MICRO-523: Optical Detectors

Week Ten: CMOS Cameras: Advanced Systems and Technical Aspects/2 – Solutions

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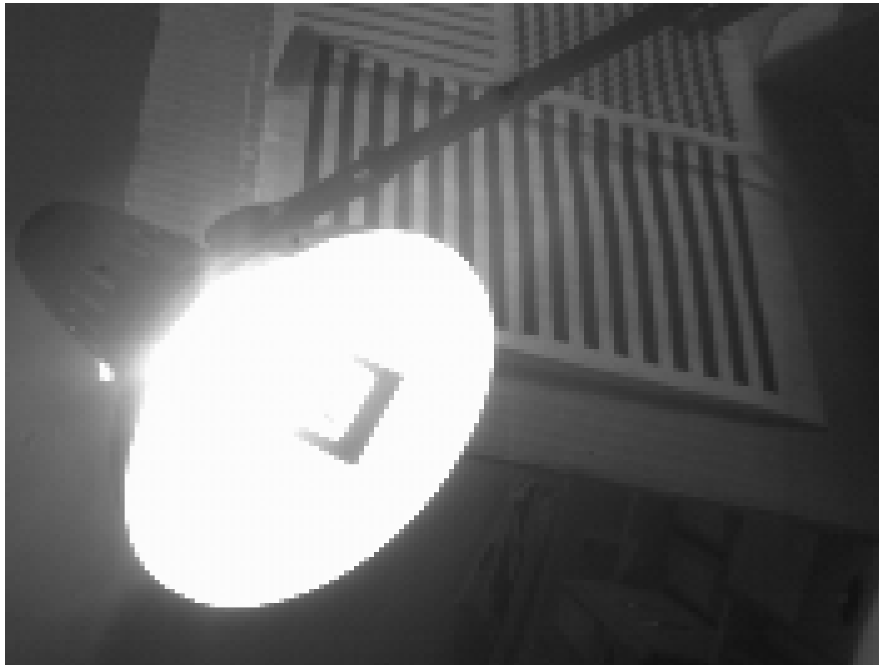
Outline

10.1 Introduction: Dynamic Range of CMOS Imagers

- In nature the dynamic range in the visible range is above 100dB
- The human eye can have a dynamic range up to 90dB
- CMOS APS imagers generally have a dynamic range of 40-70dB (2-4 decades, single exposure) but they can extend it using a number of techniques
- Scientific grade CCDs: D/R of up to 120 dB (6 decades)



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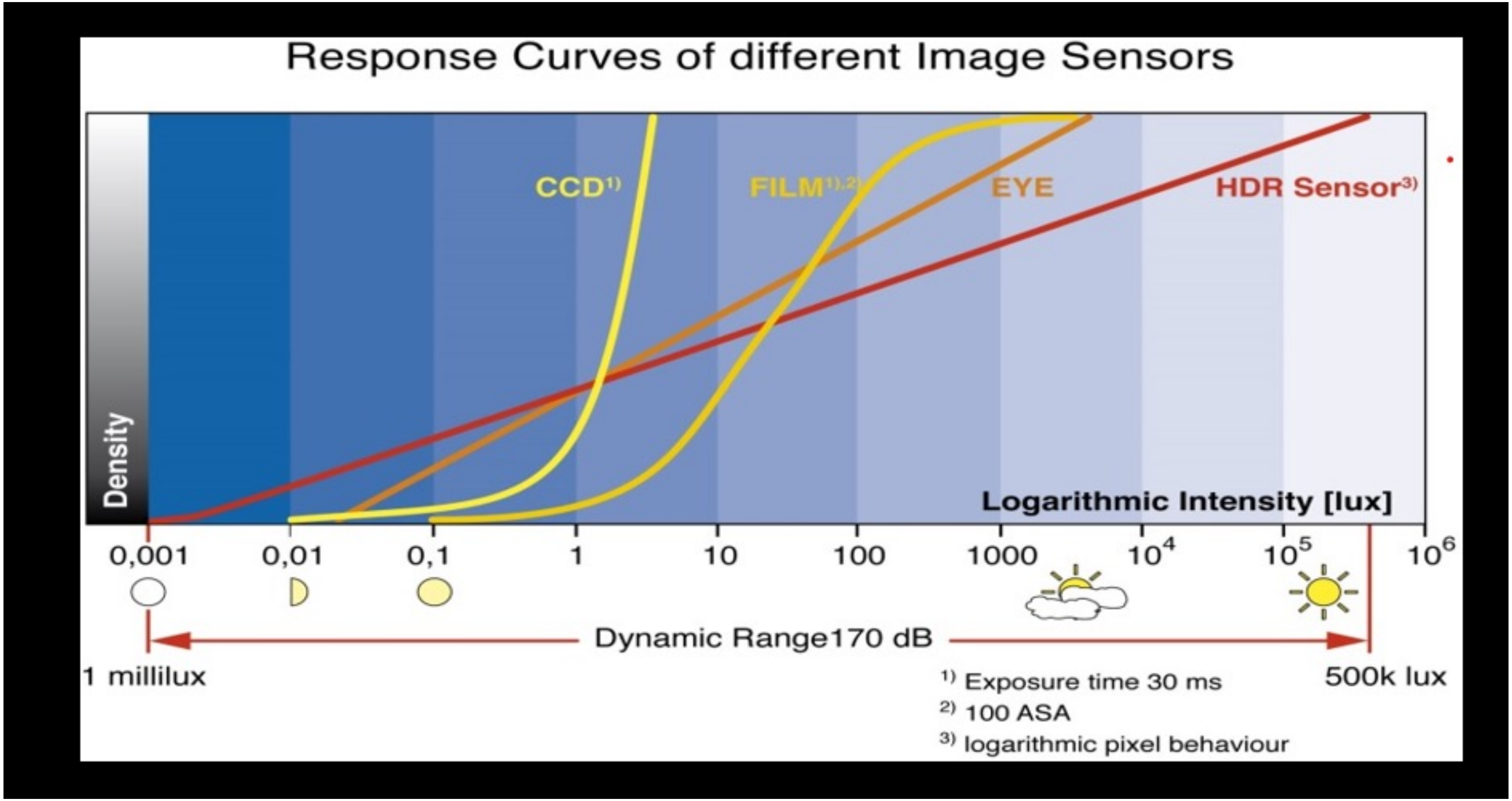
A) Low noise B) High full well

10.1 DR Examples



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10.1 DR Examples

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10.1 Dynamic Range Definition

Dynamic range is known as the maximum signal (maximum output swing) divided by the *rms* noise floor (temporal noise) → possible linearity range of a sensor.

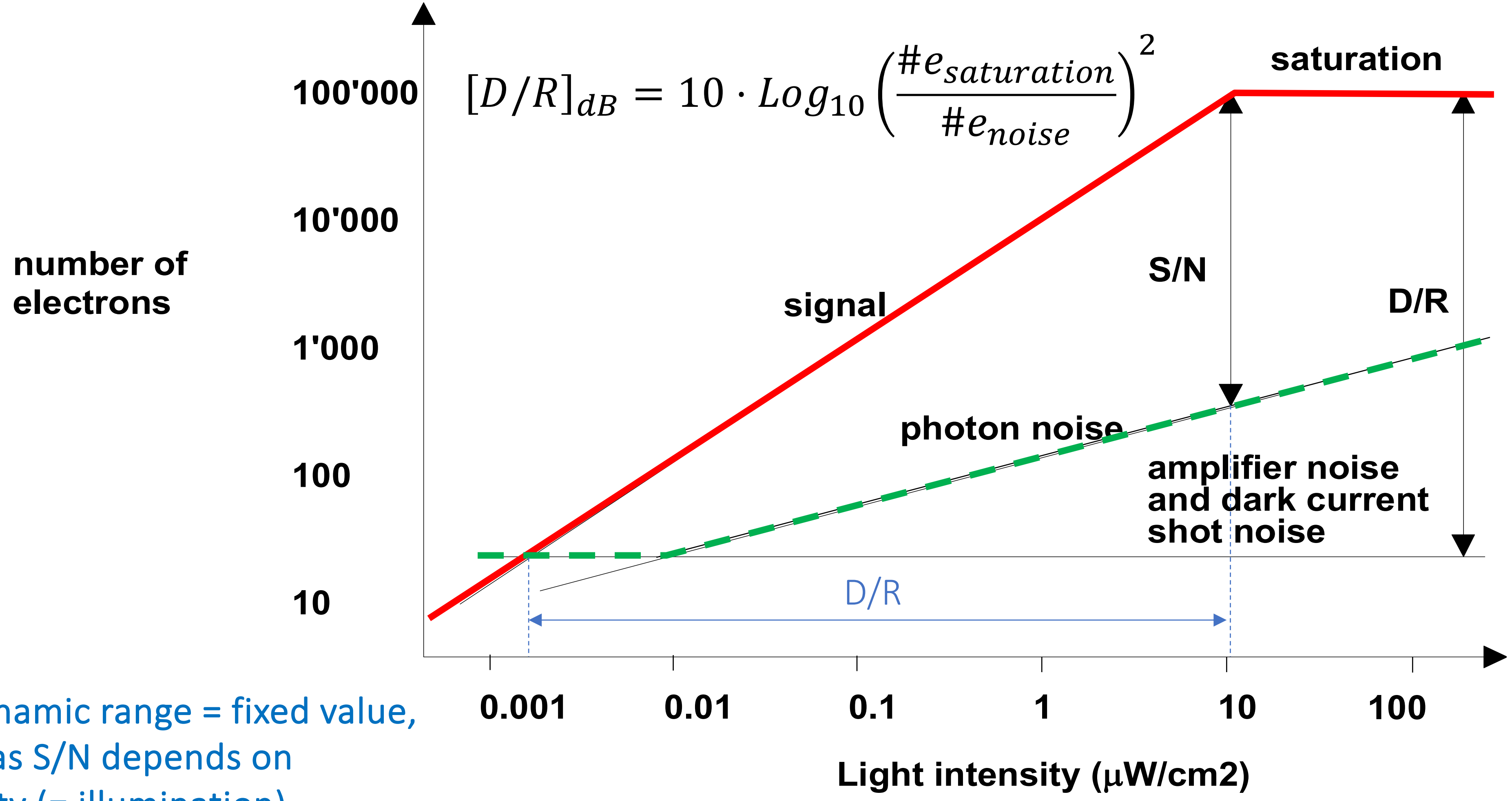
Dynamic Range = Full Well Capacity (electrons) / Read Noise (electrons)

$$[DR]_{dB} = 10\log_{10}\left(\frac{Q_{MAX}^2}{Q_{NOISE}^2}\right) = 10\log_{10}\left(\frac{V_{\max}^2}{V_{NOISErms}^2}\right)$$

$$Q_{MAX} = Full\ \ Well$$

$$[DR]_{dB} = 20\log_{10}\left(\frac{Q_{MAX}}{Q_{NOISE}}\right) = 20\log_{10}\left(\frac{V_{\max}}{V_{NOISErms}}\right)$$

10.1 Dynamic Range Definition



NB: dynamic range = fixed value, whereas S/N depends on intensity (= illumination)

10.1 Dynamic Range: Examples

- FW: 10.000 e- | Noise: 2e- |
  - DR: 74 dB
- FW: 100.000 e- | Noise: 1e- |
  - DR: 100 dB
- FW: 200.000 e- | Noise: 0.5e- |
  - DR: 112 dB

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10.1 Dynamic Range Extension Techniques

- Change exposure time (“Classic”)
- Make conversion gain non linear (“Not Linear”)
- Change conversion gain (“Photon” → Dual Conversion Gain)
- Adjust well capacity (“Photon” → Dual Storage Node)

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10.1 Dynamic Range Extension Techniques

CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence	Antiblooming	Polarization	Sony IMX390
Interleave	LinLog	Dual Conversion Gain	On Semi AR0233
Dual Exposure	Real Log	Dual Storage Node	OVT OX02A10
Piecewise linear	Solar Cell	SPAD / QIS	STM VC 6768

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Outline

10.2 Dynamic Range Extension – Change Exposure Time

Longer exposure time for dim objects ➔more charges at floating diffusion (but also higher Poisson noise)

Upper limit pushed up but lower limit unchanged

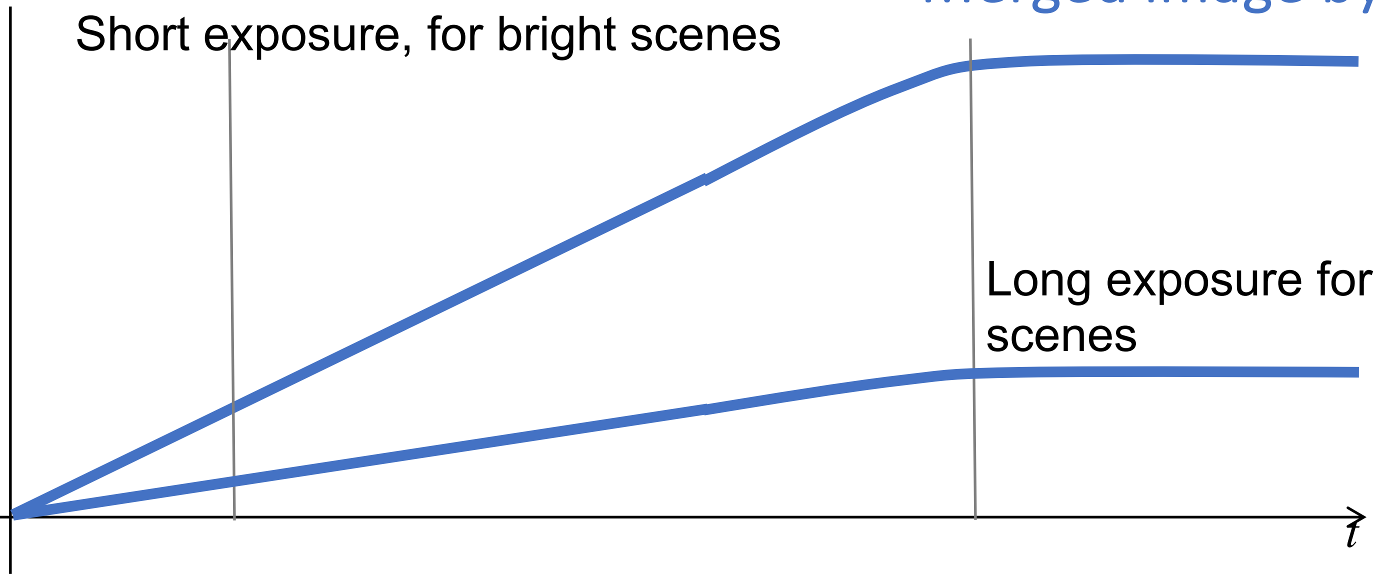
Drawback: fast moving objects incorrectly interpolated!

Long exposure

Short exposure

Merged image by signal treatment

Photo response [arbitrary units]



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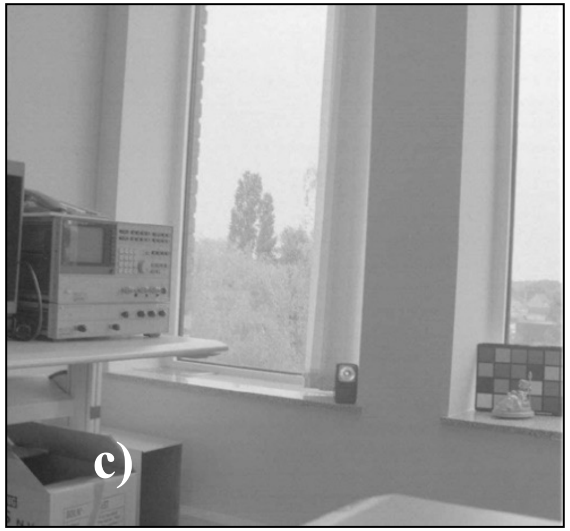
10.2 Dynamic Range – Example

Same scene taken with different DR and integration time



a) 60dB DR and a short integration time ("Ibis 4 imager")

b) 60dB DR and a long integration time ("Ibis 4 imager")

c) 120dB DR ("Fuga imager")

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CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence		Polarization	

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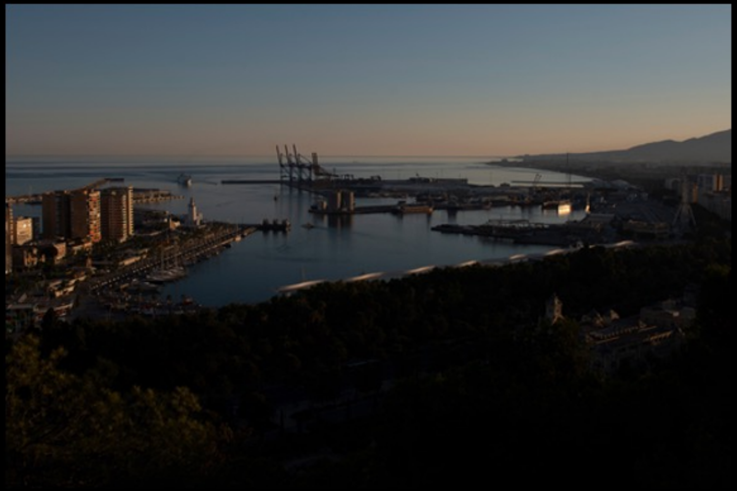
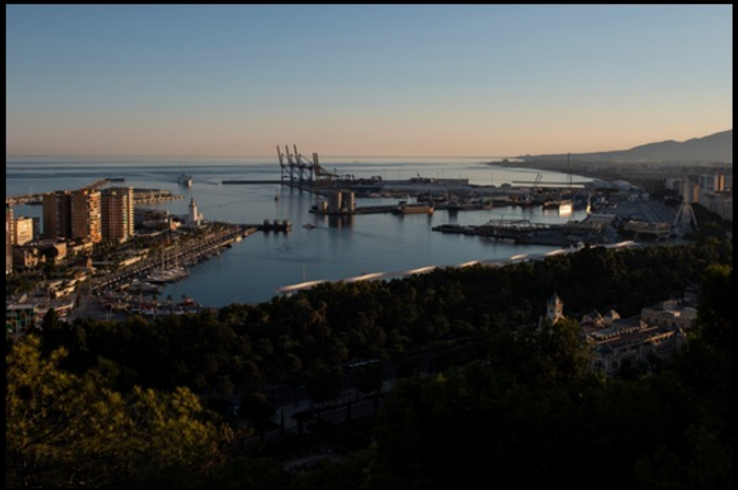
Sequencer





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Aurora HDR Software

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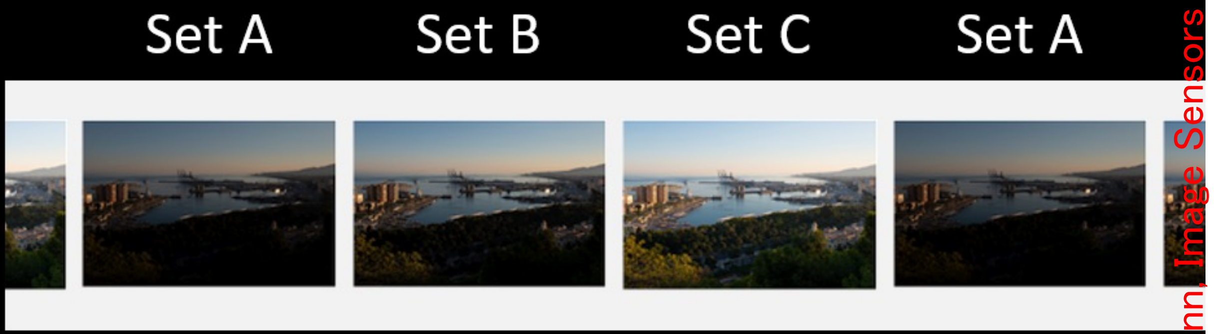
Sequencer

Sequencer

- Set of different settings (Exposure time, Gain), individual frame by frame
- DOL (Digital Overlap) in Sony Starvis Rolling Shutter Imagers: 2 to 3 Images in a sequence

Result:

- 2 to 11 different images
- @ DSC DSLR: ISP
- @ PC: Software Aurora…



Con:

- Slow in capture
- Artefacts with moving objects or changed conditions
- External processing
- Different results due to algorithms

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Outline

CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence	Antiblooming	Polarization	
Interleave	LinLog		
Dual Exposure			
Piecewise linear			

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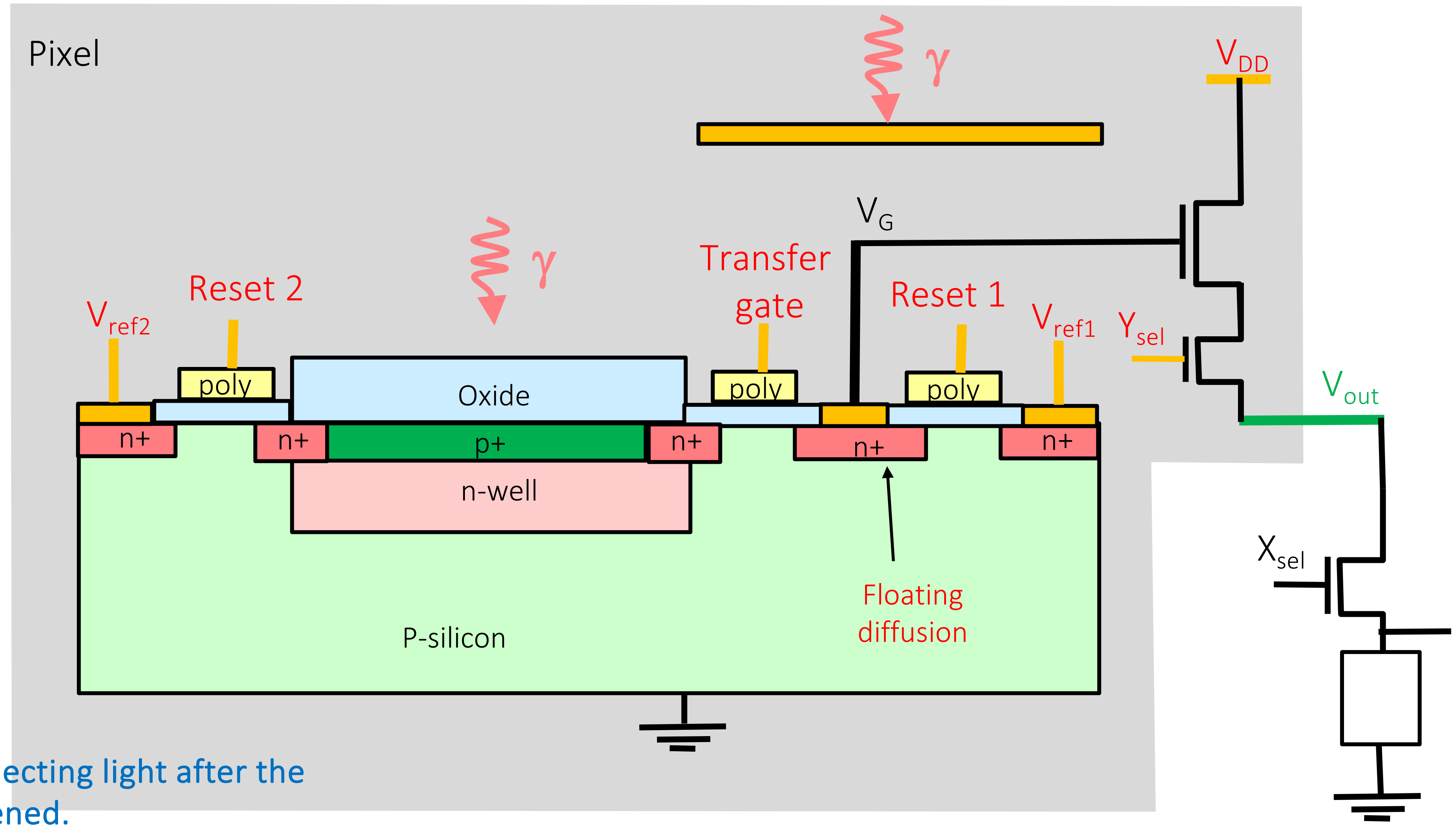
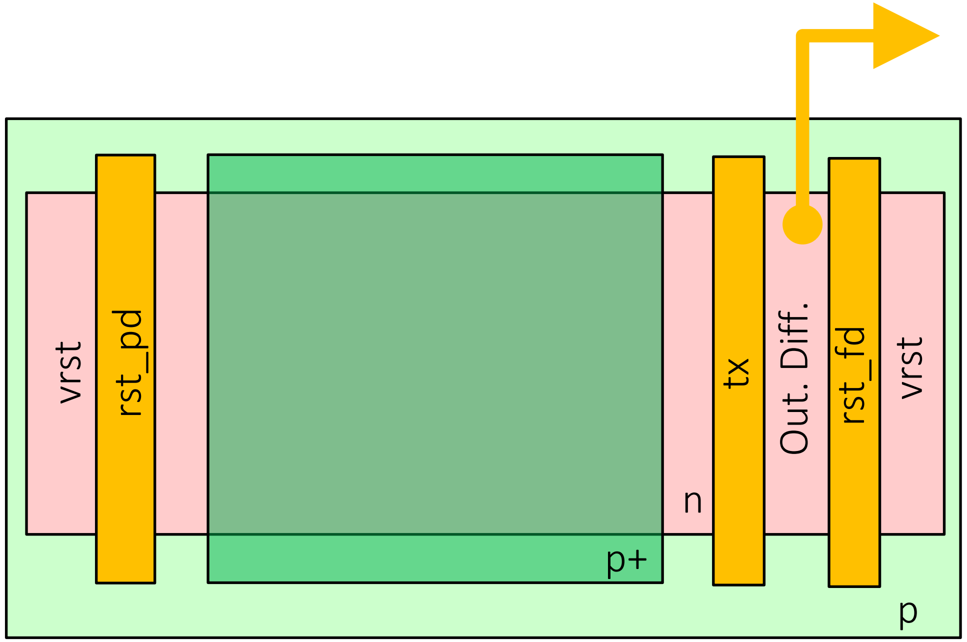
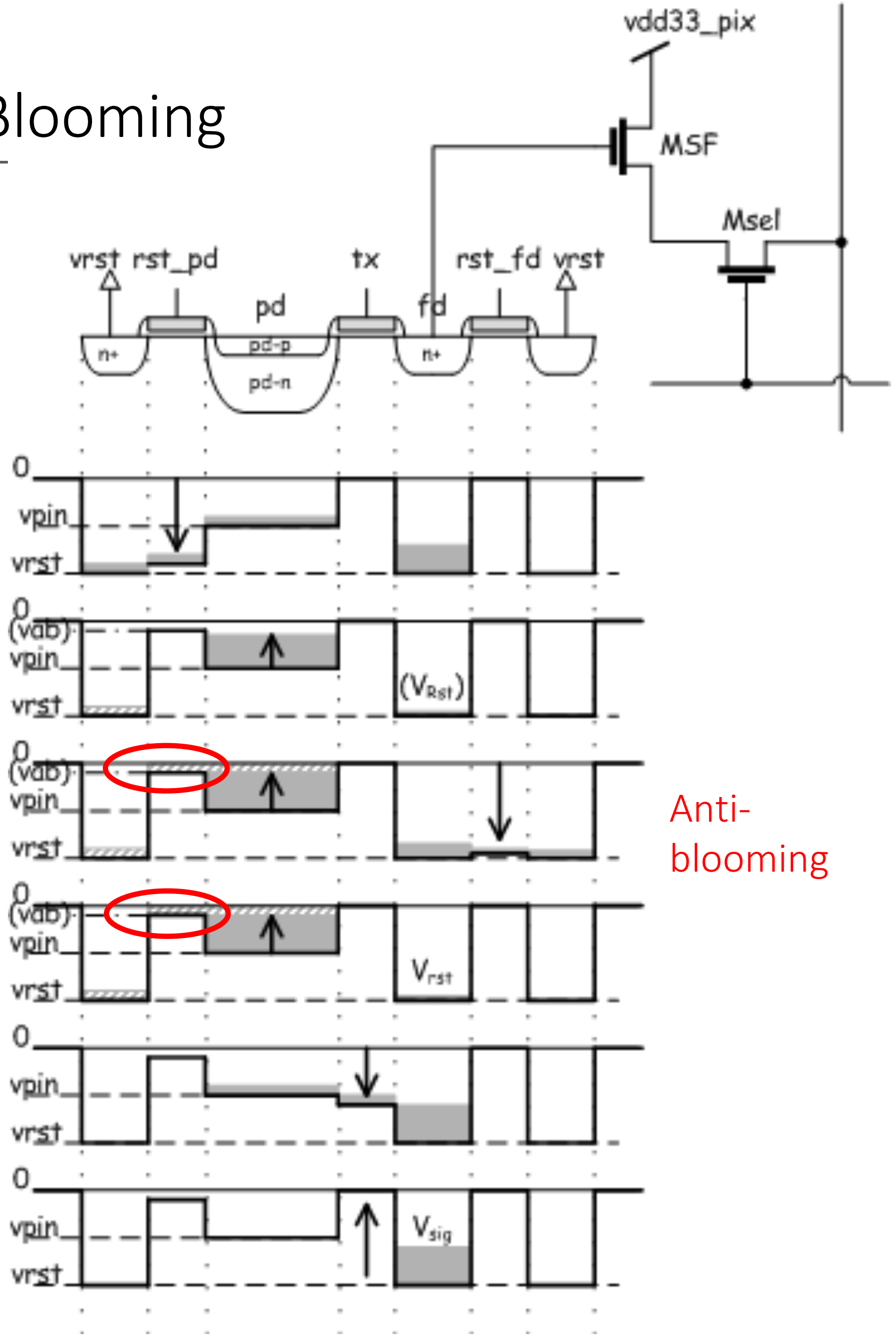
10.3 5T APS + PPD: Exposure Time Control and Anti-Blooming



PPD starts collecting light after the reset(2) is opened.

10.3 5T APS + PPD: Exposure Time Control and Anti-Blooming





Anti-blooming

LinLog | Photonfocus & Log Mode | e2v

Different Anti Blooming Voltages

Called Kneepoints

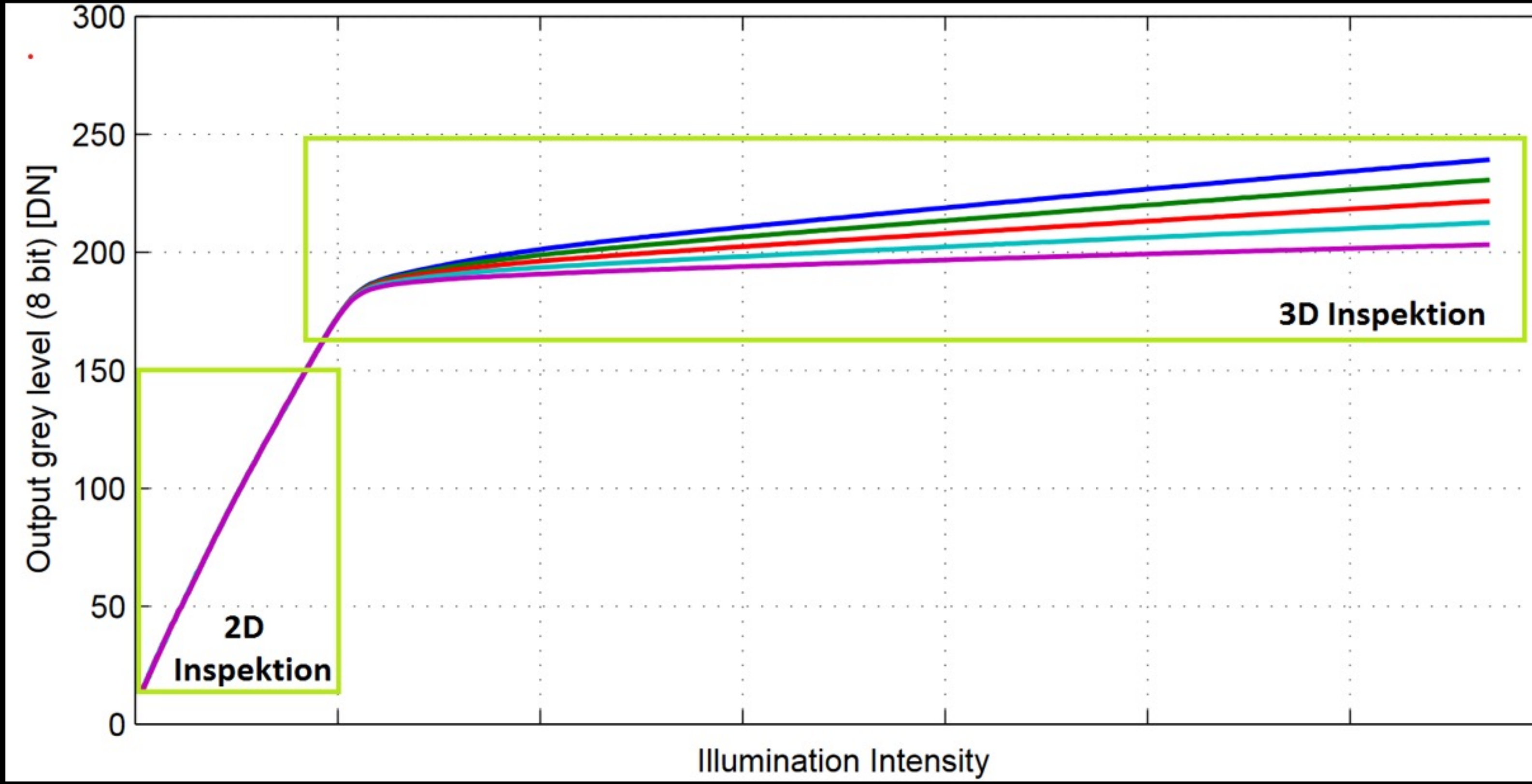
Control offset and slope

LinLog (Photonfocus)

- Offset and slope

LogMode (Teledyne e2v)

- Offset



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Con: FPN | Color Imaging | Motion artifacts with bright objects

LinLog

Only the bright parts are "damped"

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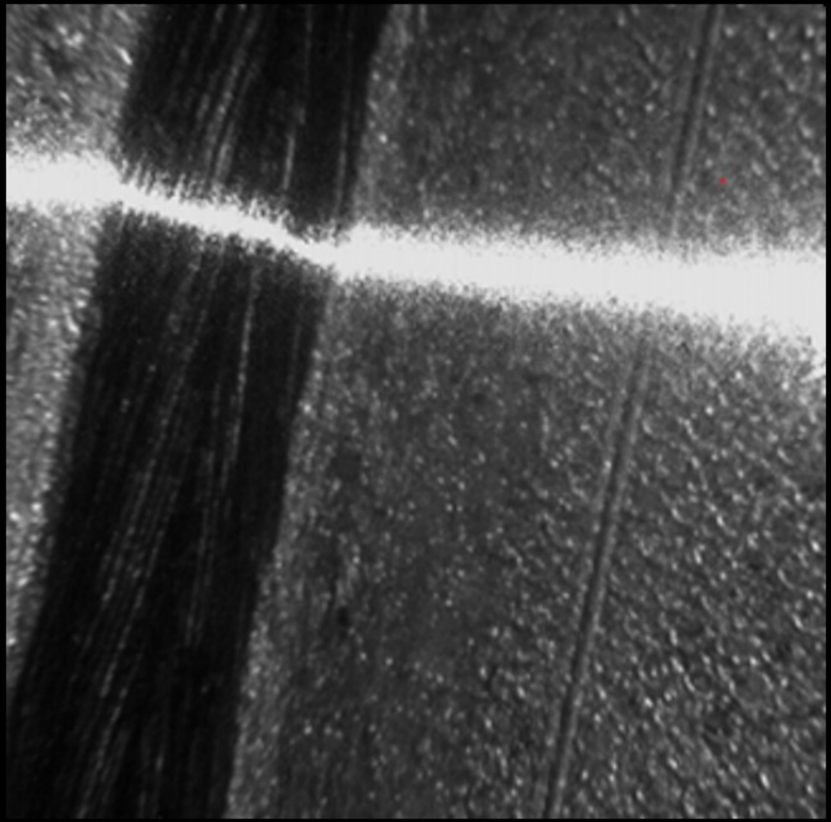
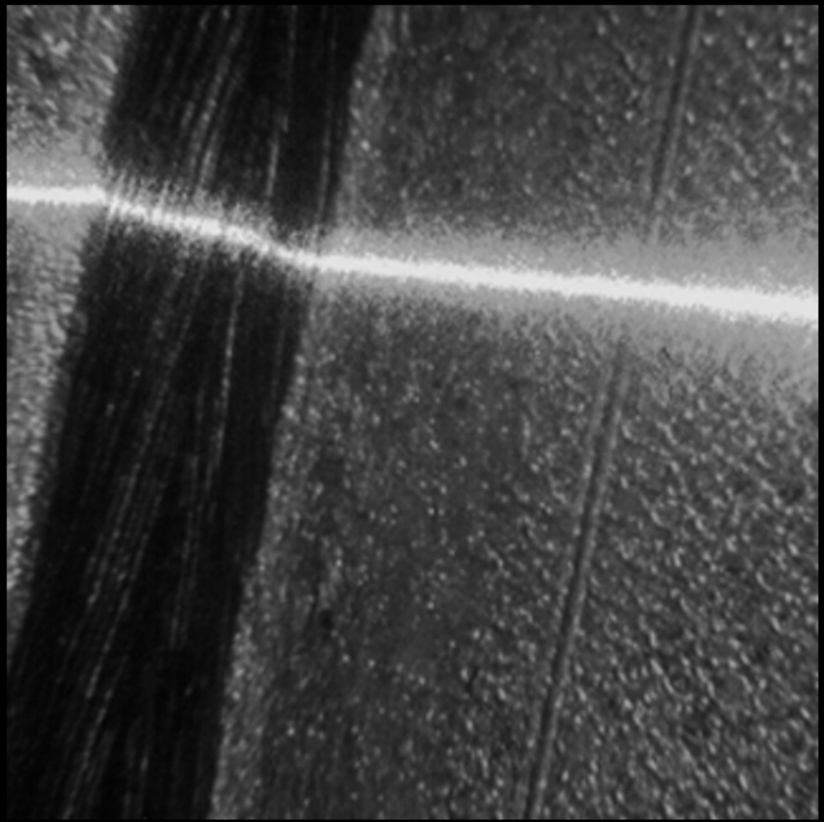
LinLog

Inspection of a Welding Seam



CMOS camera
with linear response curve (<60dB)



CMOS camera
with LinLog (120dB)

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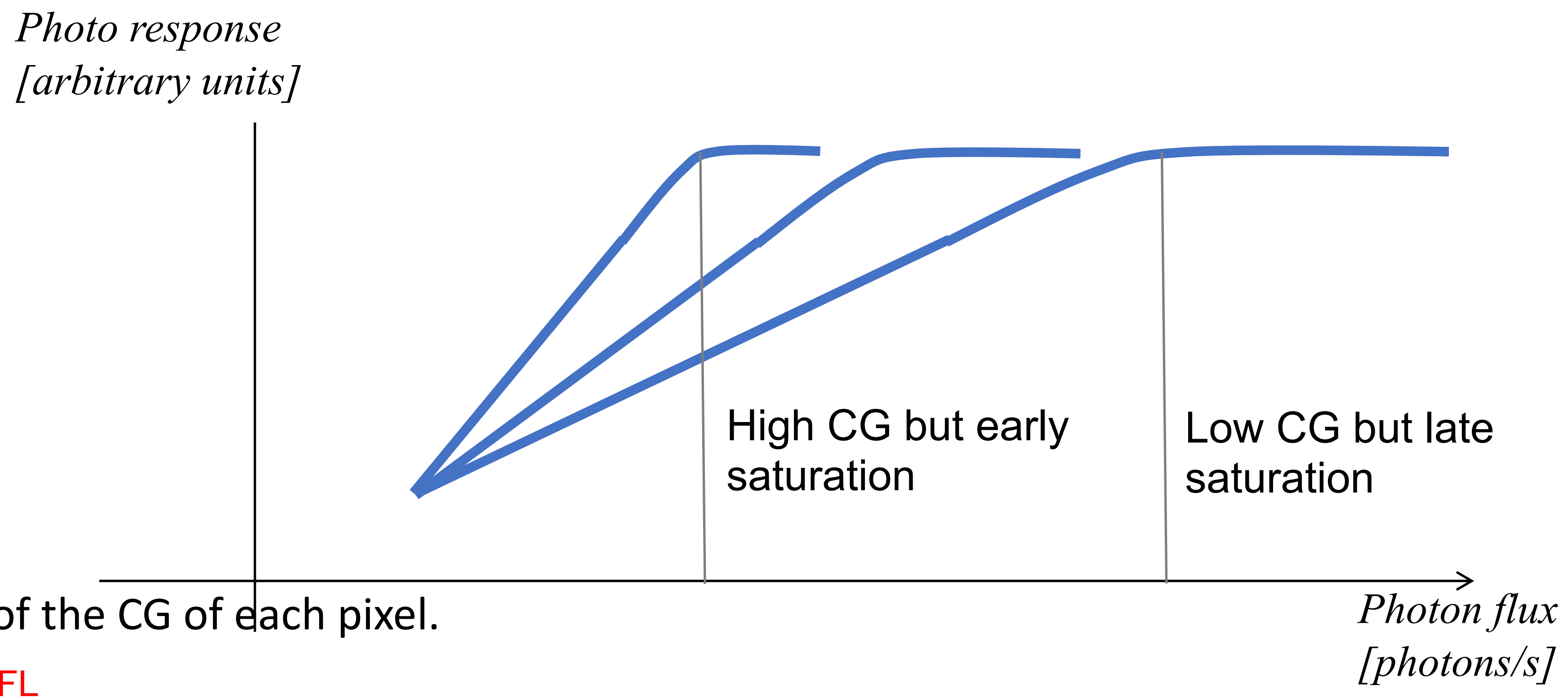
Outline

10.4 Dynamic Range Extension – Dual Conversion Gain

High CG (Charge Conversion) causes saturation in bright scenes

Low CG does not enable detection of dim scenes

DR is the same



Need to keep track of the CG of each pixel.

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CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence	Antiblooming	Polarization	
Interleave	LinLog	Dual Conversion Gain	
Dual Exposure	Real Log		
Piecewise linear	Solar Cell		

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Dual conversion gain

Convert photons twice and different into electrons!

LCG – Low Conversion Gain

This is the normal mode.

White is at 90% of pixel saturation.

For bright parts in the image.

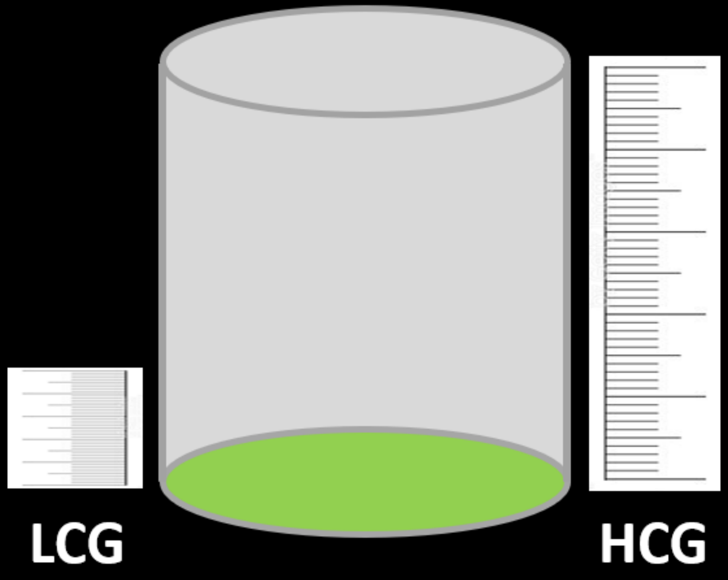
HCG – High Conversion Gain

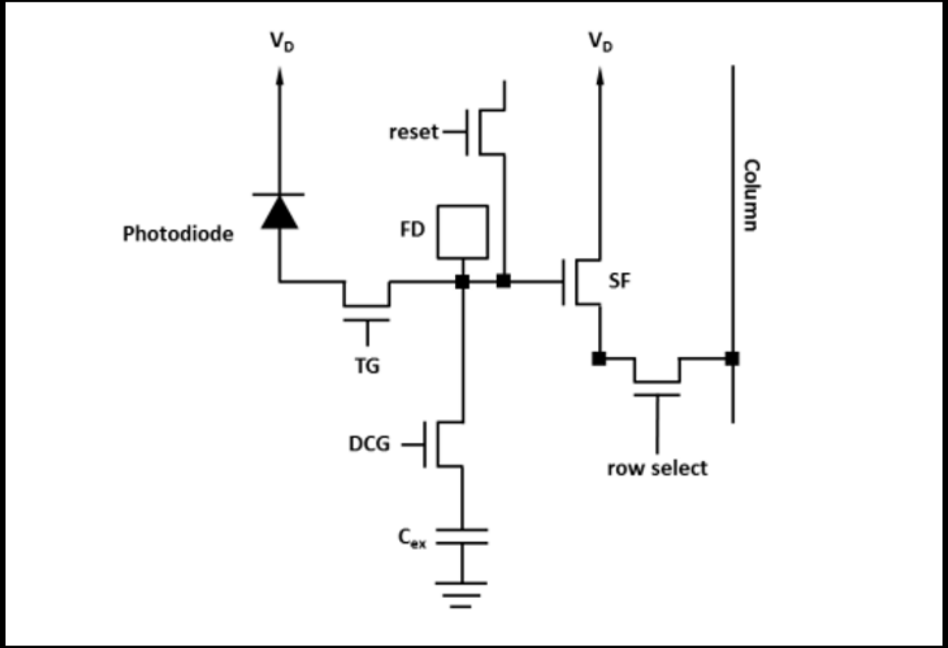
Advantage in SNR at low illuminance levels.

For dark parts in the image.

Factor 2 to 7 between LCG and HCG.

Combine on chip or with ISP!





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Outline

CLASSIC	NOT LINEAR	PHOTON	SPLIT
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Piecewise linear	Solar Cell		

On Semiconductor
AR0233

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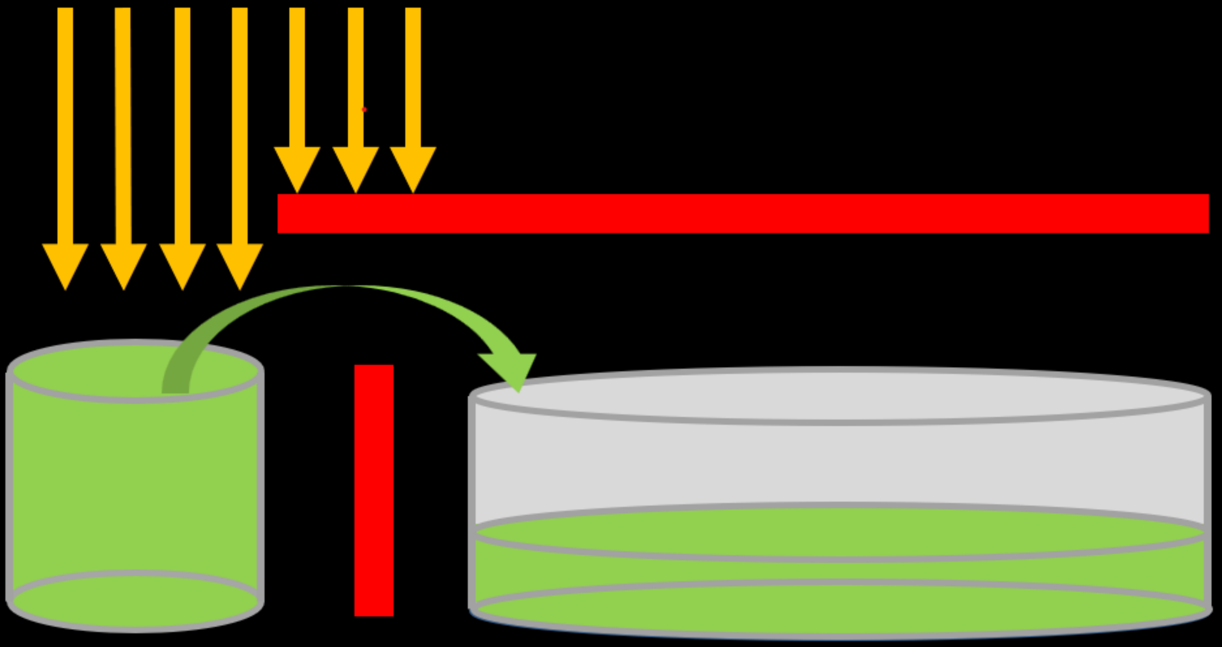
On Semiconductor

Single PD with additional local overflow „Area“

Dual CG | 4 readouts to combine



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High Dynamic Range

Single Exposure HDR Options

Split PD

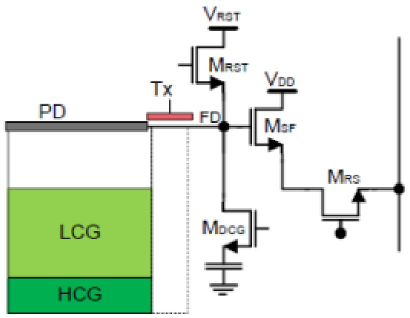
LPD for Lowlights, SPD for Highlights

DR Extension with Attenuation

Excellent performance down to 3µm

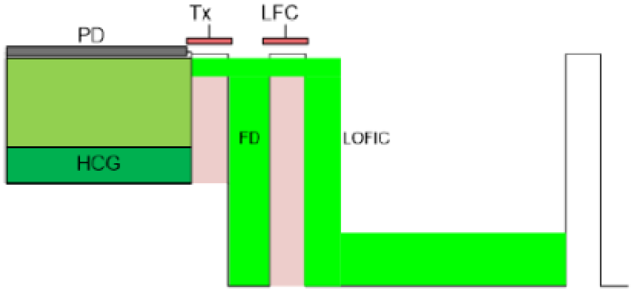
TheiaCel™

DCG™



+

LOFIC



& Engineering Excellence

DCG™: Deep Well™ Introduced to automotive by OMNIVISION in 2016

Limited Dynamic Range Extension due to photodiode physics

High Density Capacitors for DR Extension

Kneepoint SNR

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Acknowledgements

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Sources:

- Dana Diezemann, Image Sensors Europe 2020, London (Dana Diezemann Camera Consulting)
- Edoardo Charbon, EPFL MICRO-428 Metrology
- L. Grant, Omnivision