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Presented at the
Caeleste Visionary Workshop
The Future of High-end Image Sensors

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High Dynamic Range, PSN Limited, Synchronous Shutter Image sensor

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Outline

- Need for HDR, Synchronous Shutter Imaging
- “Consumer” HDR imaging
- 3-Level TG method
  - Pixel - Topology
  - Pixel - Principle
  - Merging of pixel gains
- Measurements
- Conclusions

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- Need for HDR imaging
- “Consumer” HDR imaging
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- True GS HDR Pixel
- Conclusions

Need for HDR Imaging

Why we need HDR imaging?

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Most natural scenes contains intensities varying from >100000 lx to <1lx

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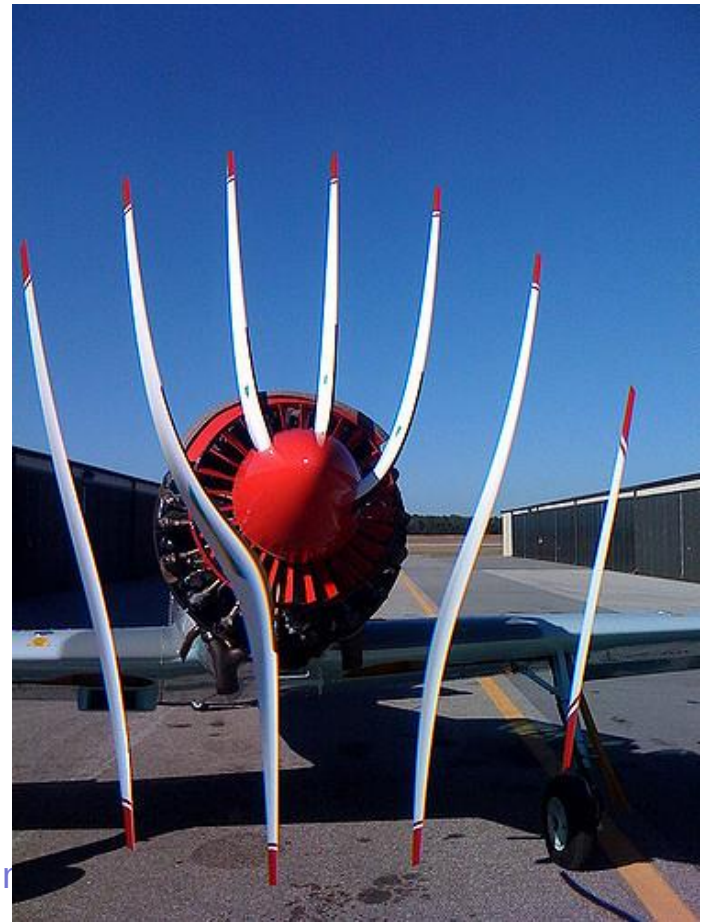
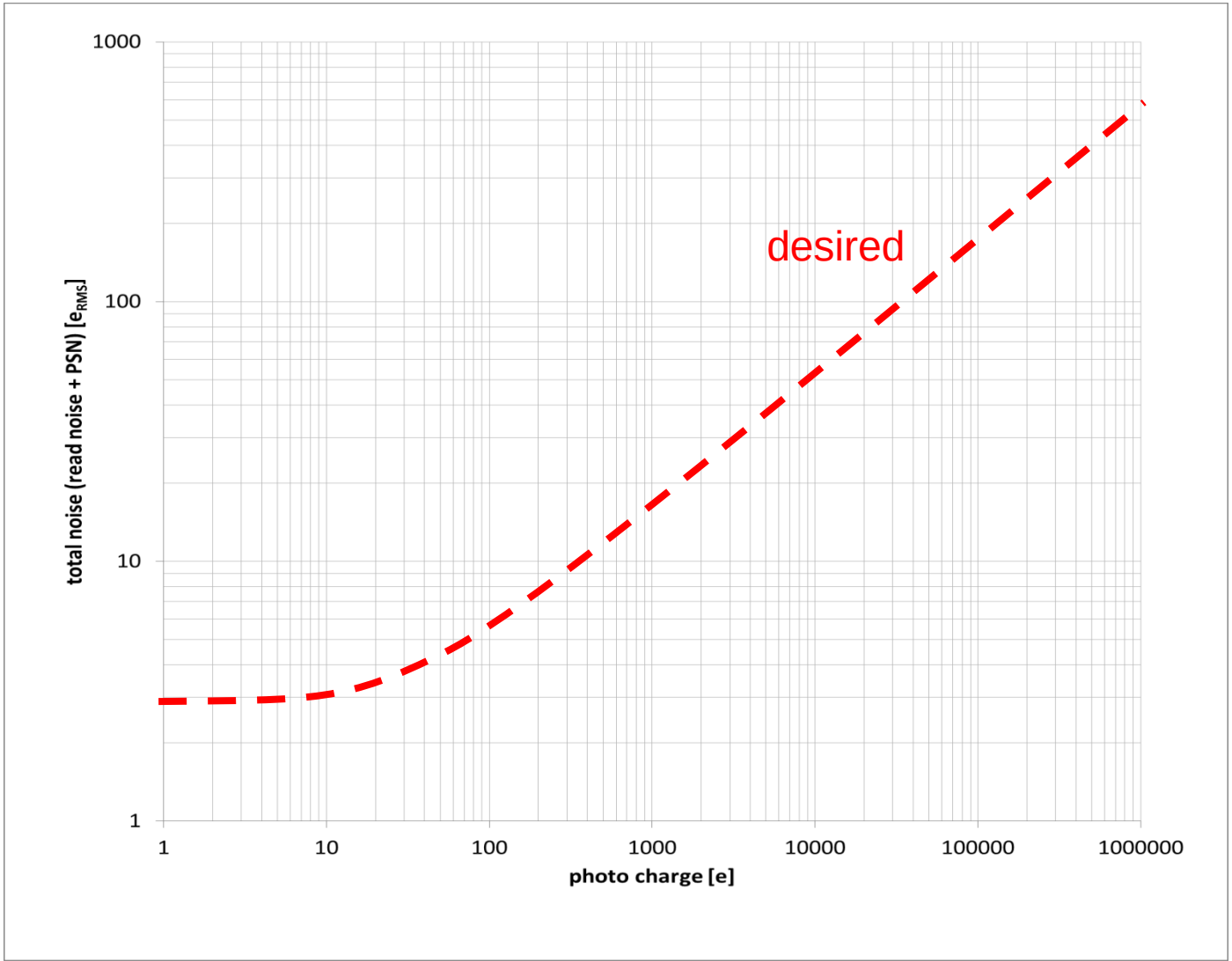
Why we need Synchronous shutter?

Synchronous shutter (“Global” shutter) is required for capturing images without motion artifacts



Noise – State of the art

CDS limited read noise at dark and PSN limited performance at higher light levels



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Consumer HDR Imaging

“Consumer” HDR imaging

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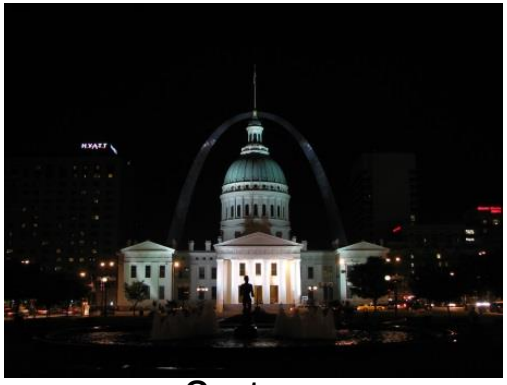
- Most methods are based on bracketing (capturing images for different exposure time) or other equivalent methods
- Pro - Can capture high dynamic range static scene
- Con - Cannot capture high dynamic range moving scene without artifacts

- 4 stops



- 2 stops

2 stops

4 stops

Local tone mapped image

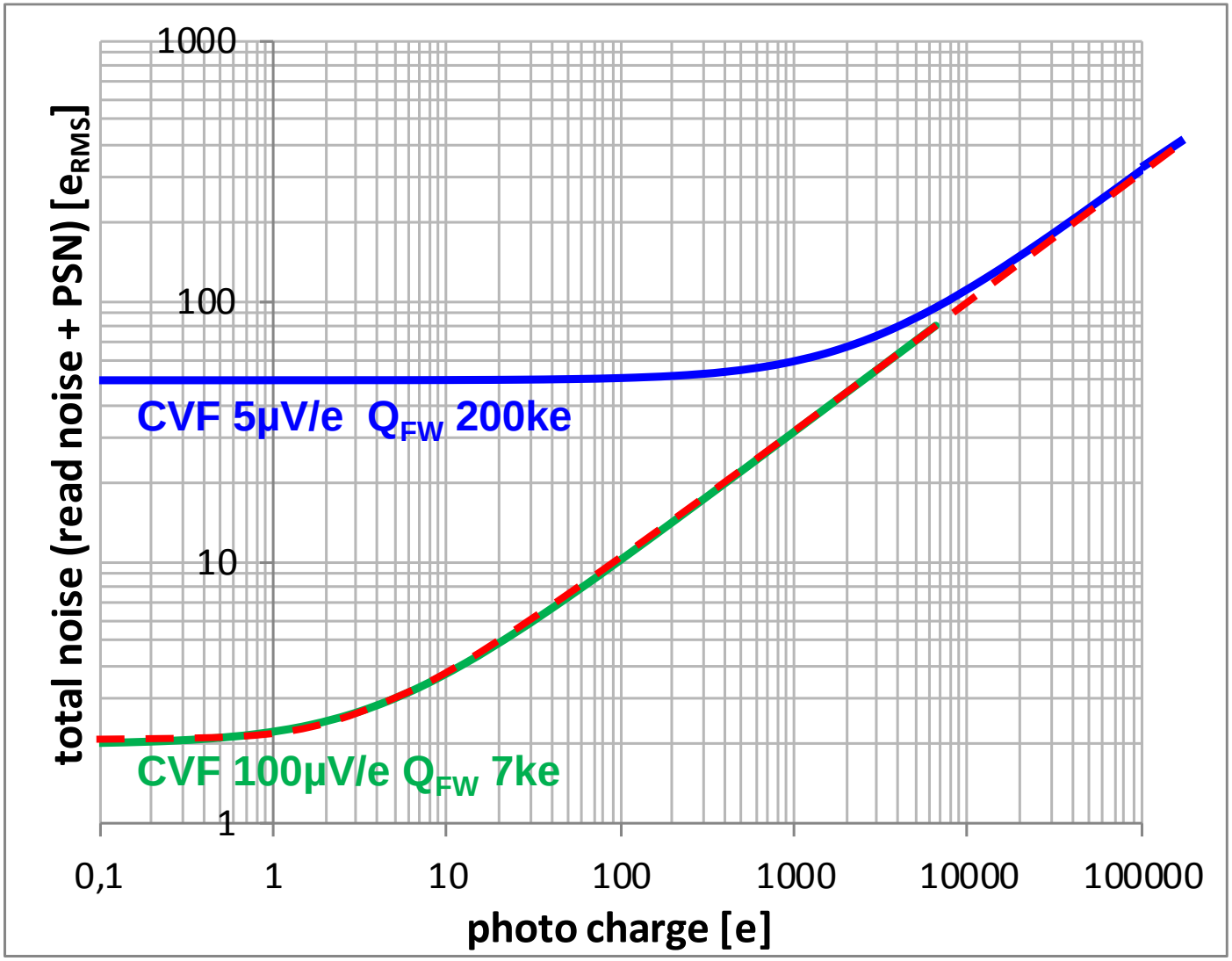
(source - https://en.wikipedia.org/wiki/High-dynamic-range_imaging)

Desirable features

	Caeleste Device A	Caeleste Device B	Caeleste Device C	Caeleste Device D
Pixel pitch (µm)	8	8	50	15
Pixel array	4Kx2K	4Kx4K	200x600	4Kx4K
Full well (e^-)	250K	350K	2.2M	170K
Read noise (e^-)	< 2	<6	<15	<10
Non-Linearity (% of FW)	< 1	< 2	< 0.2	< 1
Shutter/ Integration modes	IWR	IWR	IWR	IWR

*IWR: Integrate While Read

Desirable features



High Q_{FW} range:
DR=200000/50=4000:1

Low Q_{FW} range:
DR=7000/2=3500:1

Combination
DR=200000/2
=100000:1 **100dB**

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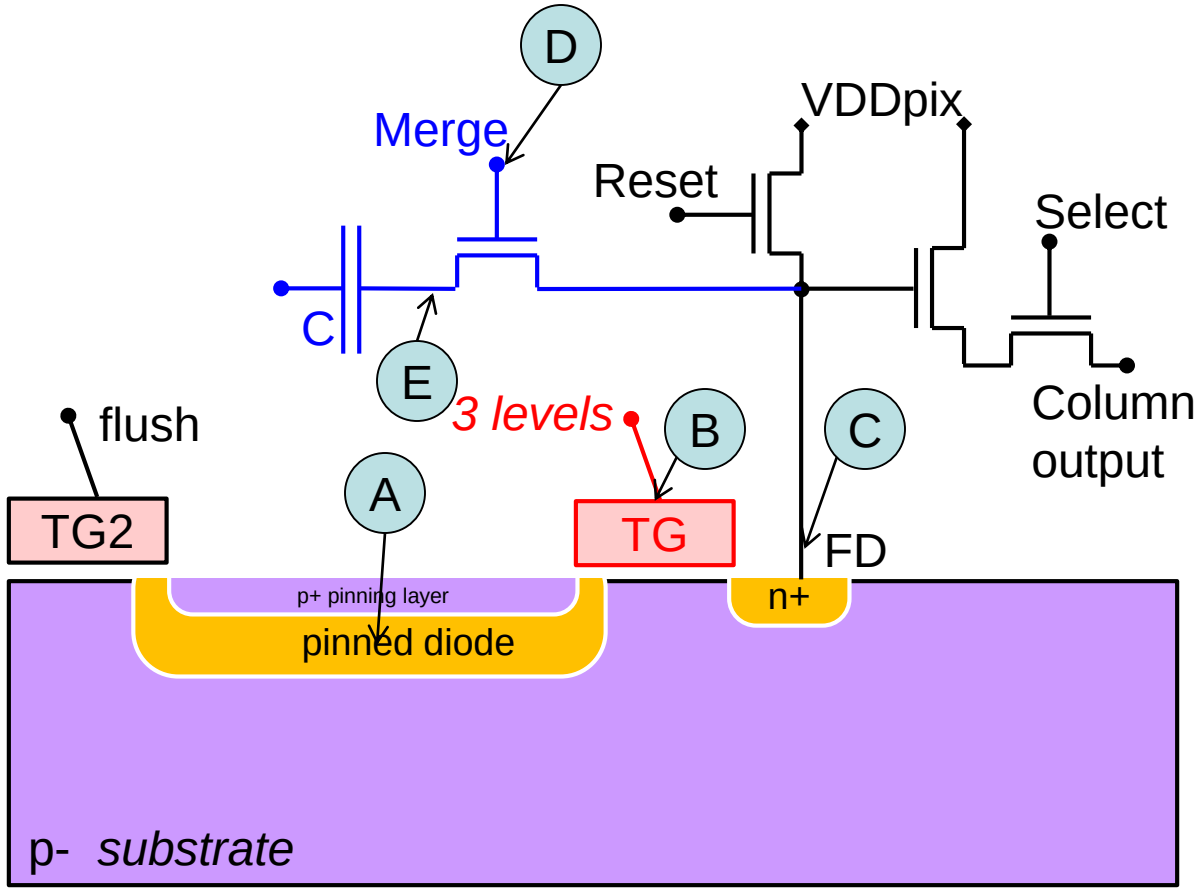
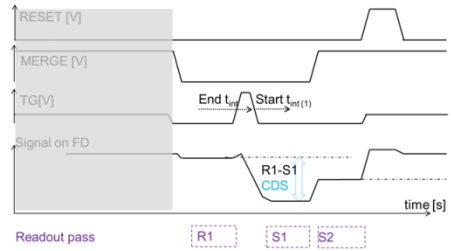
3 – Level TG Method

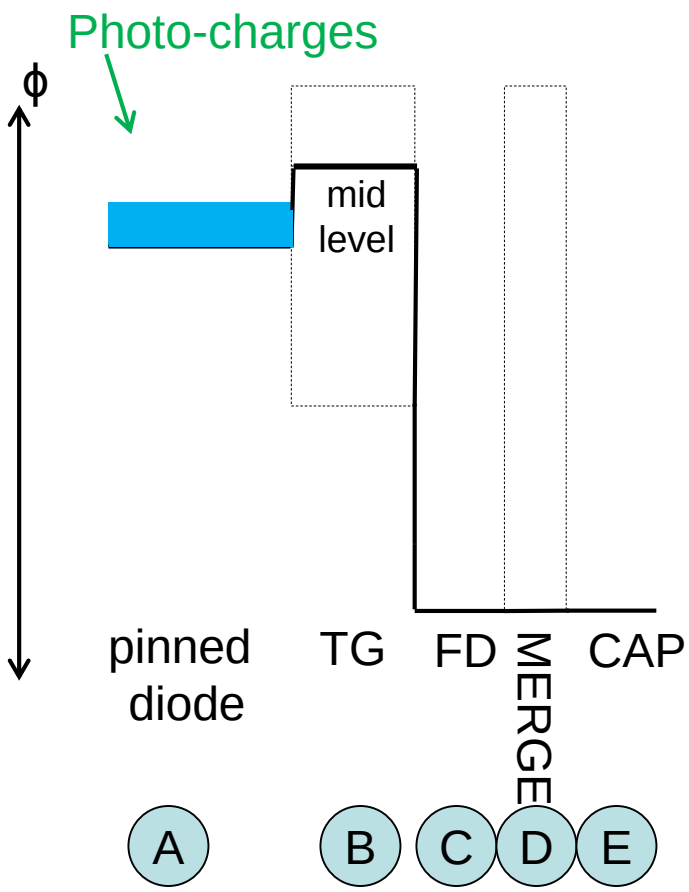
3 – Level TG Pixel - Topology



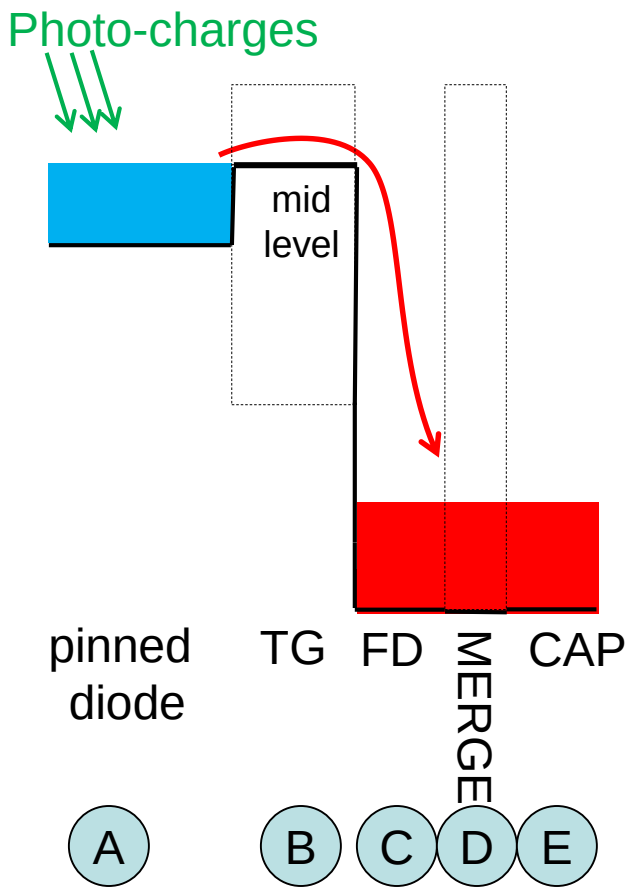
During Integration



Low Illumination

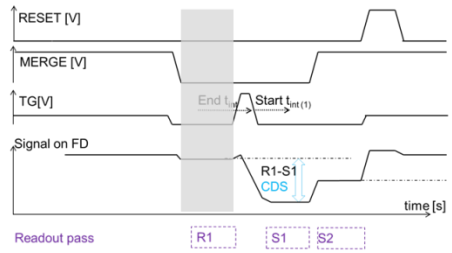


High Illumination



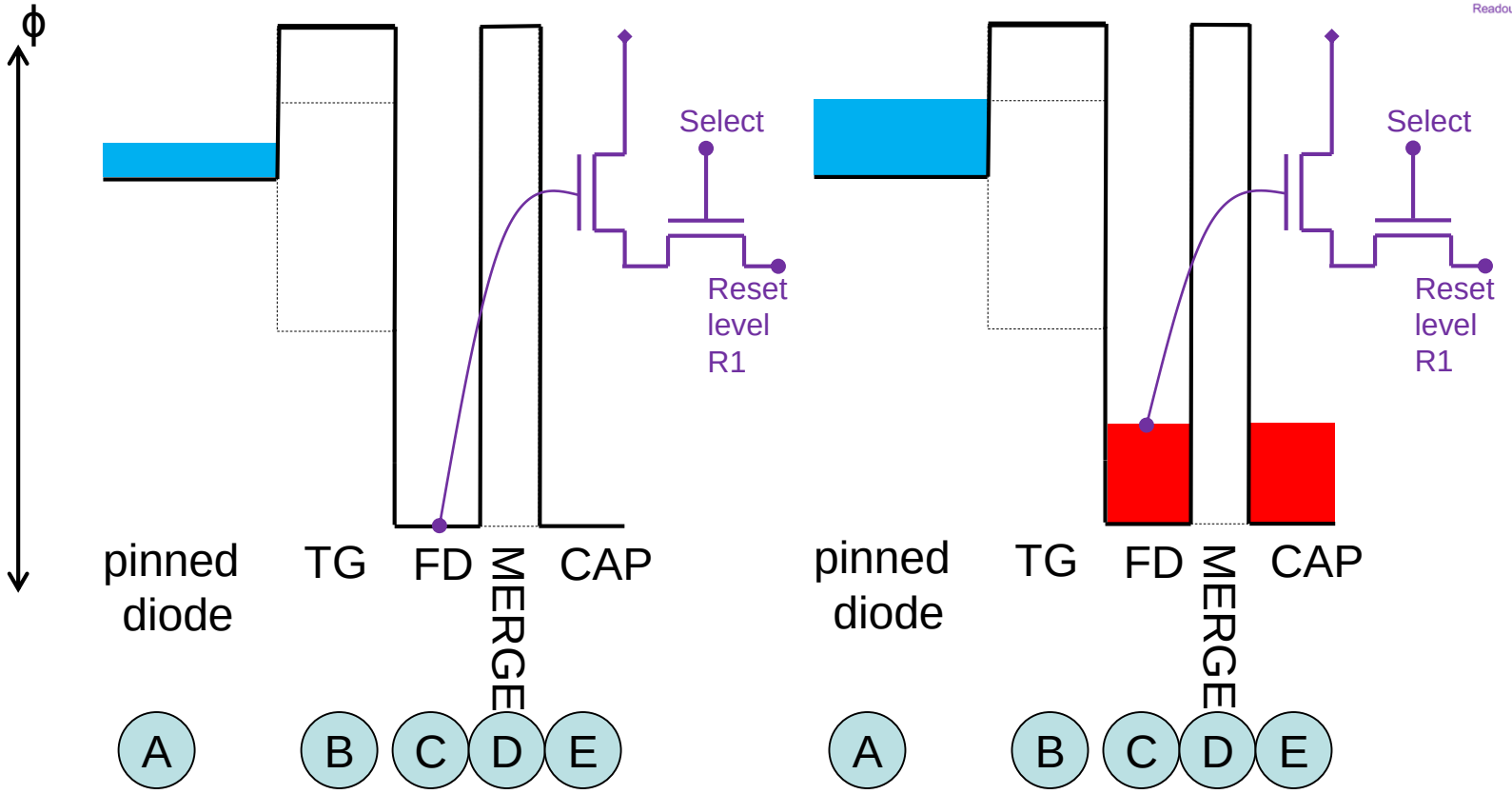
TG is set to “barrier” potential

Reset readout “R1”



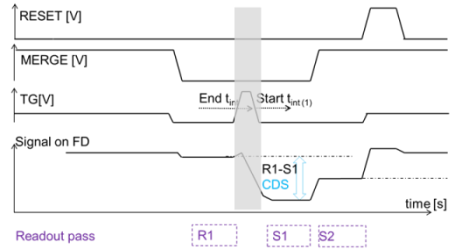
Low Illumination

High Illumination

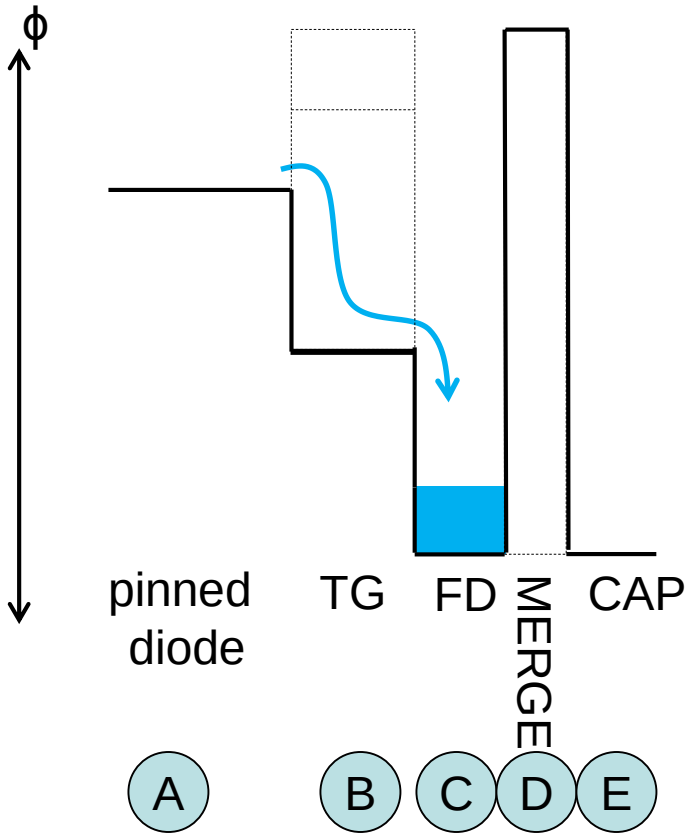


TG and MERGE is turned OFF

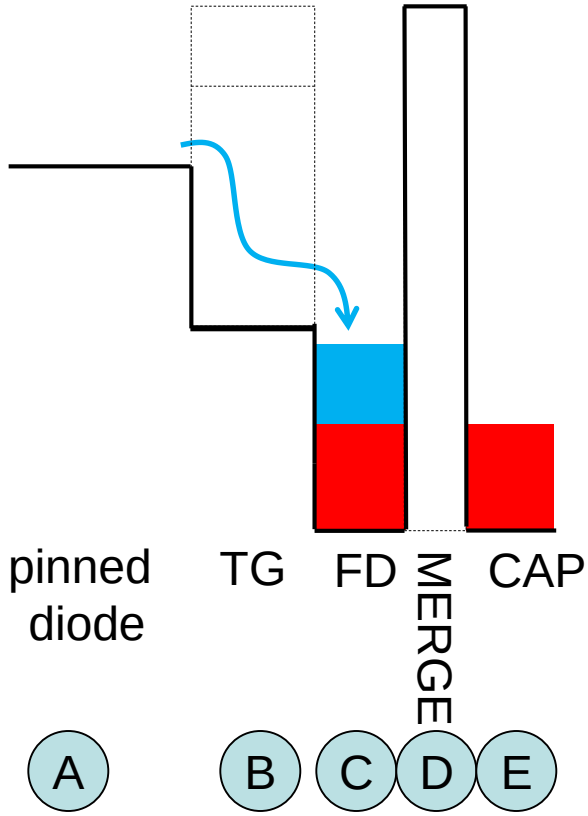
Charge transfer from PPD to FD



Low Illumination

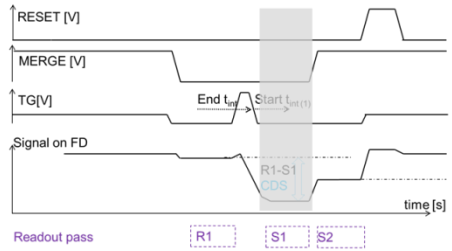


High Illumination

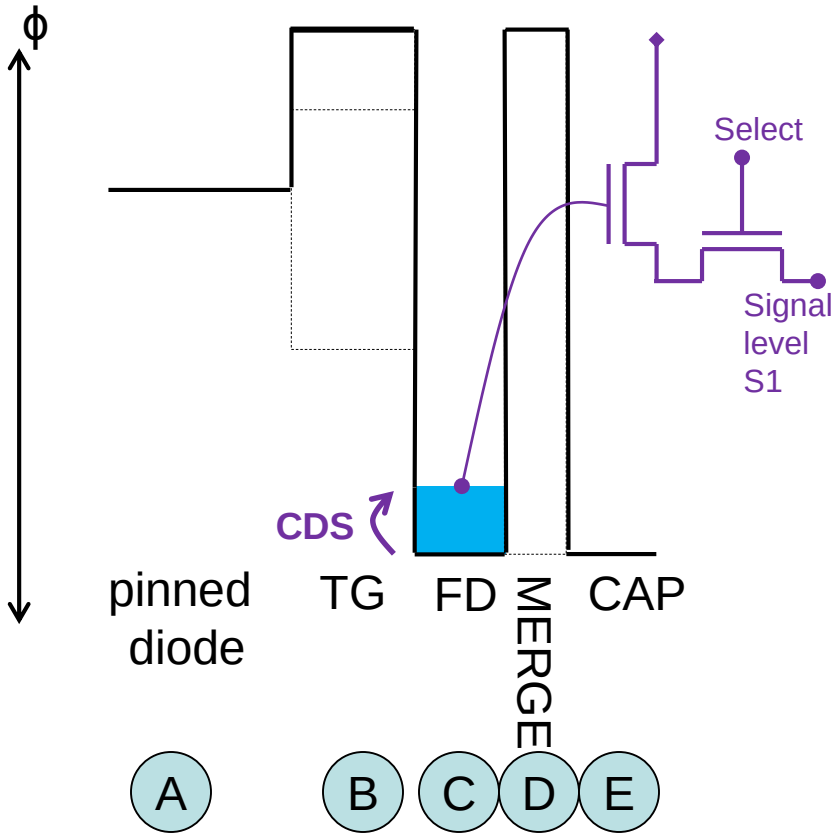


TG is turned ON: remaining photocharge flows into FD. TG is turned OFF

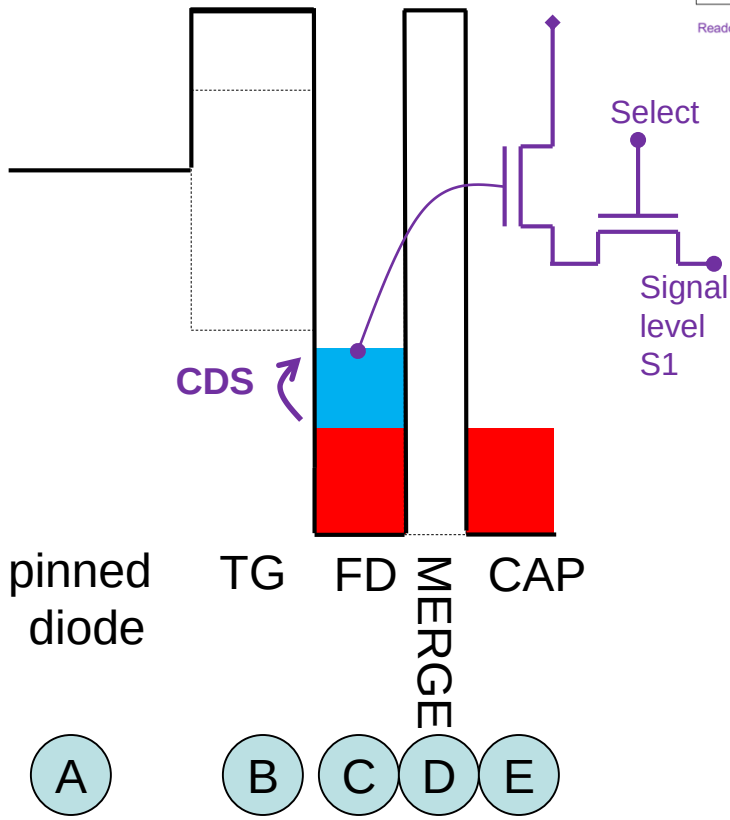
Signal readout “S1” and CDS



Low Illumination



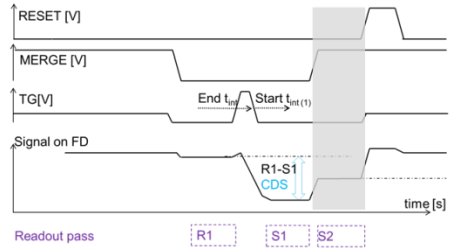
High Illumination



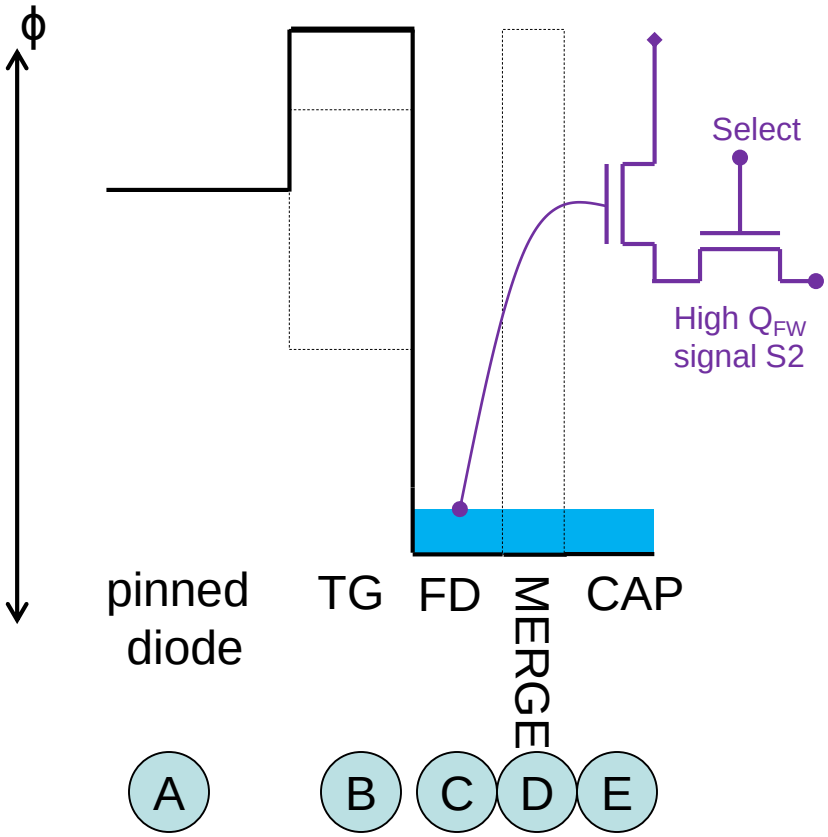
TG is turned ON: remaining photocharge flows into FD. TG is turned OFF

Downstream CDS must be done.

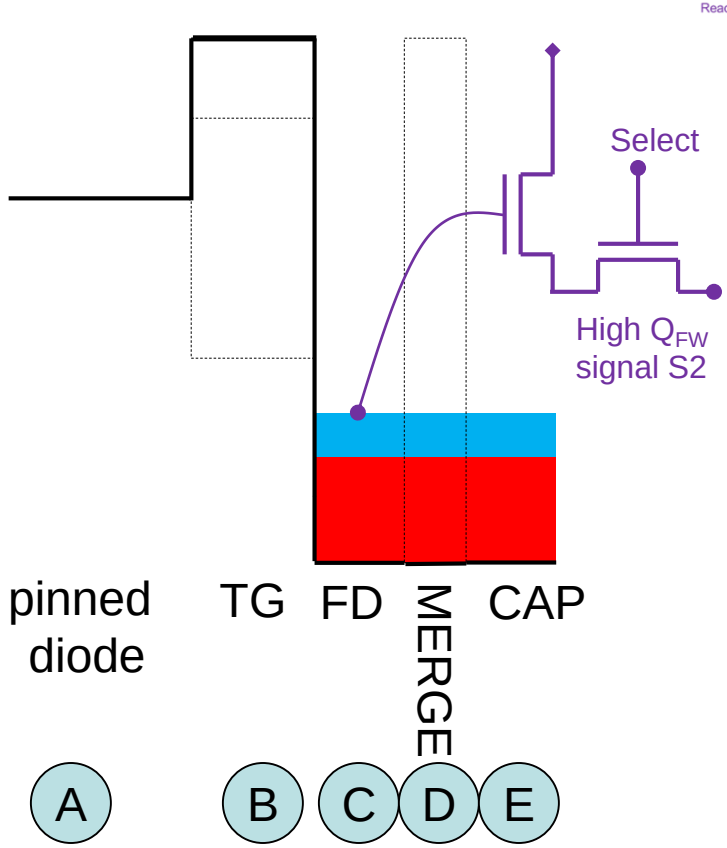
High Q_{FW} Readout "S2"



Low Illumination

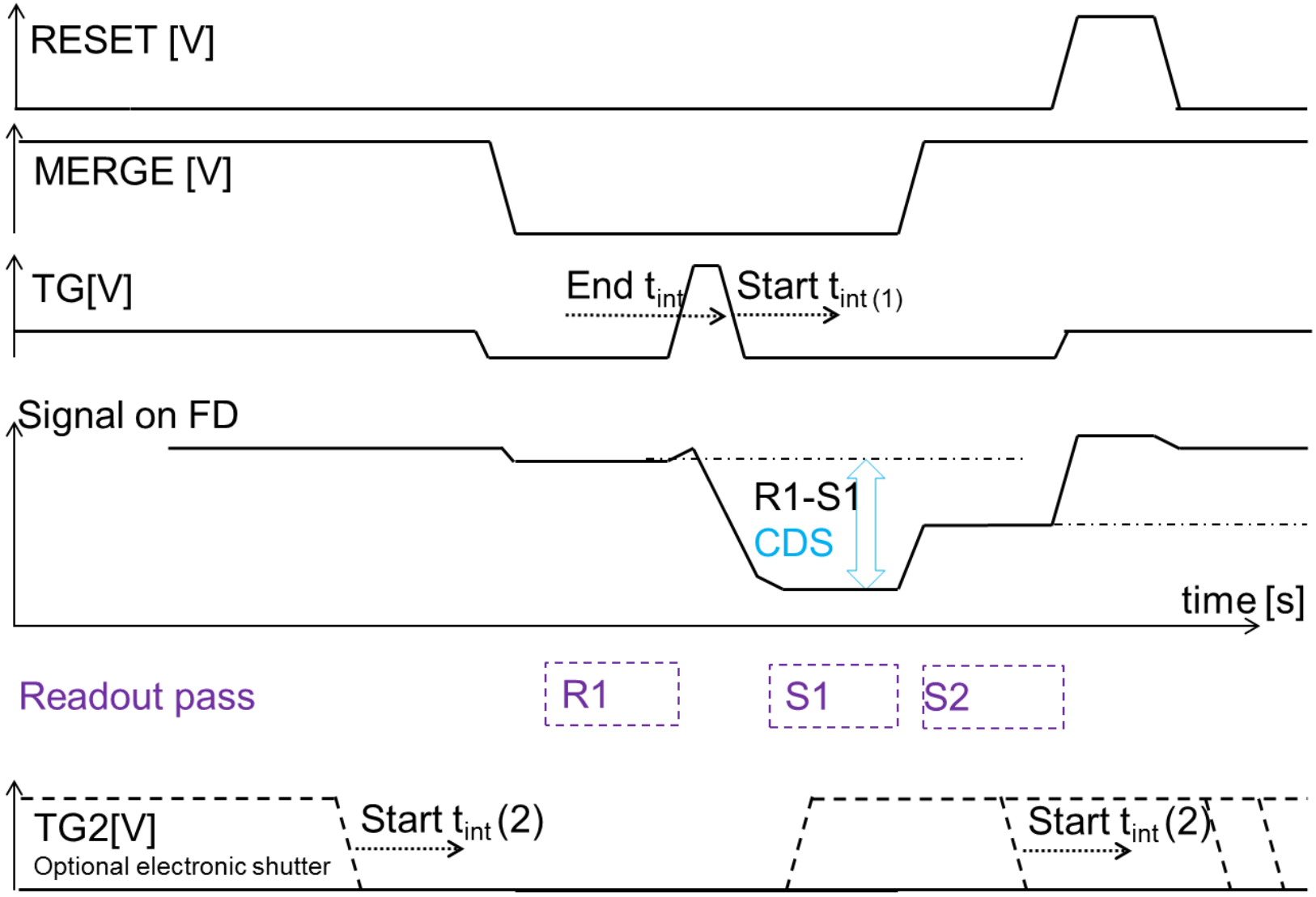


High Illumination



MERGE is turned ON: Read all the "high Q_{FW}" signal from FD

Pixel – Timing Diagram



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Measurements

Measurement Setup

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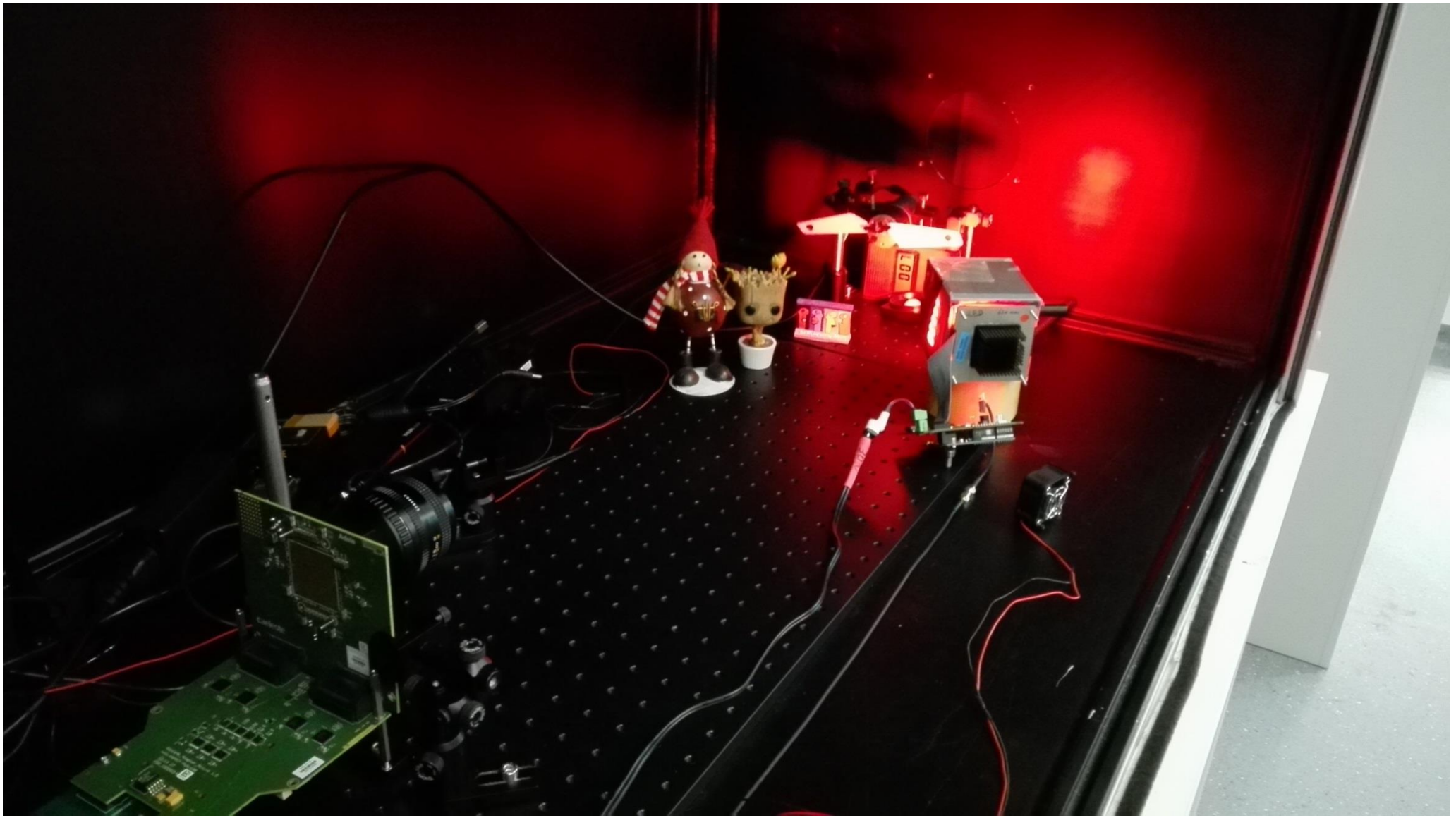

Merging of "Low Q_{FW}" and "High Q_{FW}" Images

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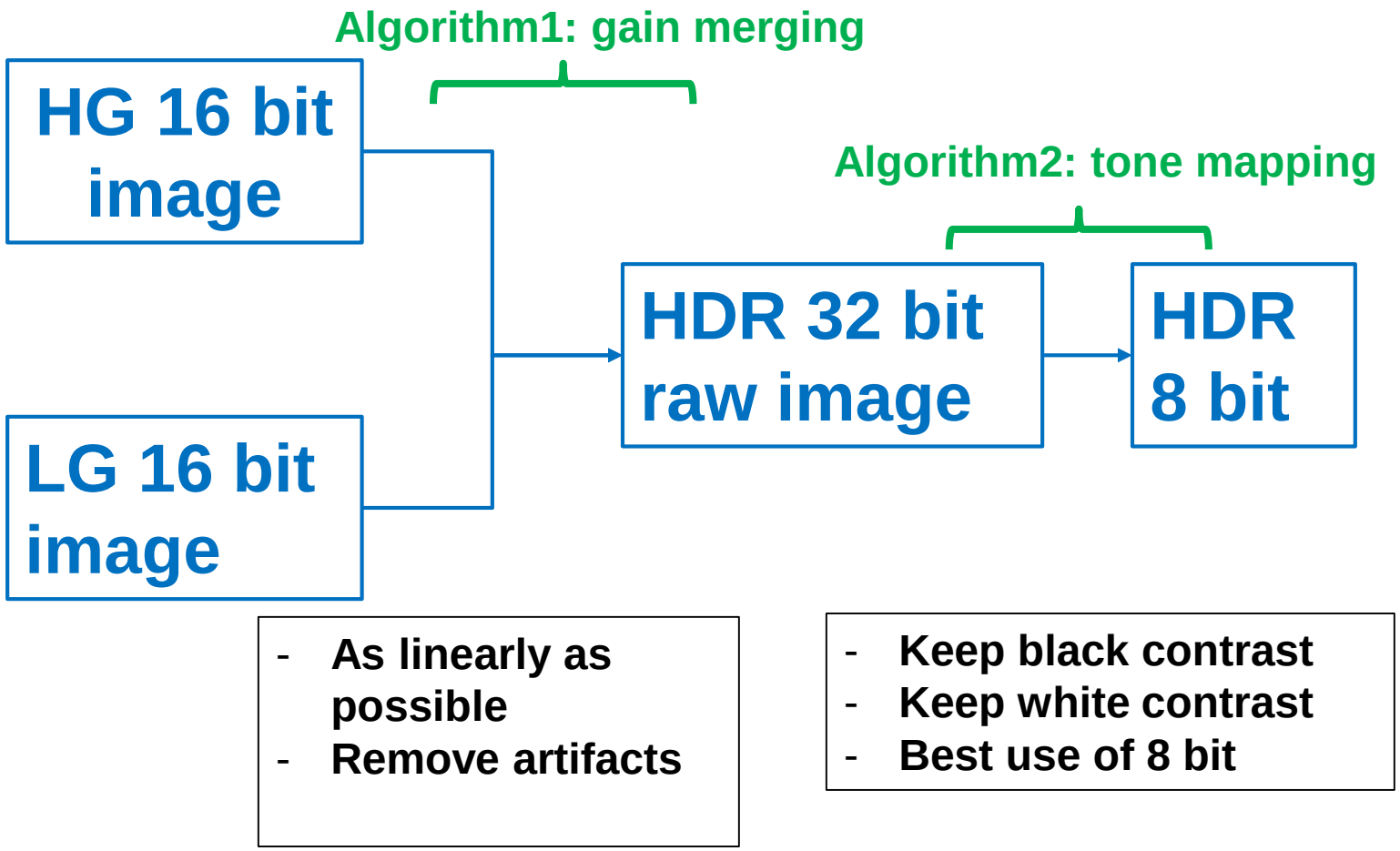

Measurement Results

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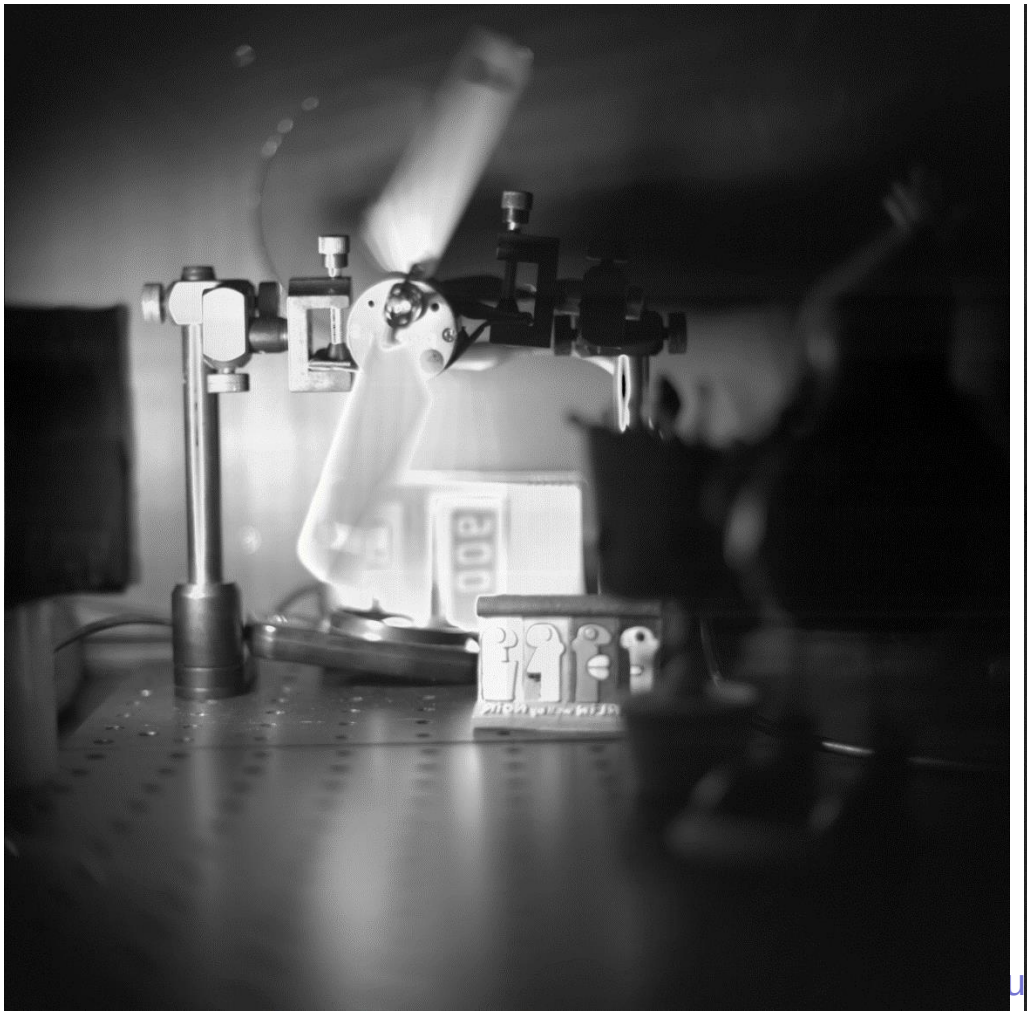
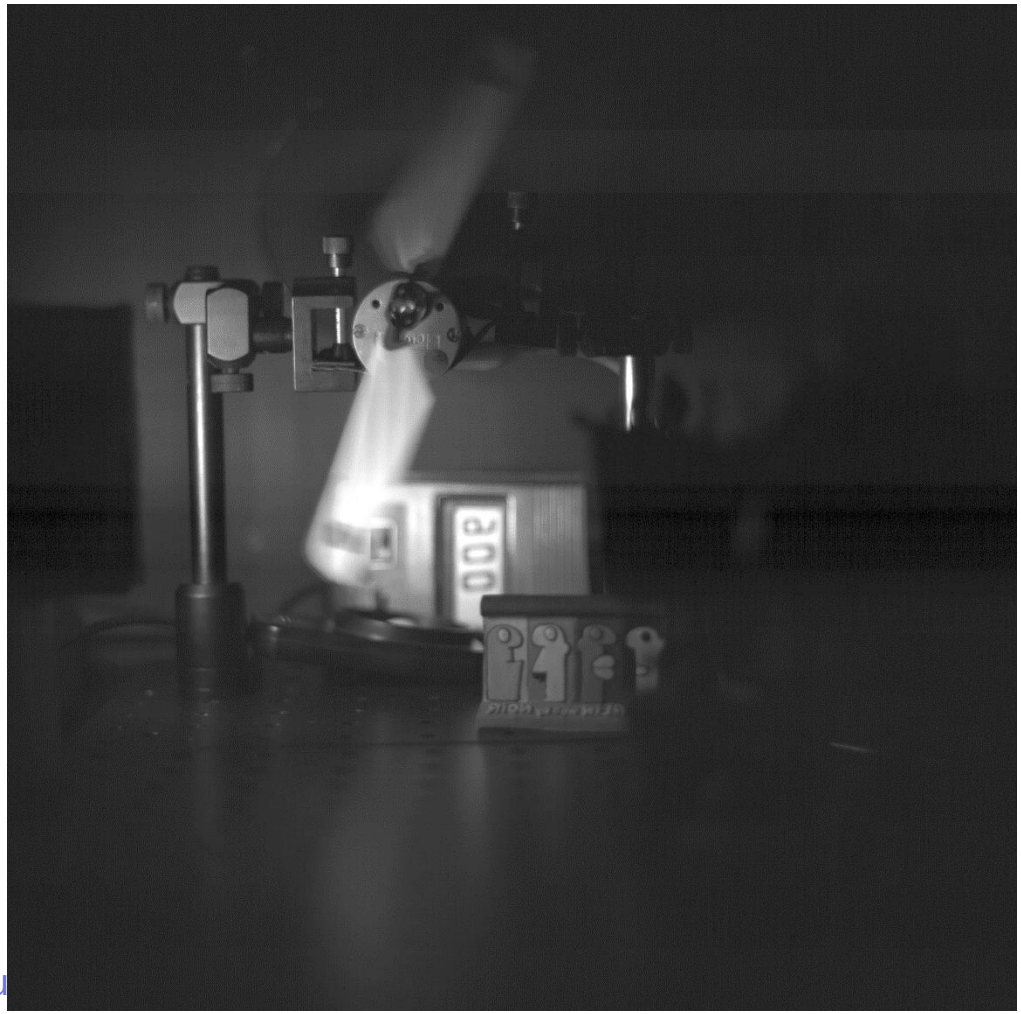
Low Q_{FW}



High Q_{FW}



Merged Images

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➡ True GS HDR Pixel
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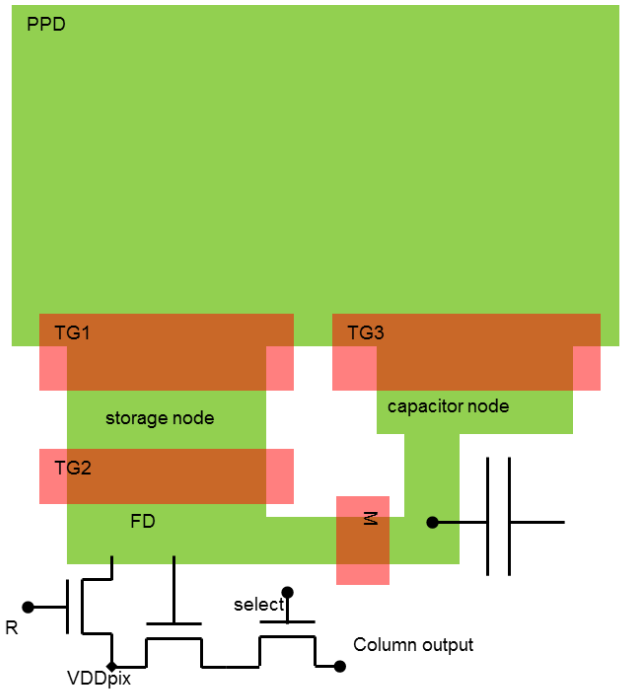
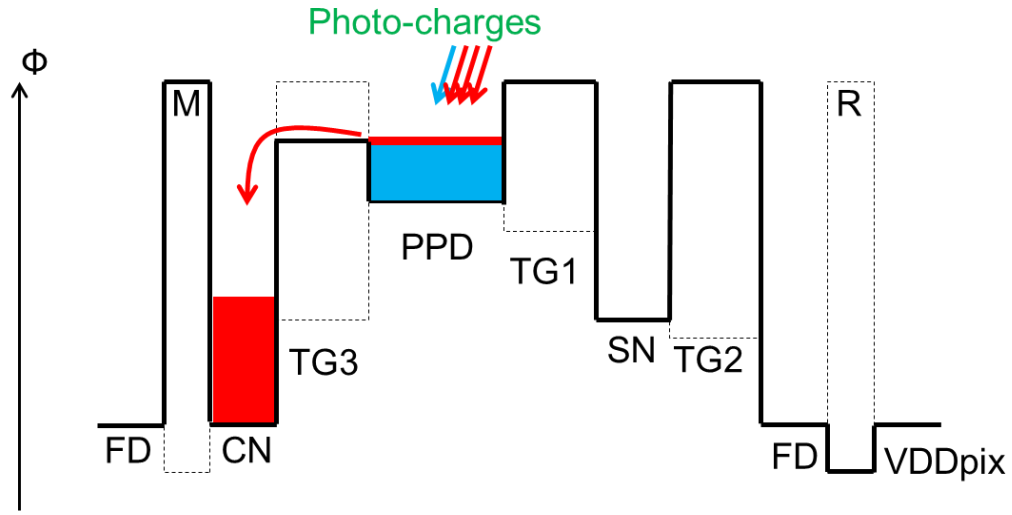
True GS HDR Pixel

True GS HDR Pixel





- TG1 is operated globally for charge transfer
- TG2 is operated in rolling readout mode
- TG3 is used for HDR functionality
- Technology optimization is required for
  - Implementing storage node
  - Reducing parasitic light sensitivity on storage node and FD

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Demonstrated:

- ⇒ HDR using two linear ranges during same integration time
- ⇒ Synchronous (global, IWR) shutter operation
- ⇒ Both linear ranges are synchronous
- ⇒ The highest sensitivity range operates in digital CDS.

Future outlook:

- ⇒ BSI (coming)
- ⇒ Global shutter CIS technology (coming)
- ⇒ Color (coming)

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Thank you!