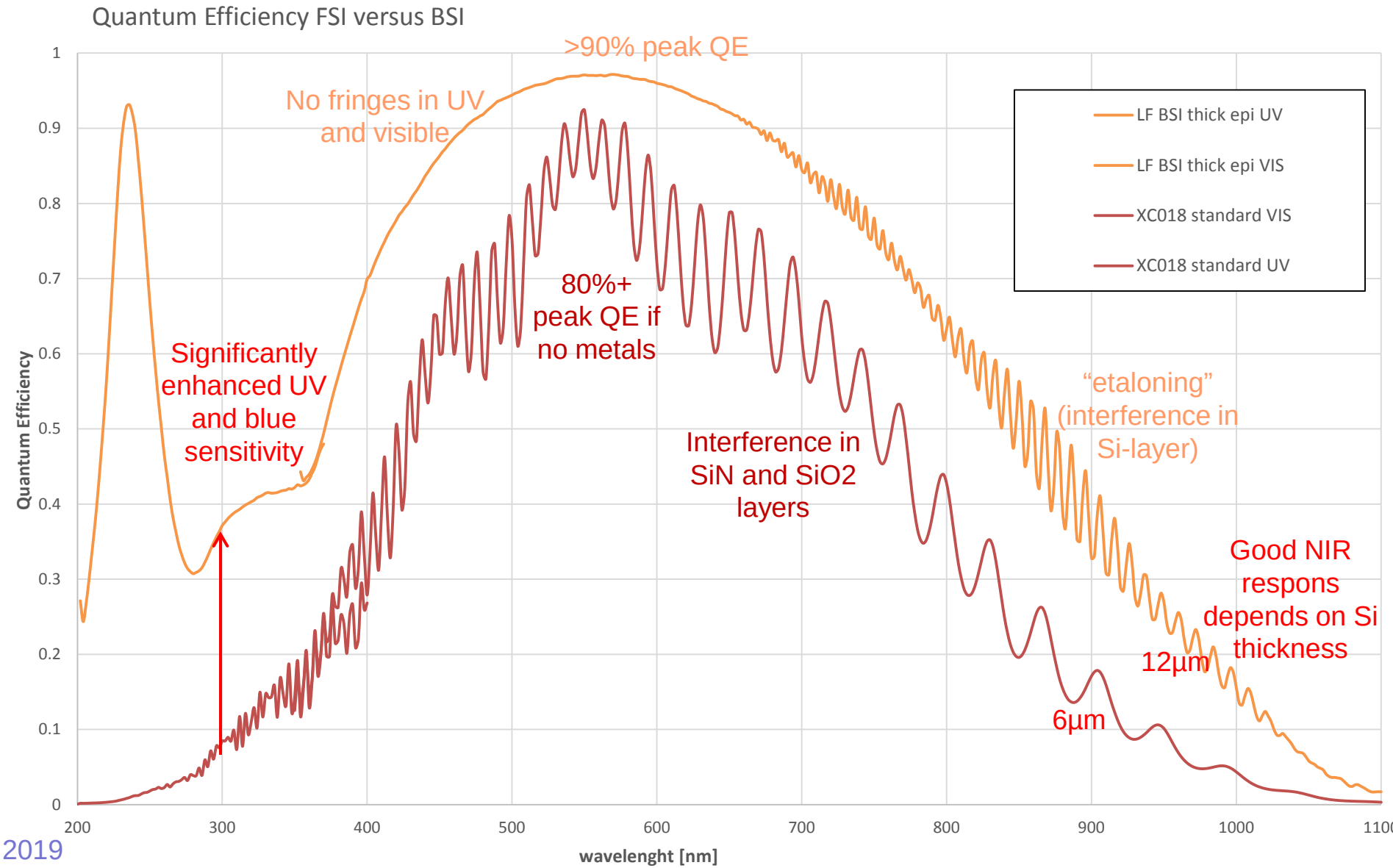
Raw data of both signal ranges



After applying a gain factor on the LG data



BSI versus FSI: QE



Key specifications measured

Geometry

- ✓ 15µm pixel pitch
- ✓ 1920x1024 pixels
- ✓ 16 parallel differential output channels
- ✓ BSI
- ✓ Stitching compatible design

Electrical performance

- ✓ 40MHz pixel rate per output channel
- ✓ 500mW at max speed

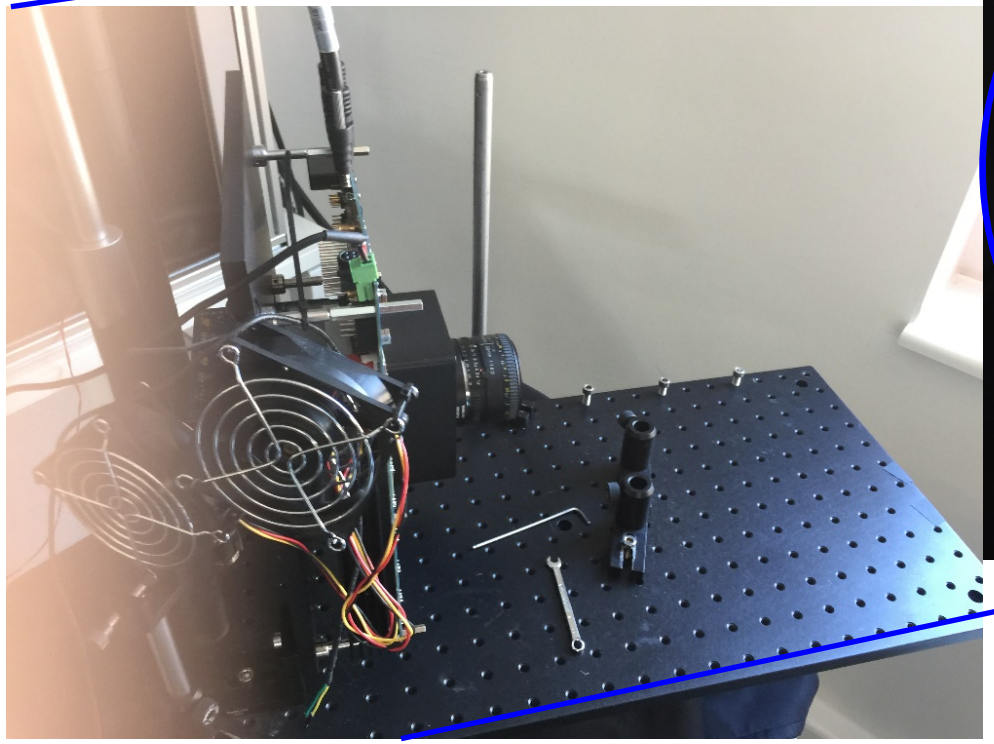
Electro-optical

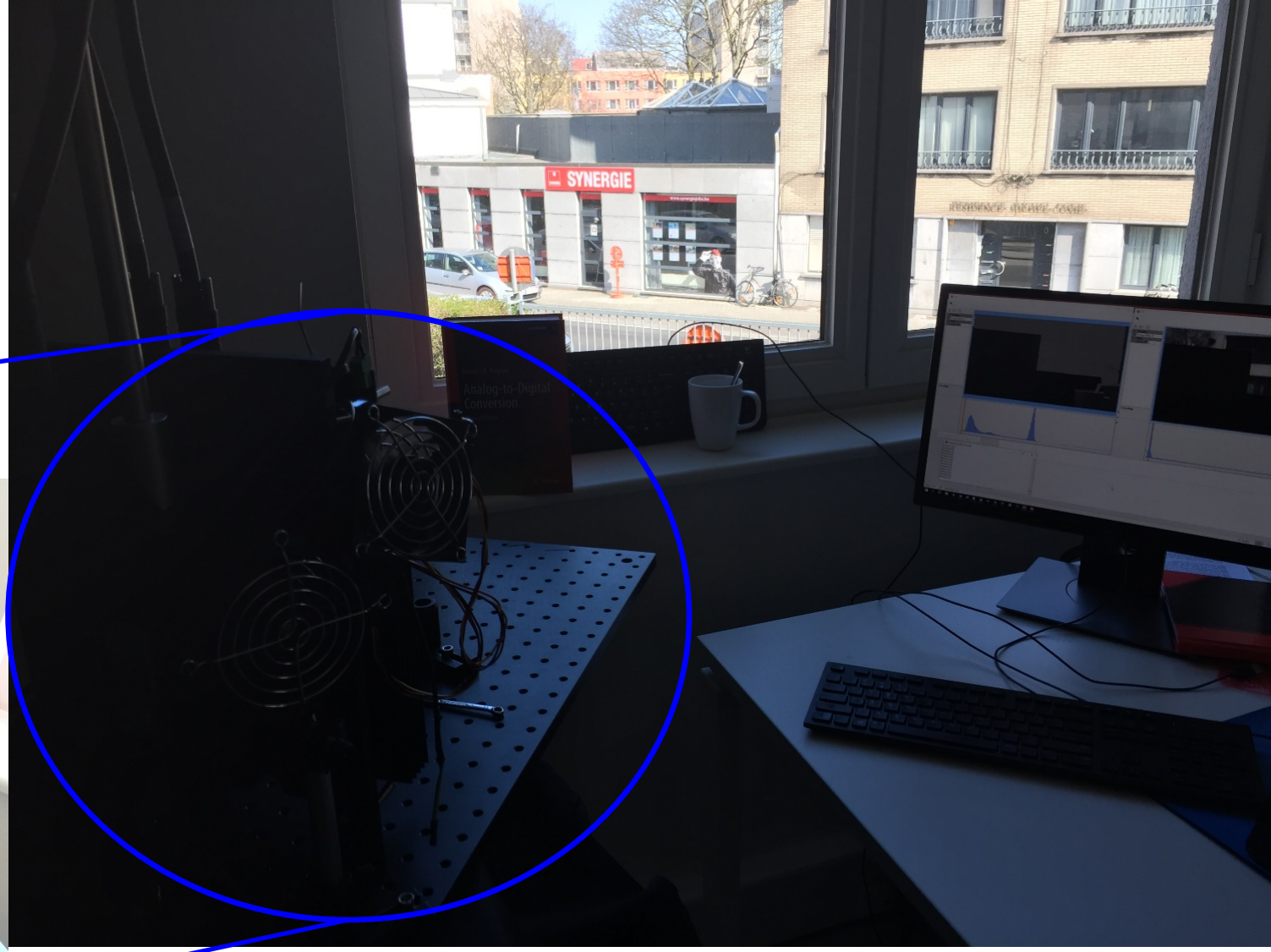
- ✓ Q_{FW} 6000e^- and 160 000e^- in IWR;
  6000e^- and 320 000e^- in ITR
- ✓ Q_{noise} 6.5e_{RMS} in nominal operation
- ✓ Peak QE > 90%
- ✓ MTF >60% for thin layer BSI
- ✓ PLS >200:1 for thin layer BSI, >500:1 for thick epi
- ✓ I_{dark} @RT:
  - ✓ PPD:60e/s
  - ✓ SN:80e/s
  - ✓ FD=140e/s

3.
HDR images

Setup

All images are taken in IWR (global shutter “integrate while read”), with $t_{frame} = t_{int} = 30ms$.



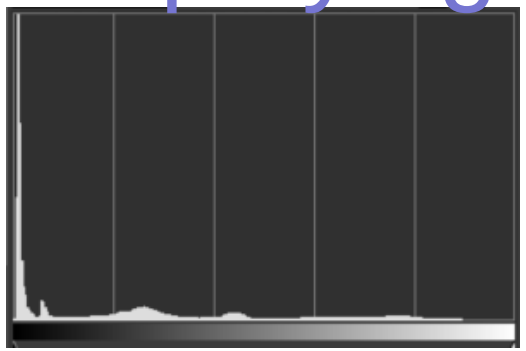


Processing the LG and HG (sub-)frames into a HDR frame

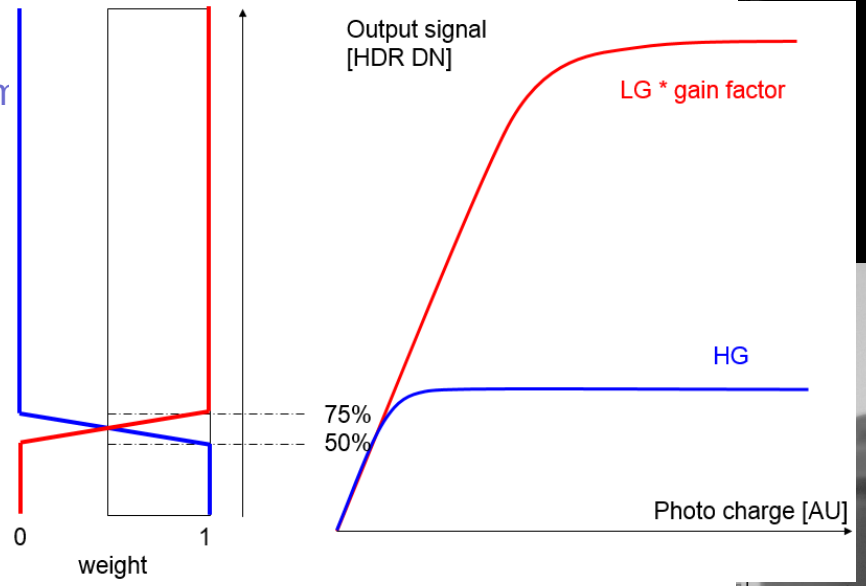
High gain (HG) sub-frame

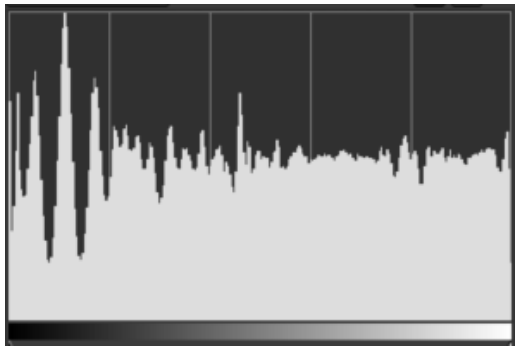
Low gain (LG) sub-frame

Displaying the HDR frame



The “raw” HDR frame histogram





The “equalized” histogram

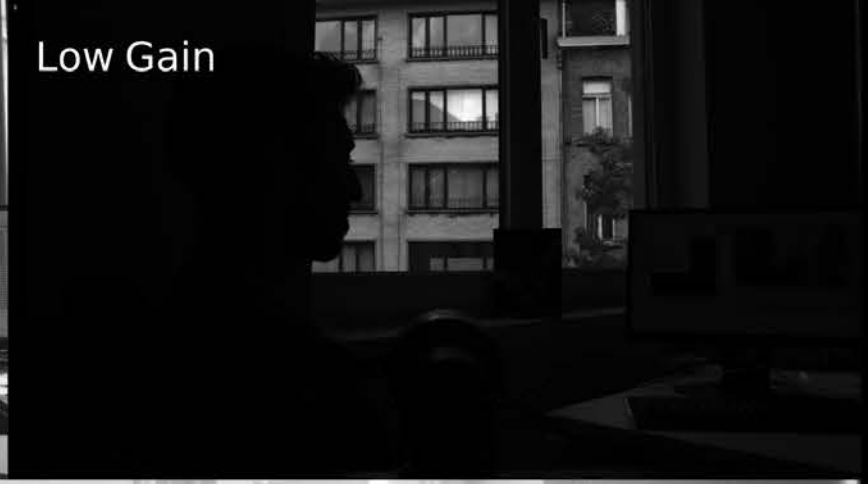
4.

HDR movie

See also https://www.youtube.com/watch?v=_SUg1v9ZSjI

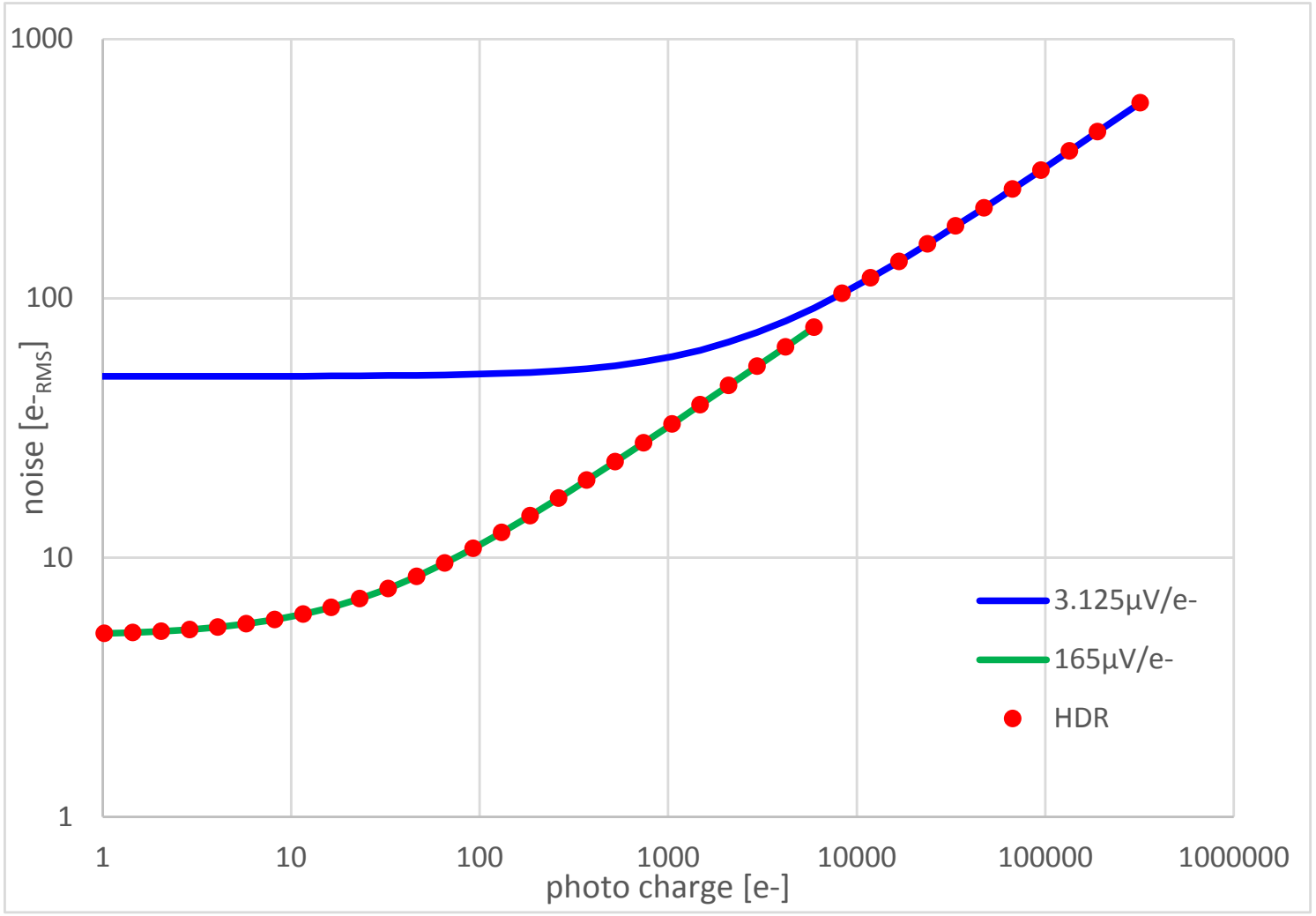
Conditions:

- ✓ IWR $t_{frame}=t_{int}$ = 30ms thus f_{frame}=33Hz
- ✓ Looking through the window to sunlit buildings
- ✓ Nikon 28mm lens, diaphragm set to 22
- ✓ On-chip CDS and dark frame subtraction
- ✓ **No** PRNU correction, no linearization was done. Two defect rows were corrected
- ✓ The HDR image is created by a weighted interpolation between the HG and the LG frames
- ✓ The image is “histogram equalized” for display



5.
HDR+GS pixel operation

HDR by combining two “normal” DR ranges



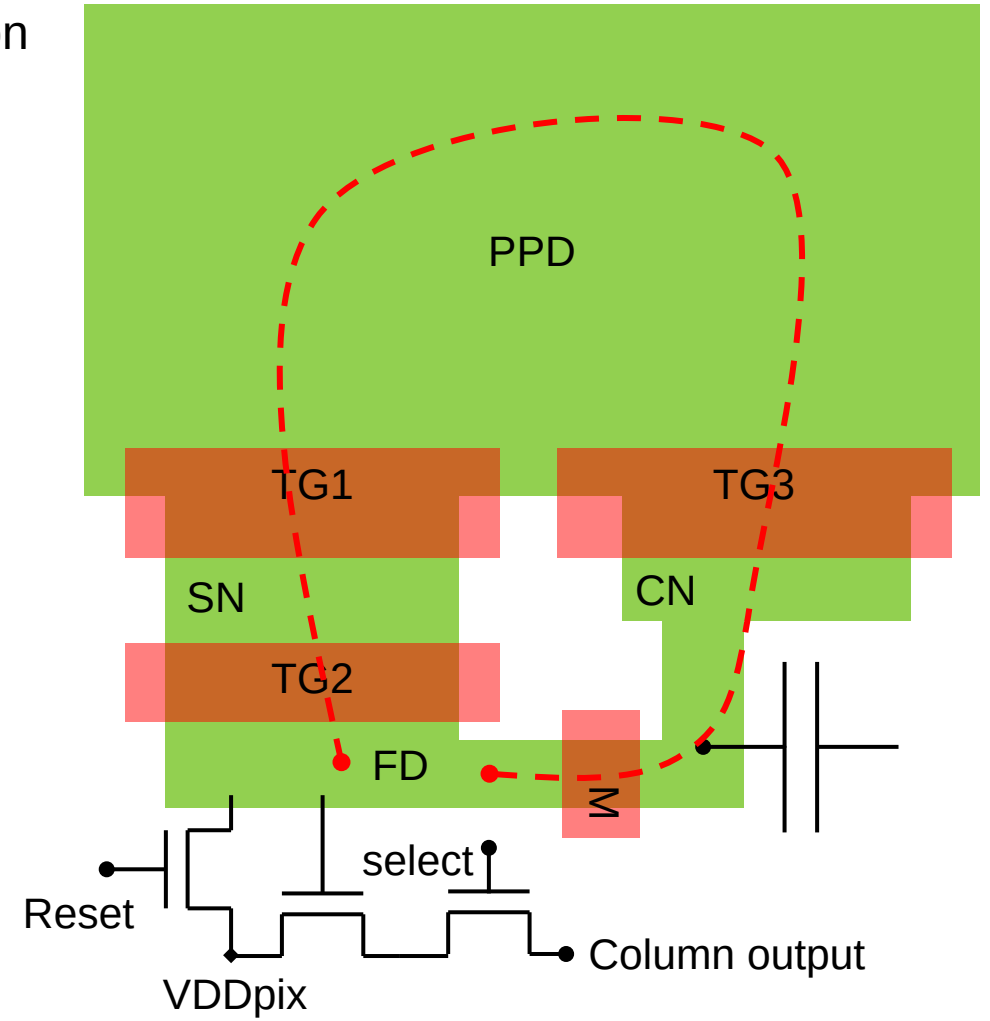
High Q_{FW} range:
DR=320000/50≈6400:1

Low Q_{FW} range:
DR=6000/5 ≈ 1200:1

Combination
DR=320000/5 ≈ 64000:1 or **96dB**

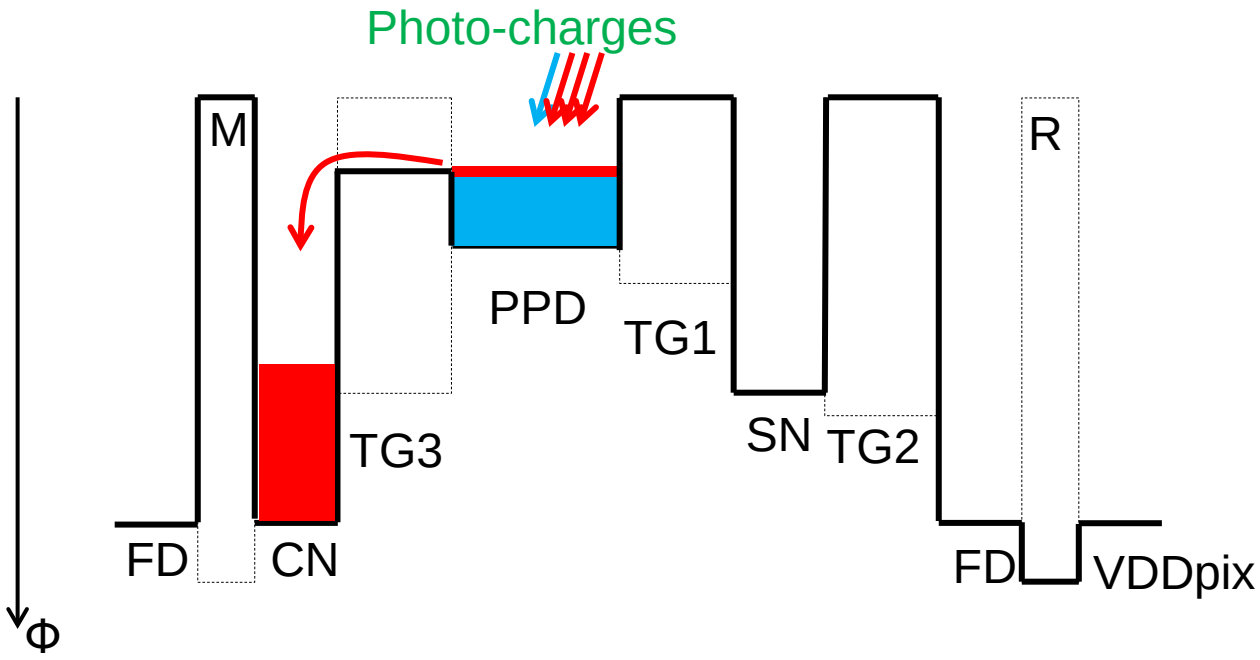
Operation of the ELFIS HDR+GS pixel, simplified

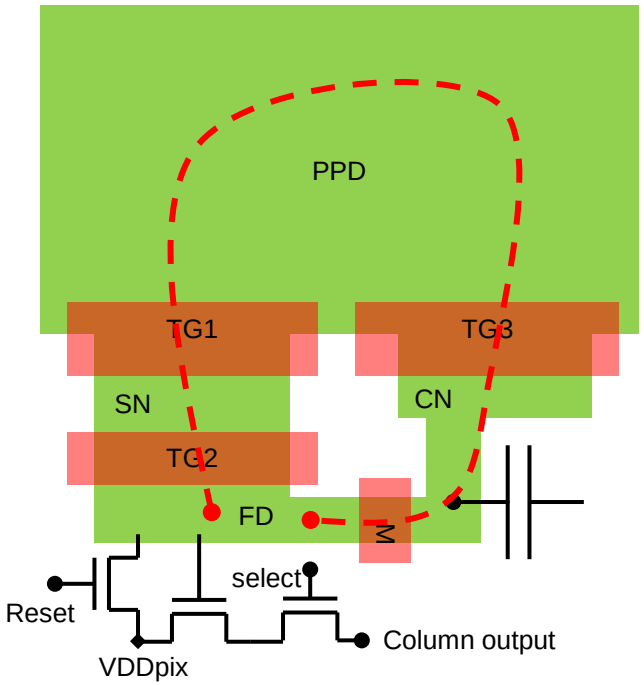
For the sake of clarity we explain the ELFIS pixel operation using a simplified version of its topology as shown at the right.
On the next slide we show a vertical cross section of this pixel along the red dashed line.
On the slides thereafter we show the potential diagram in the Silicon along the dashed red line, from FD to FD.



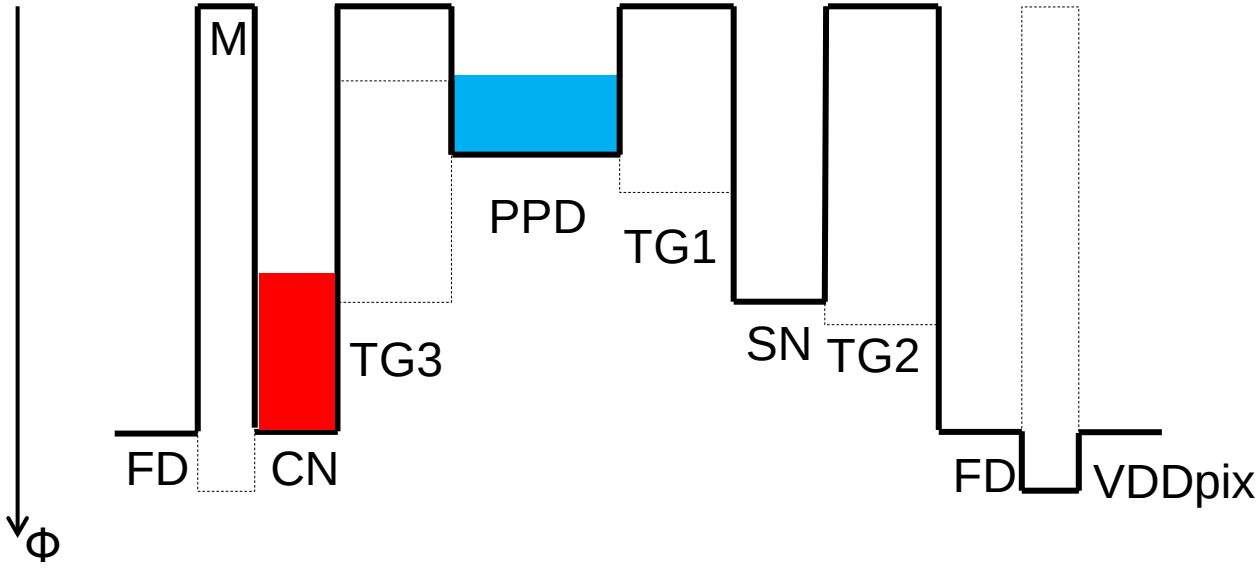
Abbreviations
PPD: pinned photodiode
SN: storage node
TG: transfer gate(s)
FD: floating diffusion
CN: capacitor node
M: merge transistor
VDDpix: pixel supply voltage

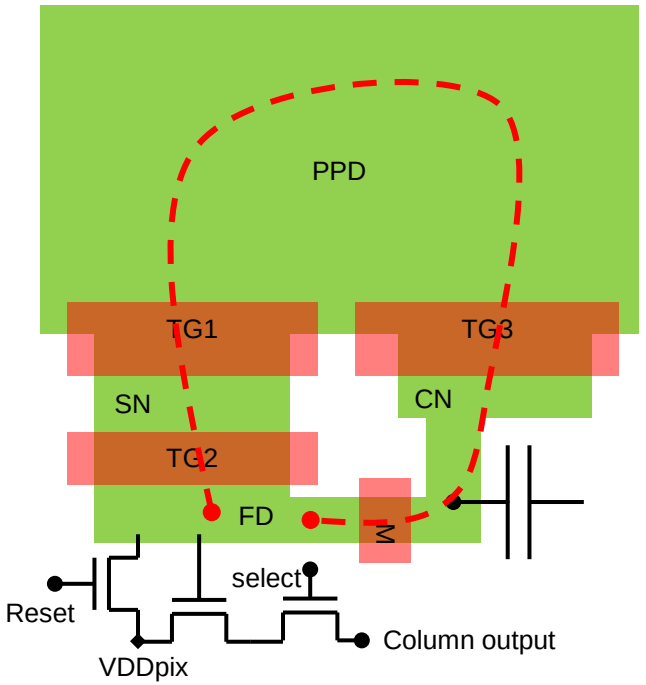
During integration photocharge is accumulated in the photodiode.
The TG3 gate voltage is set to the intermediate “overflow barrier” operation point.
When the photodiode is too full, charge overflows to the capacitor node
blue: charge fitting in the PPD
red: charge overflowing into the capacitor node.



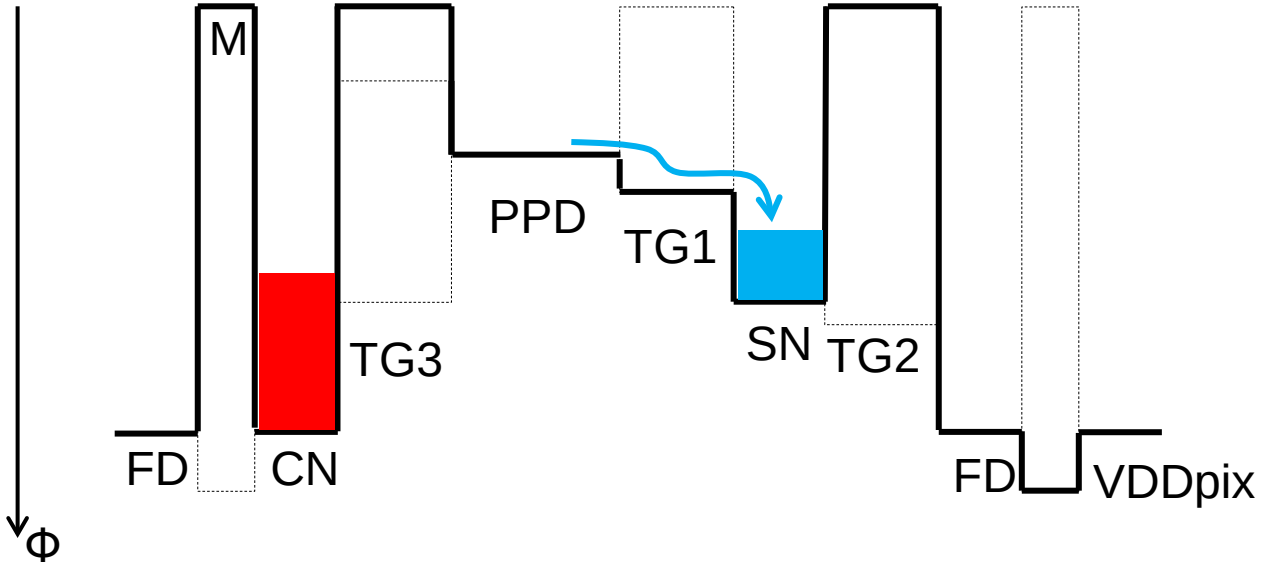


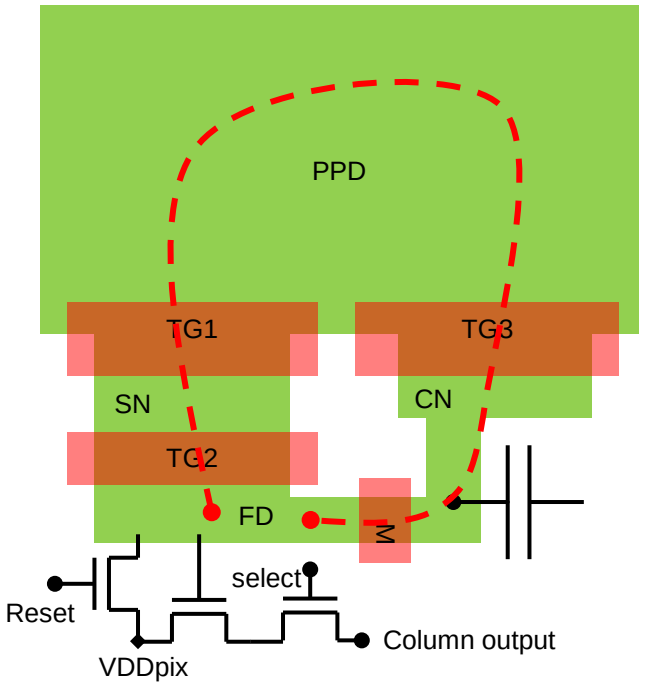
End of integration time:
1) stop overflow over TG3
2) transfer PPD (blue) charge to the SN using TG1



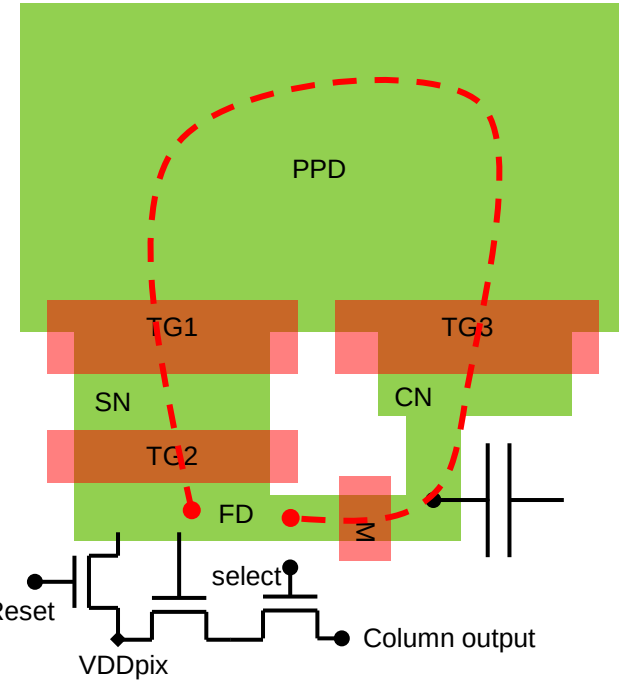


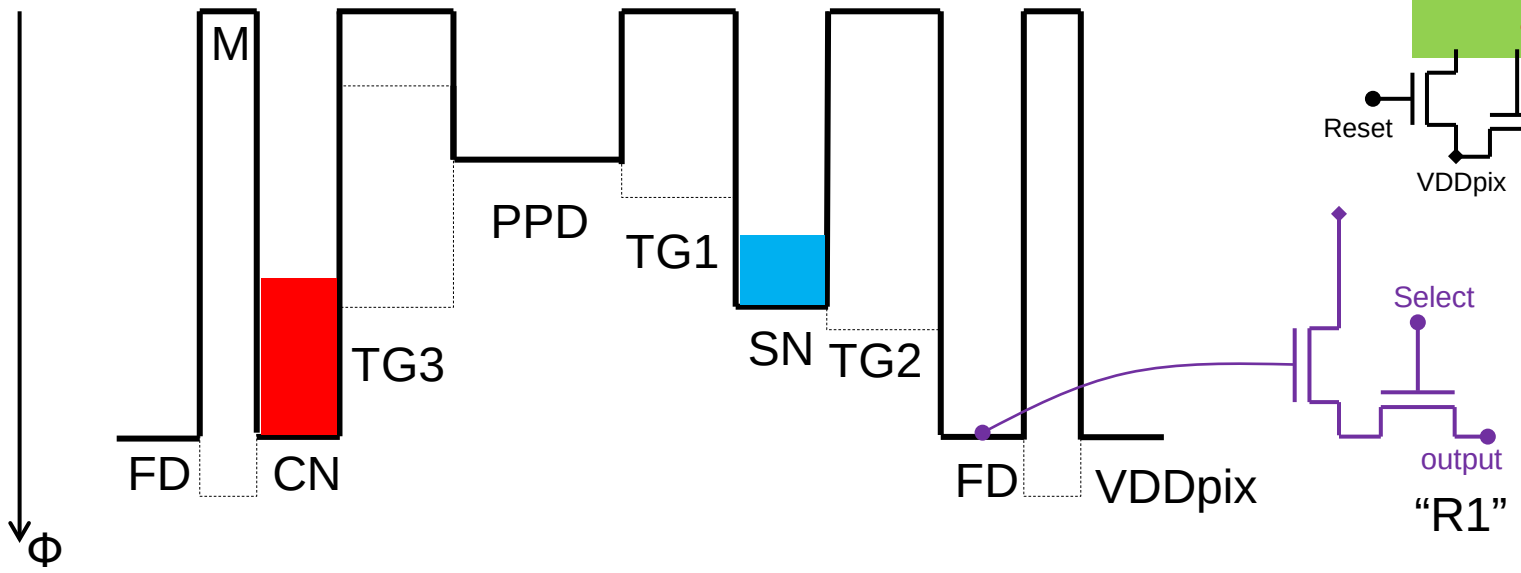
End of integration time:
1) stop overflow over TG3
2) transfer PPD (blue) charge to the SN using TG1



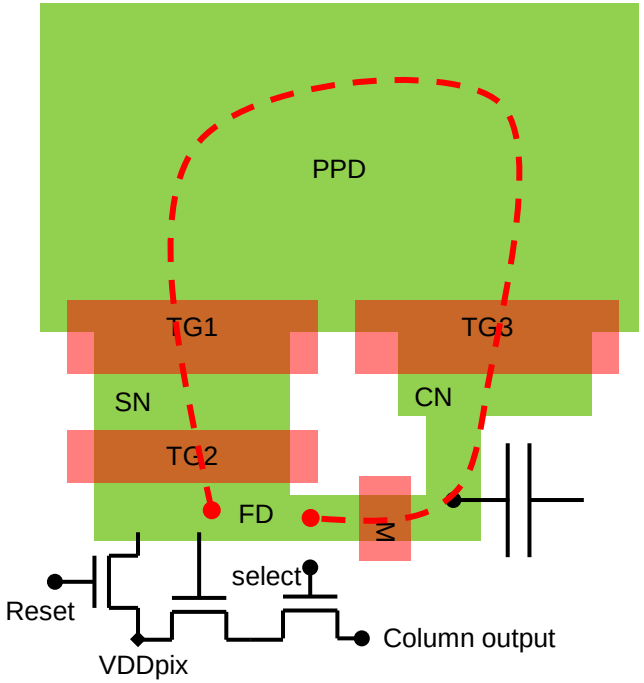


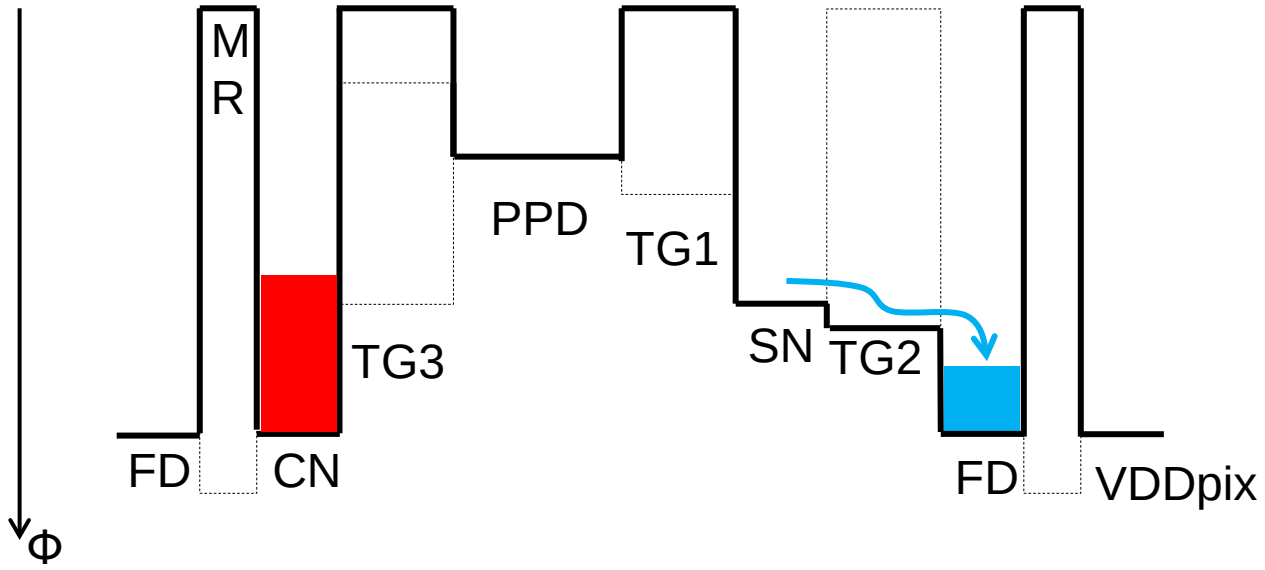
As the photocharge of the previous integration time is now in available in the SN and the CN, if can be read out. The readout of the imager happens row-by-row or in “rolling readout”. The select transistors of the rows to be read out are activated, the reset transistors are turned off, and then three voltage levels are put on the column bus: “R1”, “S1” and “S2”.
“R1” is reset level as present on the FD immediatedly after releasign the reset.



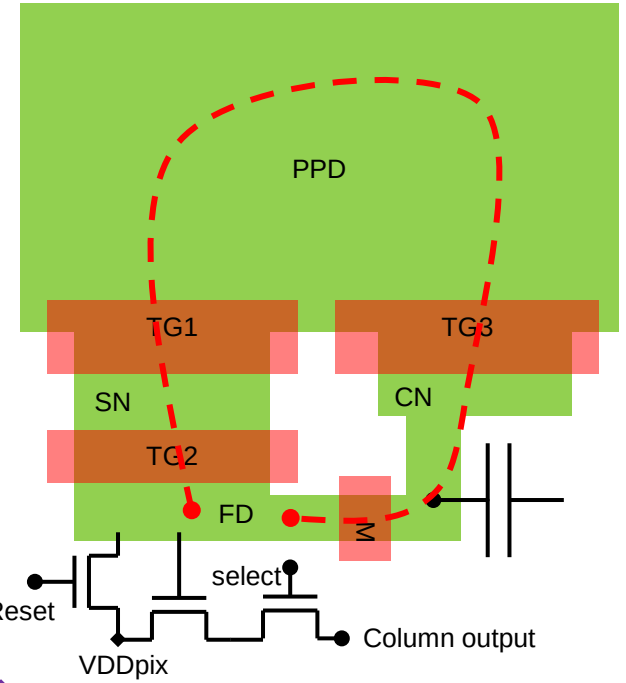


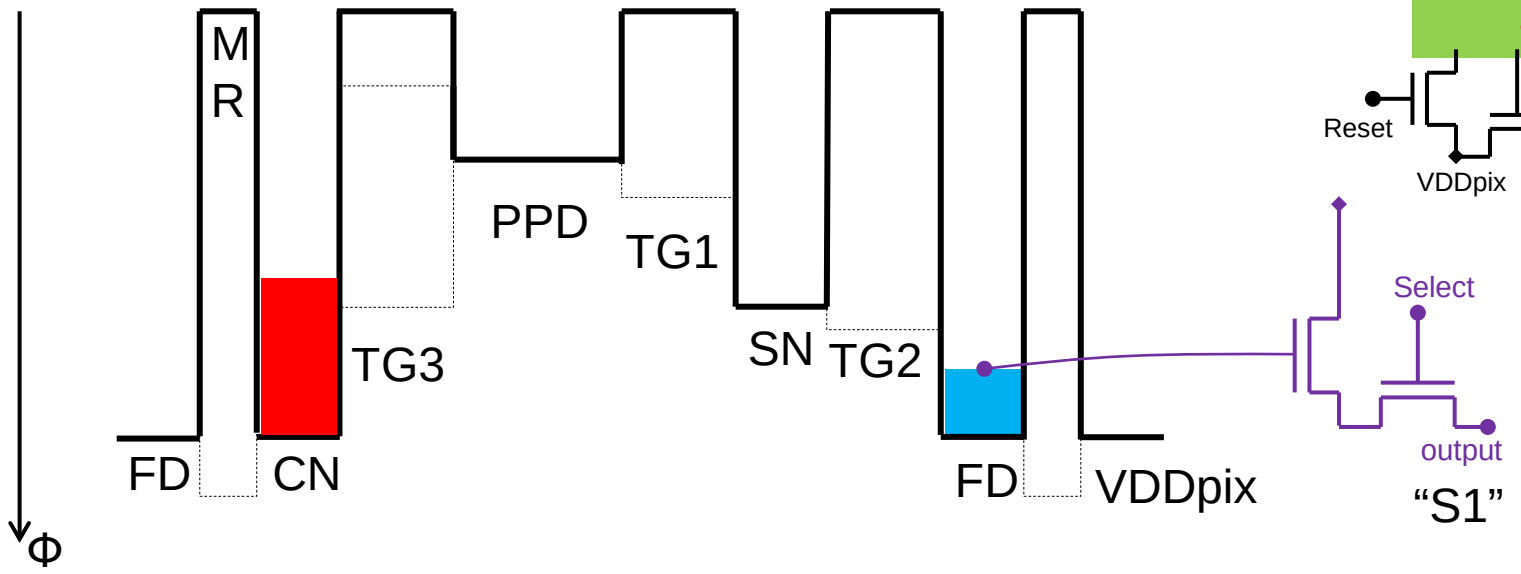
Then the gate TG2 toggled off-on-off, allowing the charge in the SN to transfer to the FD.
This is the “S1” signal level, representing the “blue” charge.



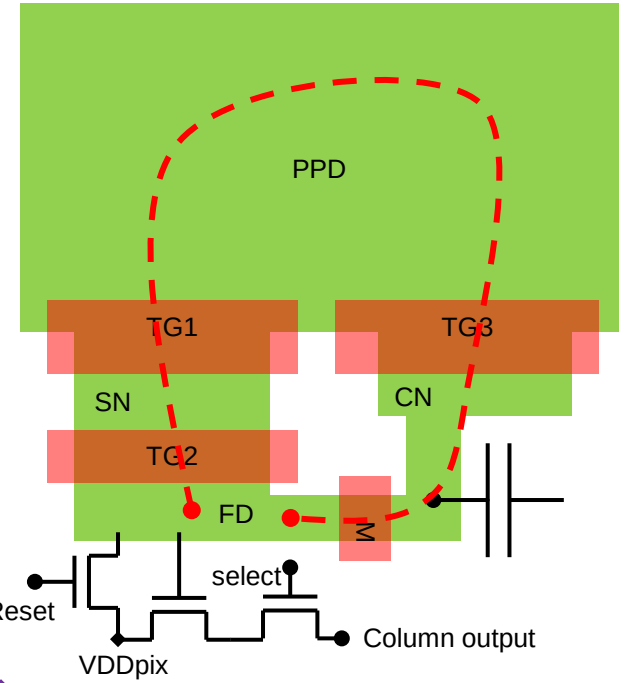


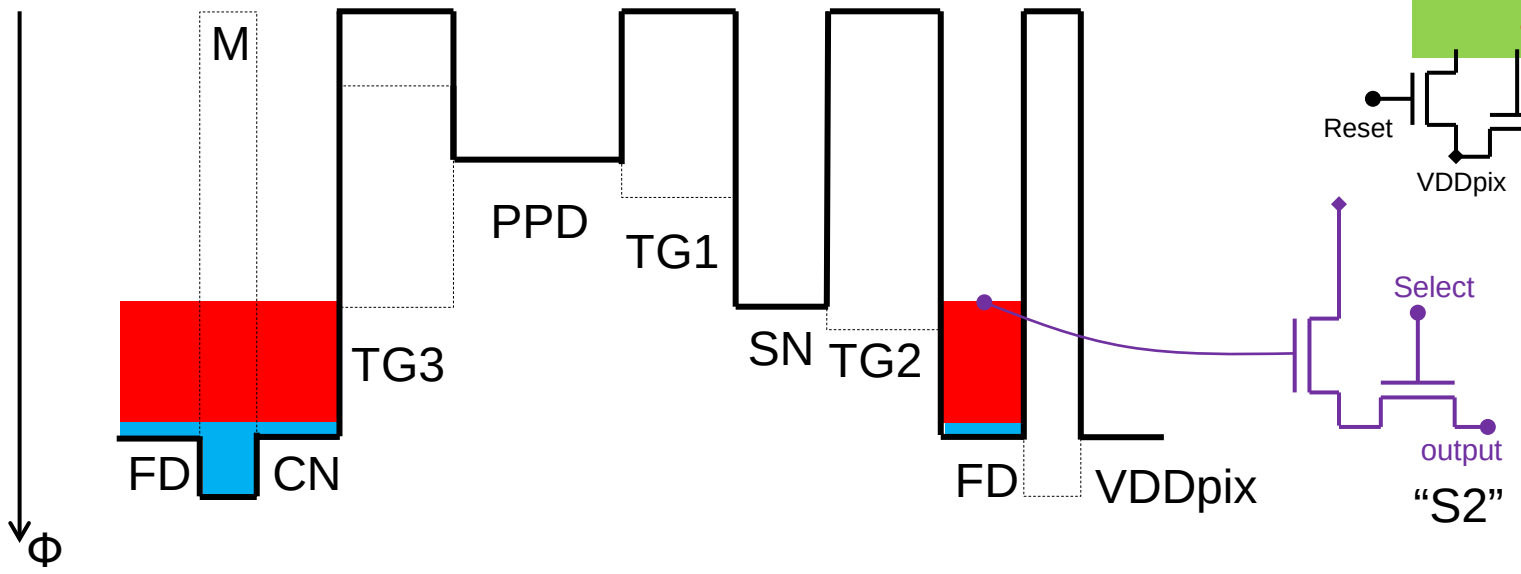
This is the “S1” signal level, representing the “blue” charge.
In the ELFIS imager, “R1” and “S1” are output as a combined differential signal (S1-R1) & (R1-S1). In this way we perform “CDS” (correlated double sampling), a technique that cancels the FD’s kTC noise and reduces the FPN (fixed pattern noise).





Then the Merge transistor is closed, shunting the FD and the CN. All photocharge, previously divided over the SN (blue) and the CN (red) is now reunited.
This signal is “S2”, being the LG or high Q_{FW} signal level. We do not apply CDS on S2; still S2 is readout differentially as (S2-ref)&(ref-S2).





6. Conclusions

Conclusions

- The operation of the ELFIS sensor is fully demonstrated
  - HDR operation
  - Global shutter operation
- Further optimizations:
  - Saturation of the storage node
  - Processing on thick epi layer
- Planned activities:
  - Radiation testing: TID and SEE

ESA contract 4000116089 “European Low Flux Image Sensor”, with LFoundry (It) and Airbus (Fr)

Questions ?