DESIGN OF A TRUE HDR, BACKSIDE ILLUMINATED IMAGE SENSOR WITH CHARGE DOMAIN BINNING

<u>DIERICKX B.</u>, KALGI A.K., SEZGIN B., OBLAN S., LIEKENS K., SALINAS I.,

CAELESTE (B)

Acknowledging the fruitful collaboration with the staffs of
ESA/ESTEC (NL)
LFoundry (IT)
AIRBUS Toulouse (FR)
Caeleste (B)

Context and achievements

Project is funded by ESA/ESTEC Contract 400011608916 “European low flux image sensor” (“ELFIS1”), continued in Contract 4000133295 “European low flux CIS development and optimization - Phase 2”

The ELFIS2 is the first image sensor combining

- ✓ Stitching up to wafer scale
- ✓ Charge domain global shutter
- ✓ “Motion artifact free” high dynamic range, beyond 100dB
- ✓ High QE by backside illumination
- ✓ Low noise by CDS
- ✓ TID and SEU/SEL hard
- ✓ Charge domain binning
- ✓ Backbias capable

Making it suitable for a wide range of space applications.

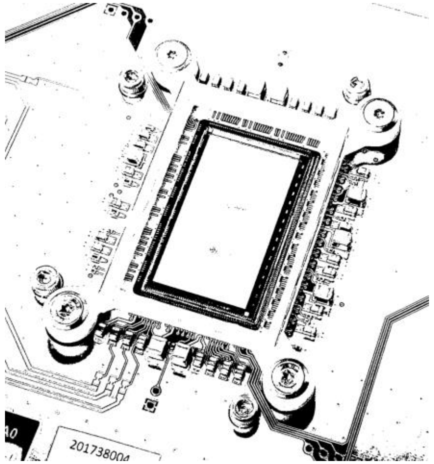
Outline

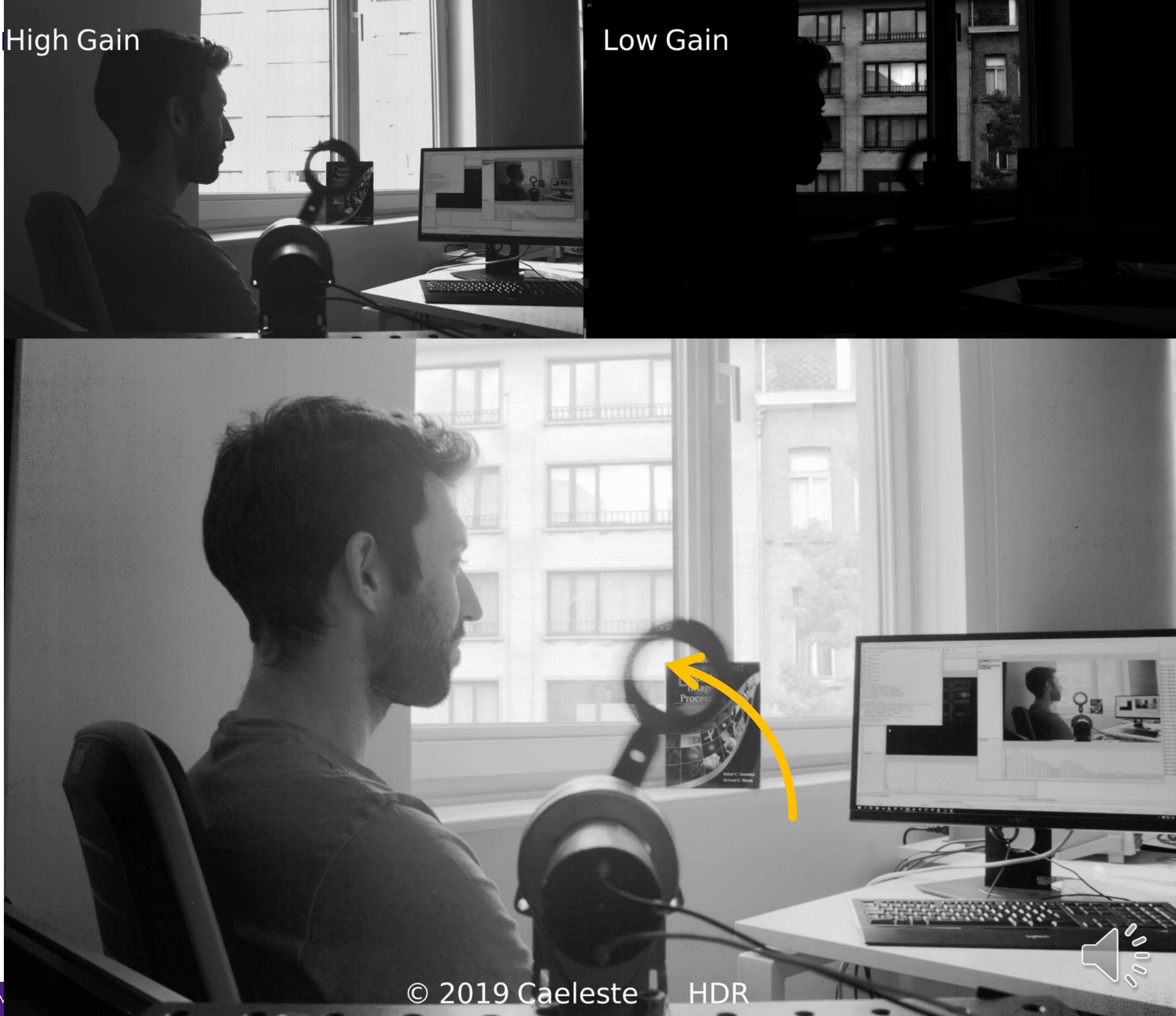
- ✓ Context and Achievements
- ✓ Short reference to the predecessor “ELFIS(1)”
- ✓ ELFIS2 Floorplan and stitching configuration
- ✓ ELFIS2 Pixel
- ✓ High dynamic range operation
- ✓ Charge domain binning method

ELFIS1 results

"Moving" HDR scene recorded with ELFIS1, reported in 2019.

In this frame from a video sequence, the rotating black ring "cuts through" the dark interior background as well as through the sunlit outside background. The motion blur is not affected by the local light intensity.





ELFIS2

ELFIS2 is the successor of ELFIS(1) and in many respects an improvement.

Status:

- Tape out: March 2021

Stitching configuration:

- 2k x 2k pixels

ELFIS2: Expected specifications

Array size	2048 x 2048 pixels
Pixel pitch	15 um
Illumination	Backside illumination (BSI) EPI thickness up to 22 µm
Shutter	Charge domain global shutter
Target read noise at nominal speed Target read noise in “low noise mode”	< 4e- in high gain mode < 2e- in high gain mode
(Linear) Full well charge (Q_{FW})	10ke- in high gain mode 160ke- in low gain mode, global shutter IWR 320ke- in low gain mode, global shutter ITR
Linear High Dynamic Range	92 dB in nominal mode, global shutter IWR 104dB in low noise mode, global shutter ITR
Pixel rate per channel	40 MHz pixel frequency
Number of output channels	16 Analog differential outputs per stitch block (8 per stitch block)
Frame rate	140 fps for 2k x 2k resolution, single pass

ELFIS2: expected specifications

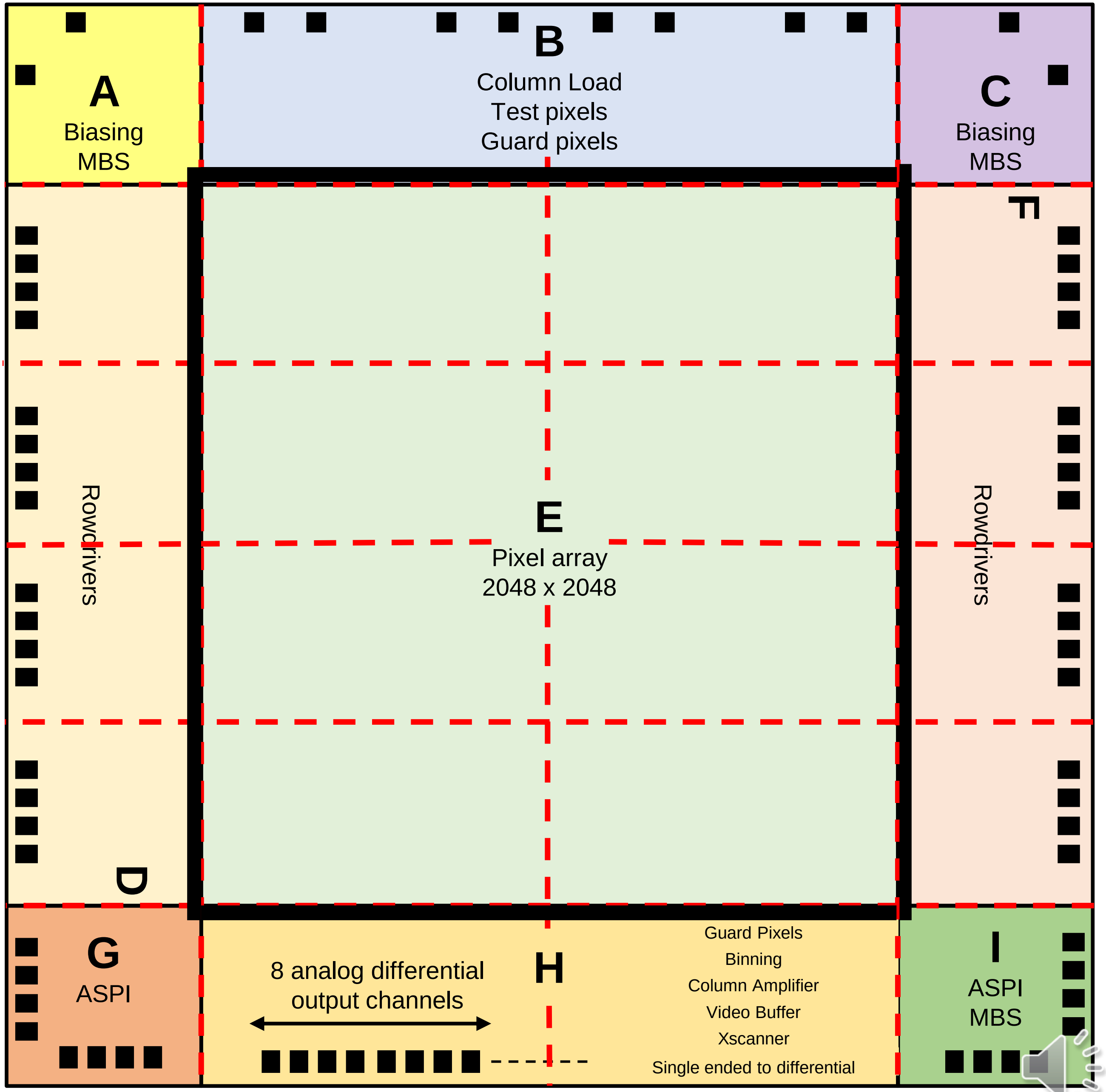
PLS	>200:1 … 1000:1 Strongly depending on wavelength and epi thickness
Binning	2x2 Charge domain binning
Backside illumination	Yes
Back biasing	Design is back bias compatible.
Color filter	No color filters, color-filter compatible.
Radhardness	Fully radhard design: TID >> 50kRad SEU, SET, SEL: LET > 60 MeV.cm^2/mg
Off-chip companion ADC	Companion 12-bit (nominal mode) ADC implemented outside the sensor area to be assembled on PCB

Floorplan

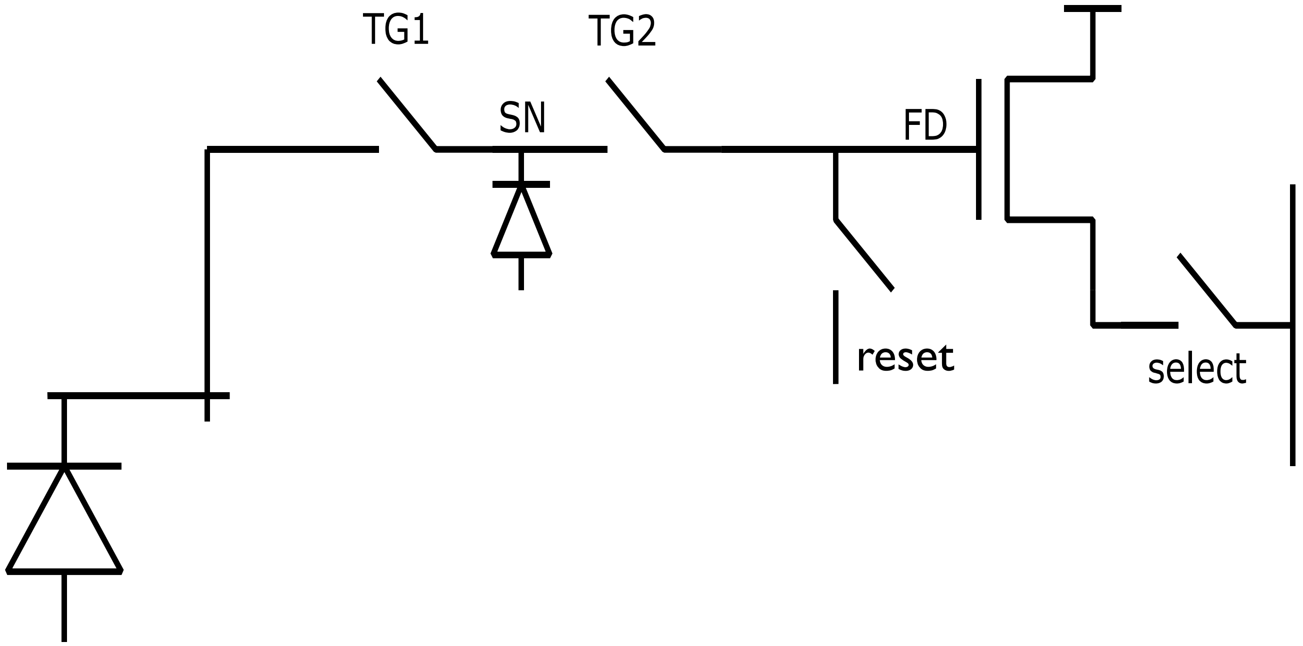
The “nominal” ELFIS2 imager

Stitching configuration:

- E block: 1024*512 pixels
- F and D: row control and Y-scan
- B: column load and biasing
- H: analog output channels
- A,C,G,I: housekeeping



ELFIS2 pixel

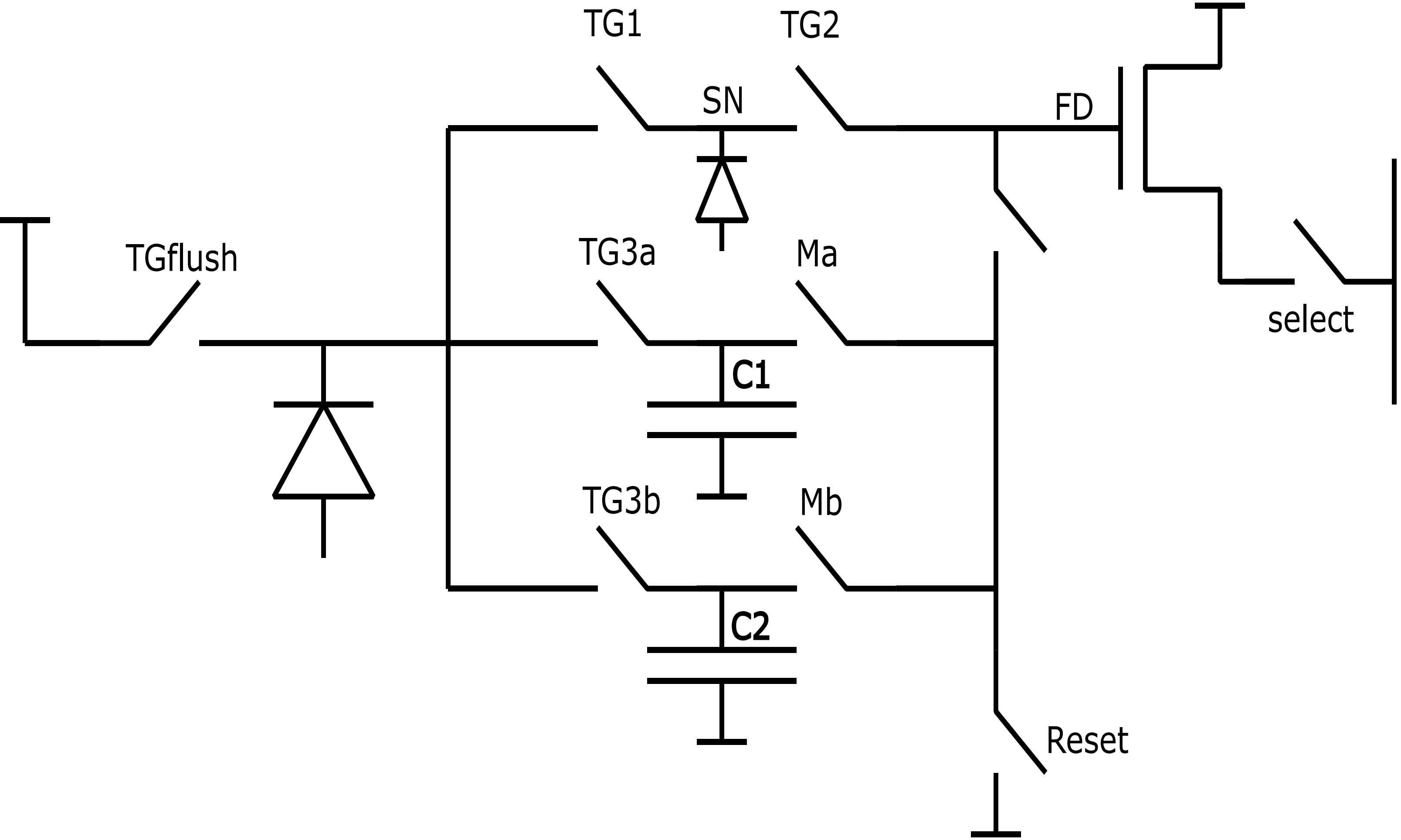


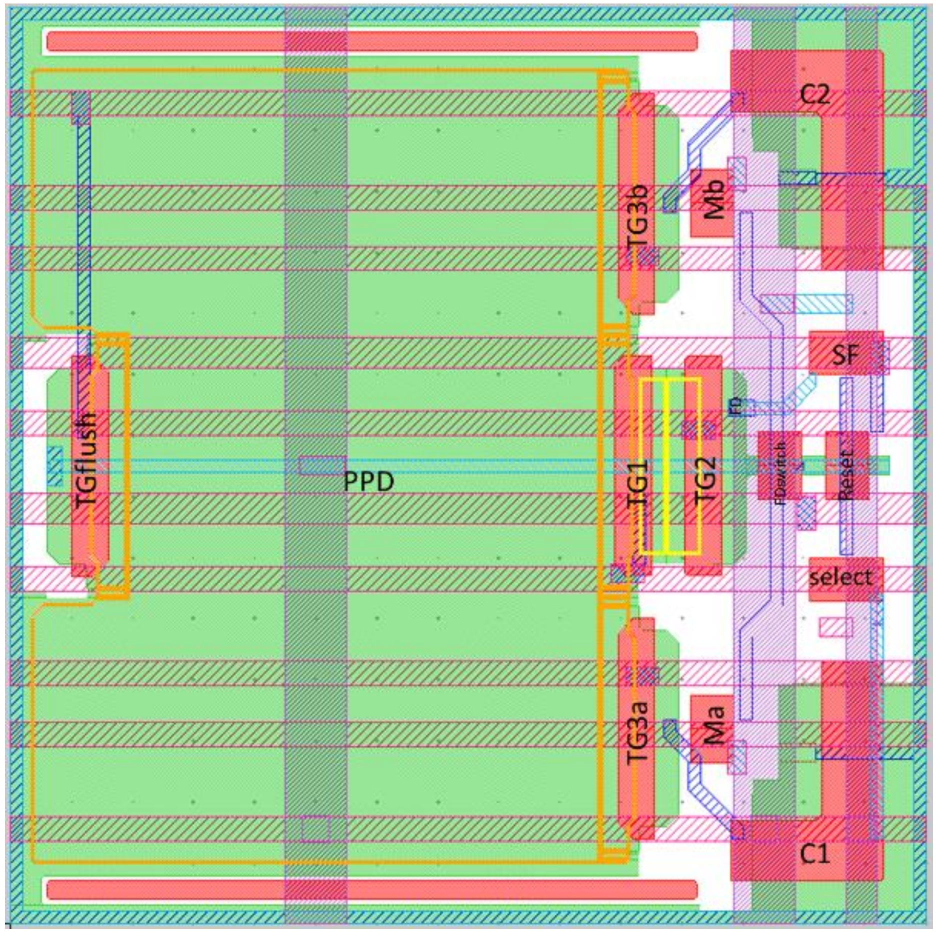
As starting point a “normal” charge domain global shutter (GS) pixel.

Maximum charge handling in PPD, SN and FD ~10000 electrons

Next slide: adding extra storage to handle up to 320000 electrons.

ELFIS2 pixel



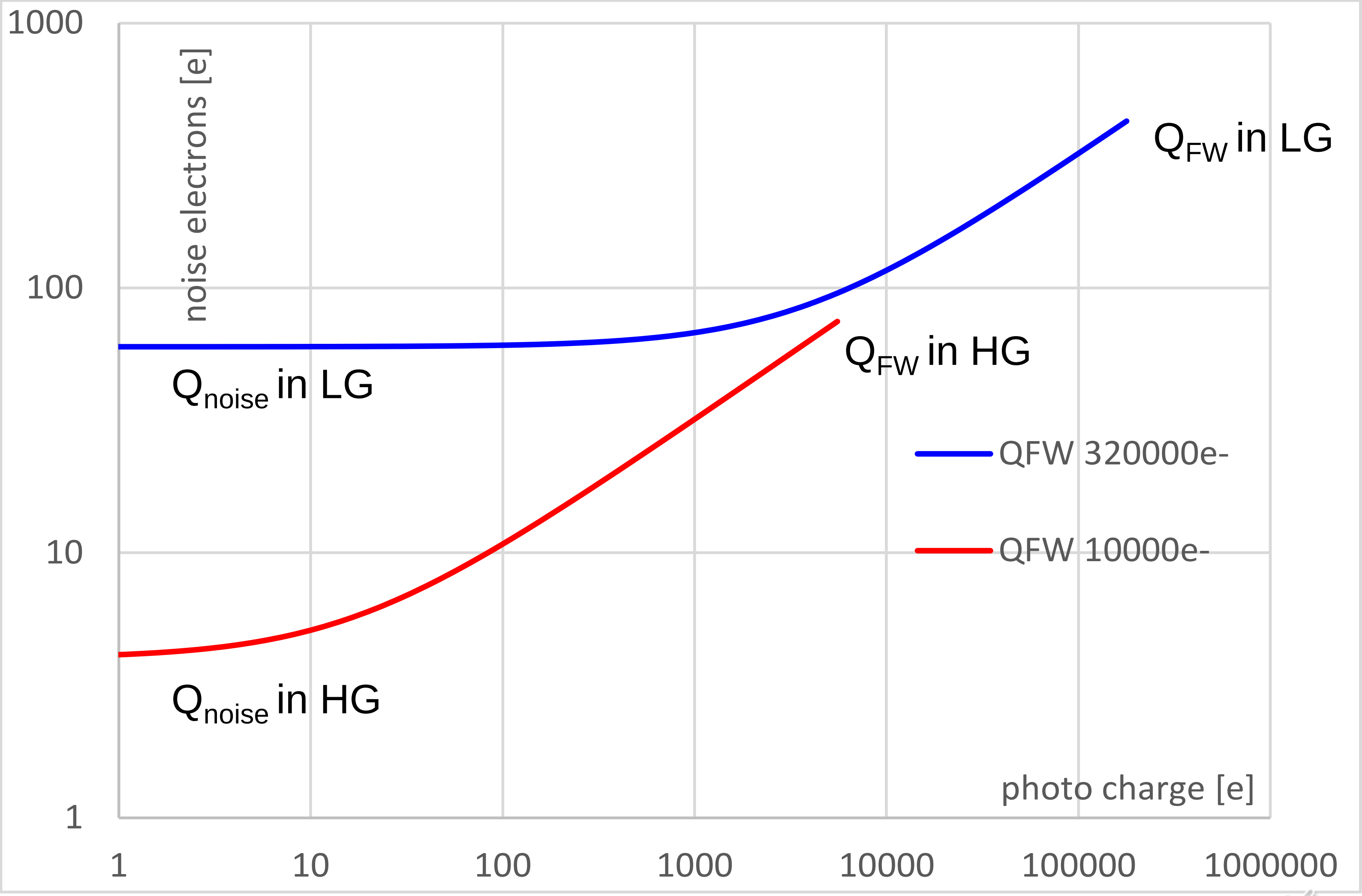


HDR

The high dynamic range is reached by splitting it up in 2 “normal” dynamic ranges

High gain Q_{FW}=10000e

Low gain Q_{FW}=320000e



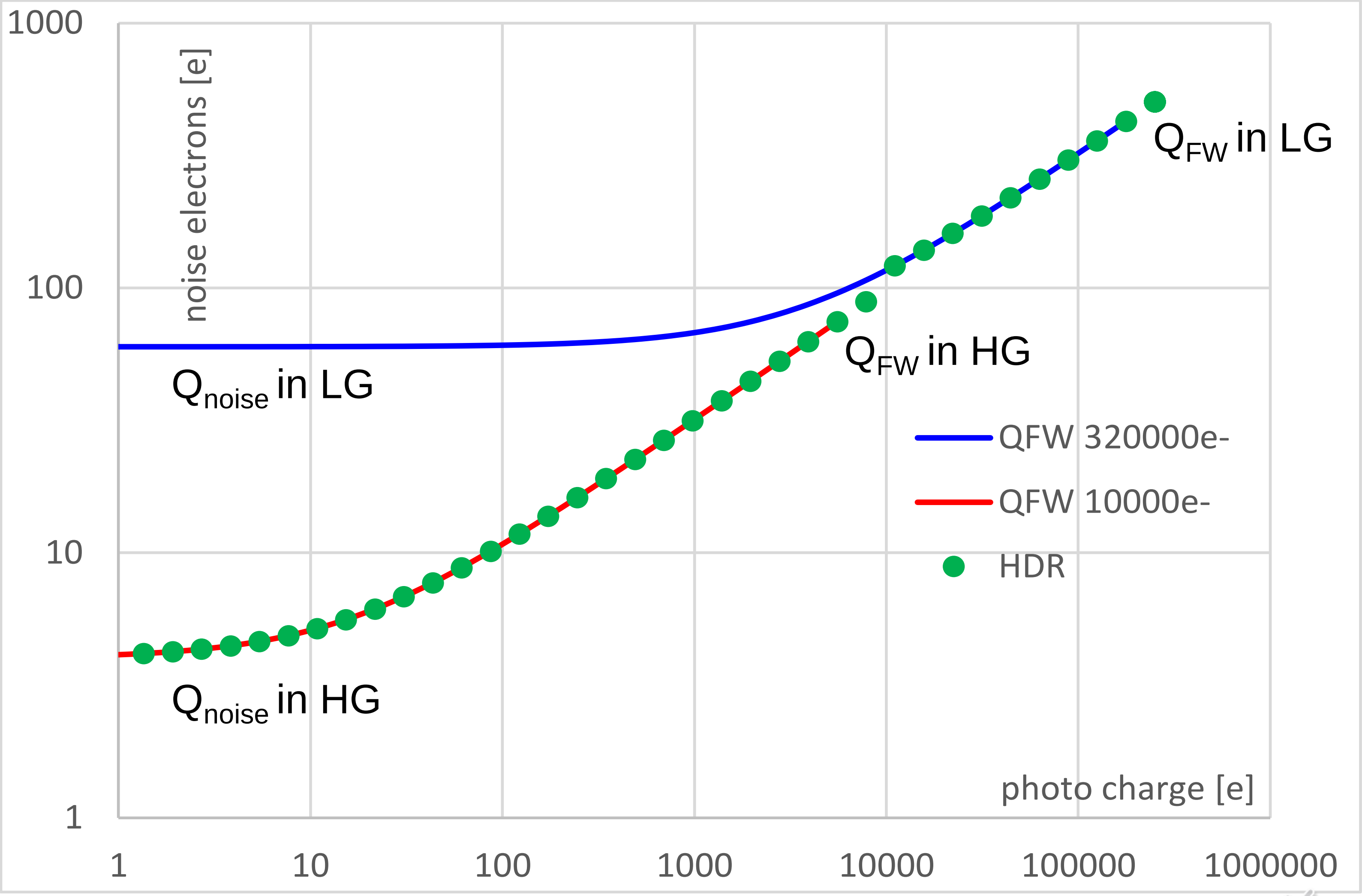
HDR

The high dynamic range is reached by splitting it up in 2 “normal” dynamic ranges

High gain Q_{FW}=10000e

Low gain Q_{FW}=320000e

Combined HDR ● ● ●



Operation of the ELFIS pixel:

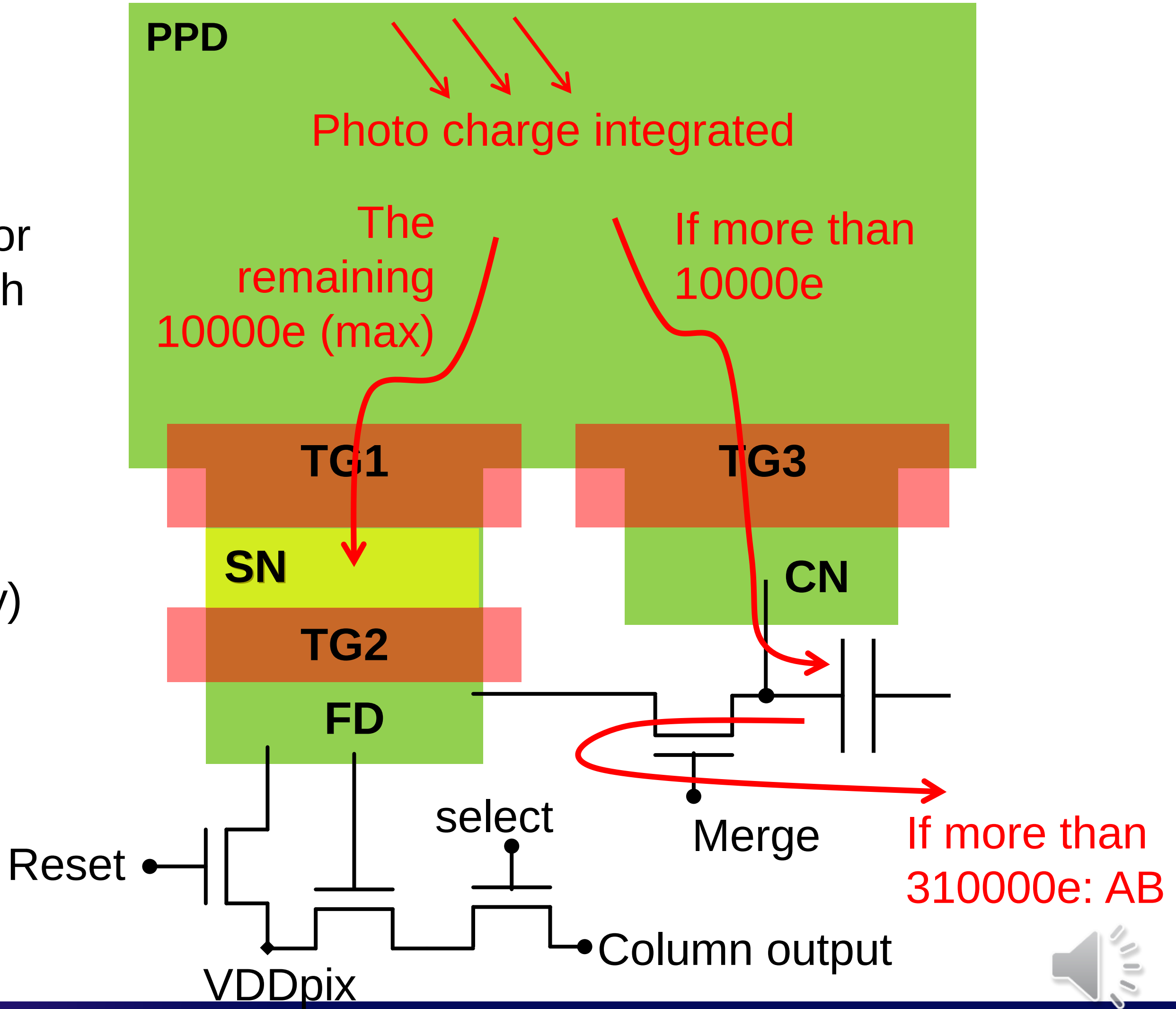
how to read the same photo charge with two conversion gains

During the integration time photo-electrons are accumulated in the pinned photodiode (PPD)

If the amount of electrons in the PPD exceeds 10000, these overflow over TG3 into the capacitor node (CN) , for later use. There are two CNs with a total capacity for 320000 electrons

If the total charge exceed 320000 electrons, it goes to the anti-blooming drain.

At the end of the integration time, the (maximally) 10000 electrons still present in the PPD are transferred by transfer gate TG1 to the storage node (SN). The SN cannot contain more.



Operation of the ELFIS pixel:

how to read the same photo charge with two conversion gains

Just before the moment of readout, there are

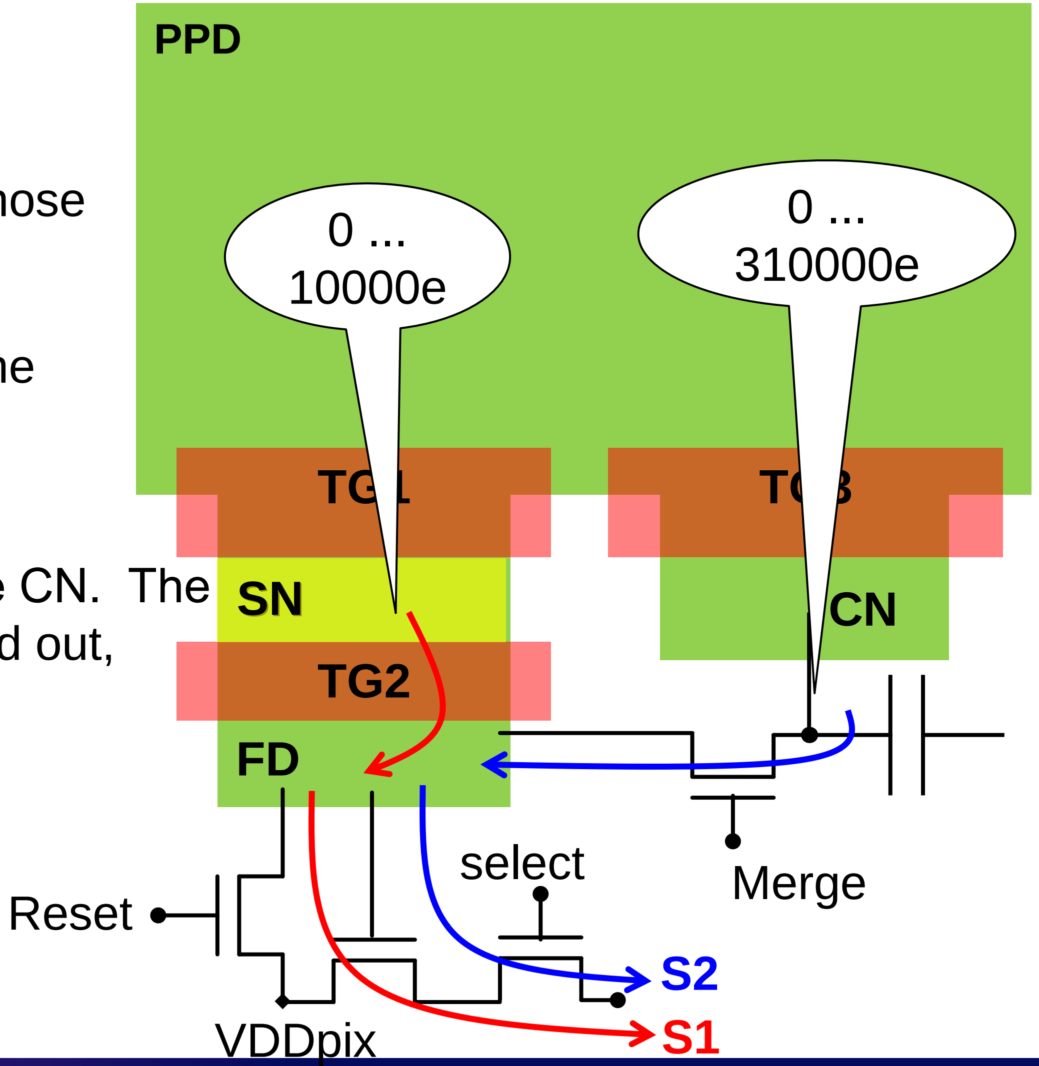
- Between 0 and 10000 electrons in the SN
- Between 0 and 310000 on the CN(s)

The total integrated photocharge is the sum of those two

TG2 is toggled and transfers the SN charge to the FD, where is it read out using correlated double sampling (CDS), yielding a signal "S1"

Then "Merge" is closed, shunting the FD and the CN. The sum of both charge packets is on FD, and is read out, yielding a signal "S2"

S1 is the "high gain" signal, with small Q_{FW}
S2 is the "low gain" signal, with large Q_{FW}

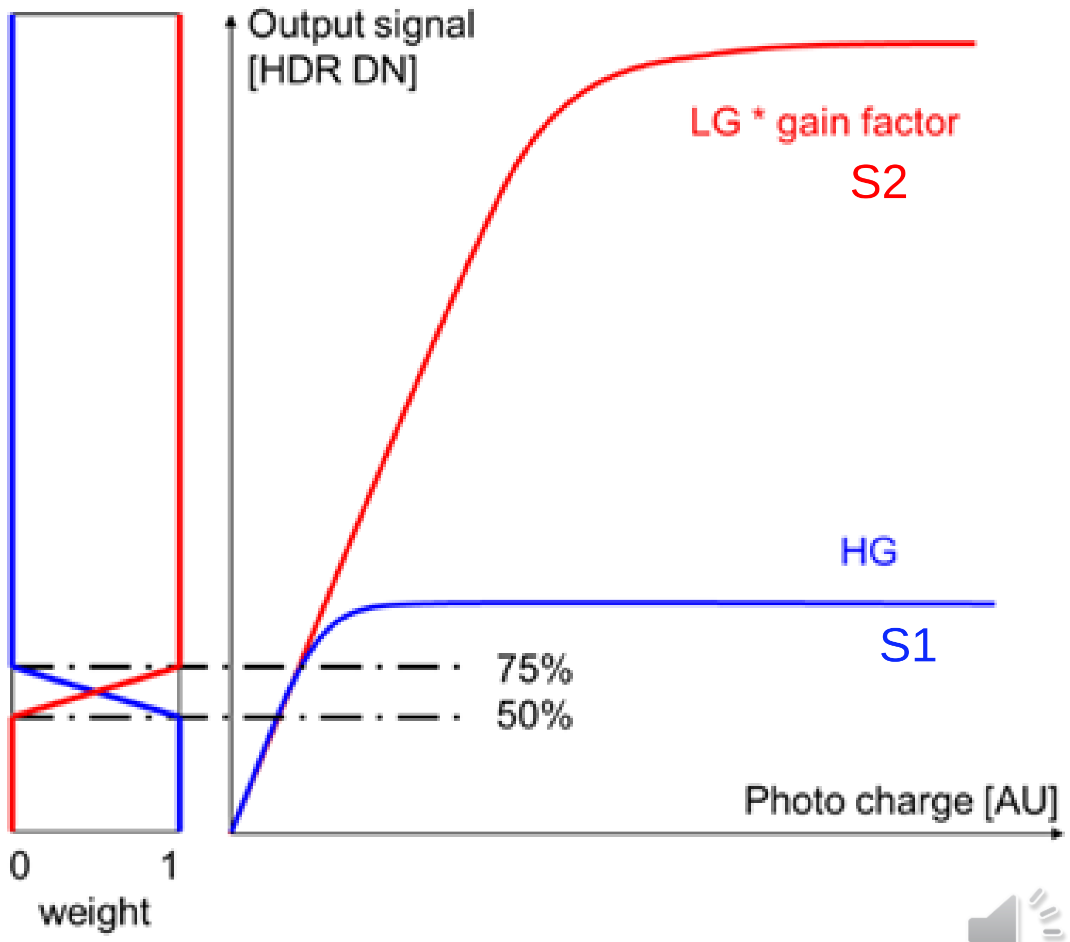


HDR interpolation algoritm

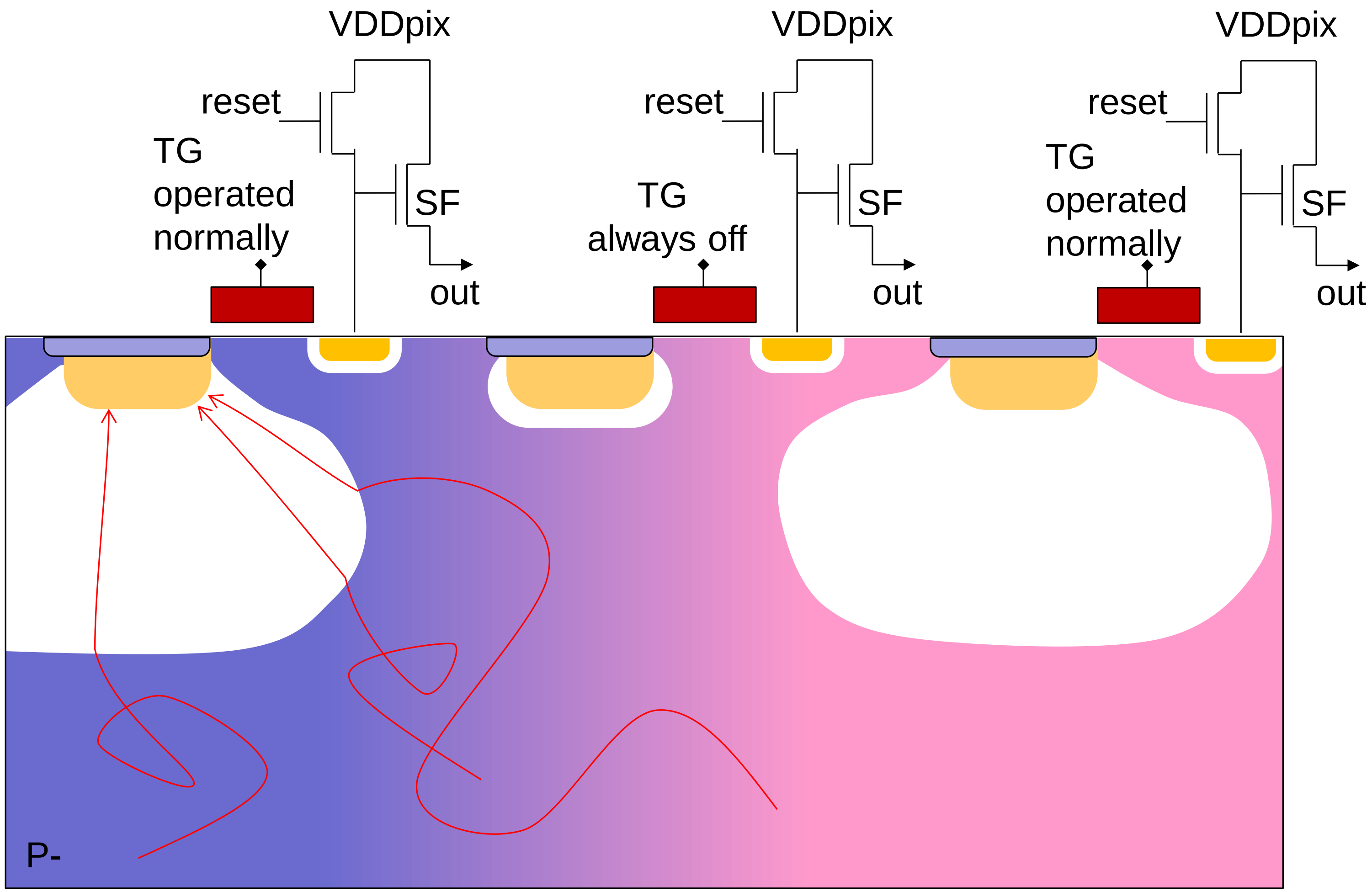
For each pixel starting from the two signals HG (S1) and LG (S2)

First apply FPN and PRNU correction, and scale the S1 and S2 signals so that they coincide where both exist.

When the HG signal is above 75% of HG saturation
→take the LG signal
When the HG signal is below 50% of HG saturation
→ take the HG value.
Between 50% and 75%:
→ apply a weighted average between HG and LG



Charge domain binning



One operates the pixels in the pixel array differently.

Certain pixels are operated normally to have “charge collecting photodiodes”. Others are operated so that they are not or less charge collecting.

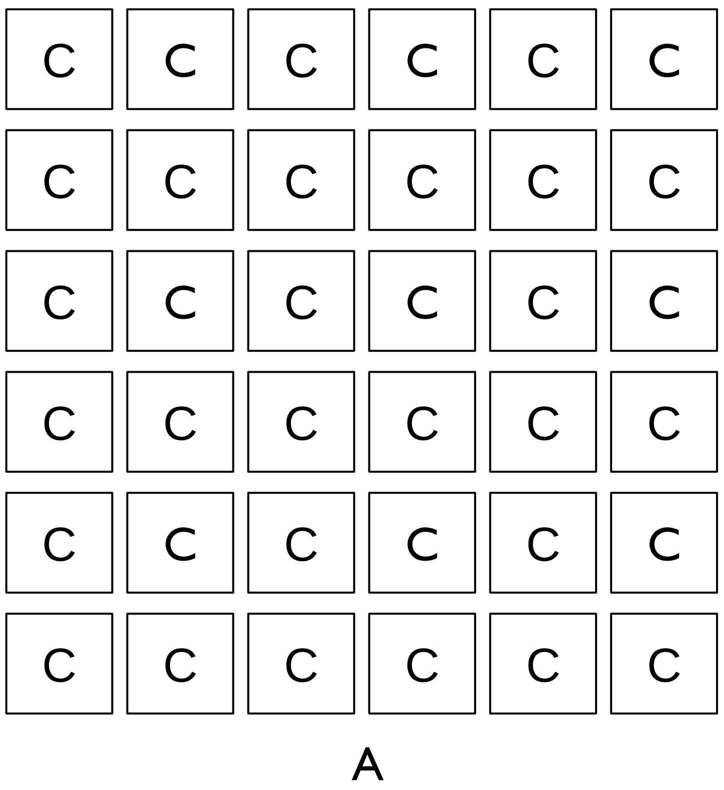
This is realized by letting the non-collecting pixels or their photodiode “float” (not being forced at a potential) or explicitly biased at a suitable potential.

Having a thick high resistivity material as compared to the pixels size is thus beneficial.

The method works best in backside illuminated configuration, yet also in frontside illuminated image sensors the method should work.

Charge domain binning

Charge domain binning exploits the capability to program a pixel to be "charge collecting" [C] or "not charge collecting" [ ].



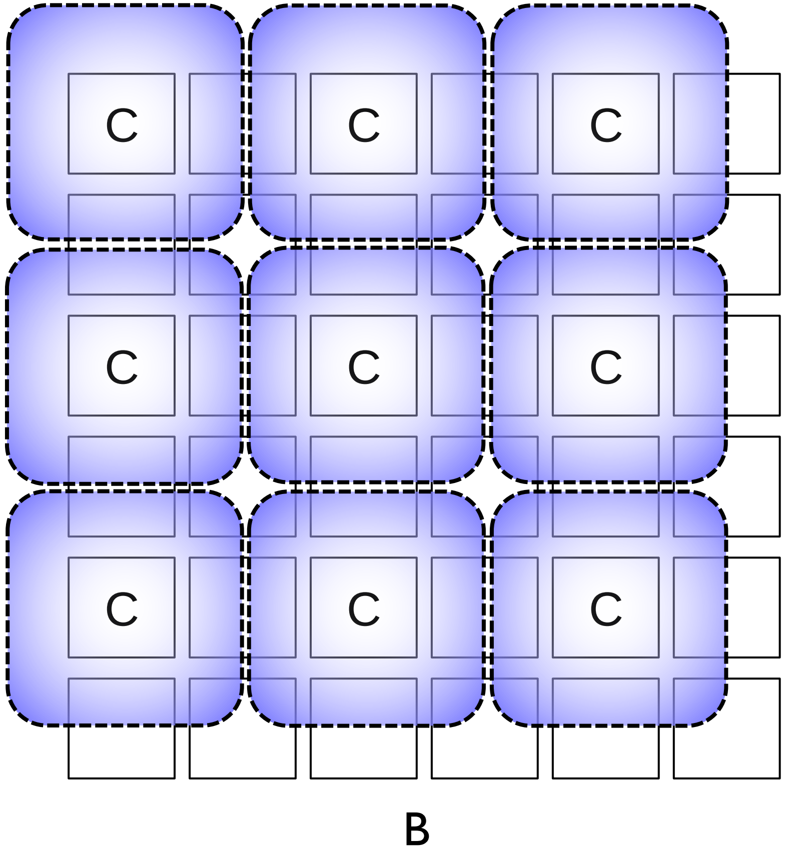


Figure A is a is a floorplan of a small array of pixels. Nominally all pixels are charge collecting "C".

Figure B: a grid of charge collecting ("C") pixels surrounded by pixels that are operated to be non-collecting, realizing 2x2 binning.

Thank you!