Dana Diezemann

High Dynamic Range Imaging | HDR

A short summary

Image Sensors Europe London | 12. 3. 2020 | Revised 11. 6. 2020

Polarized Pixels | Sony

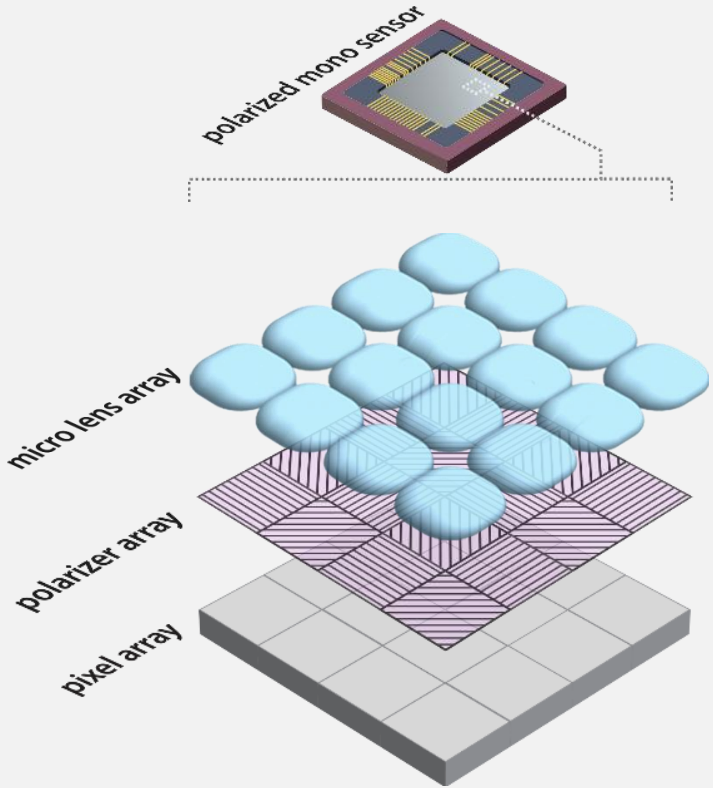

0d

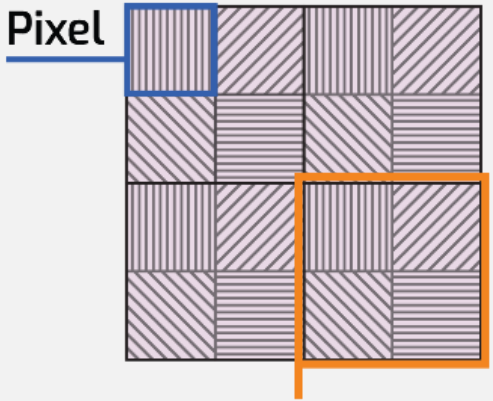

45d


90d

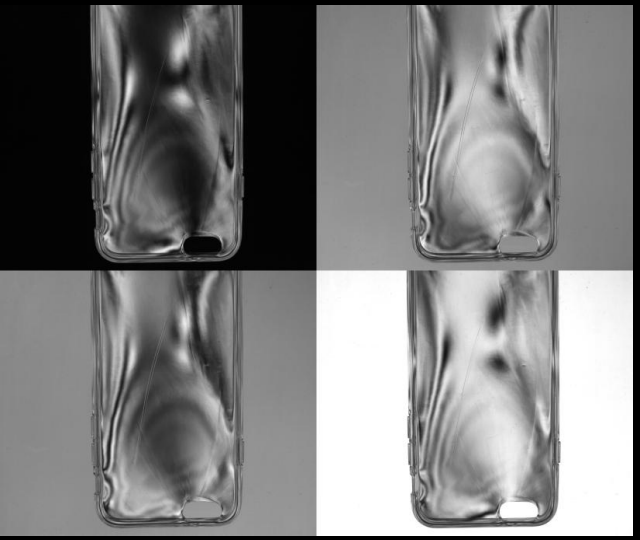

135d

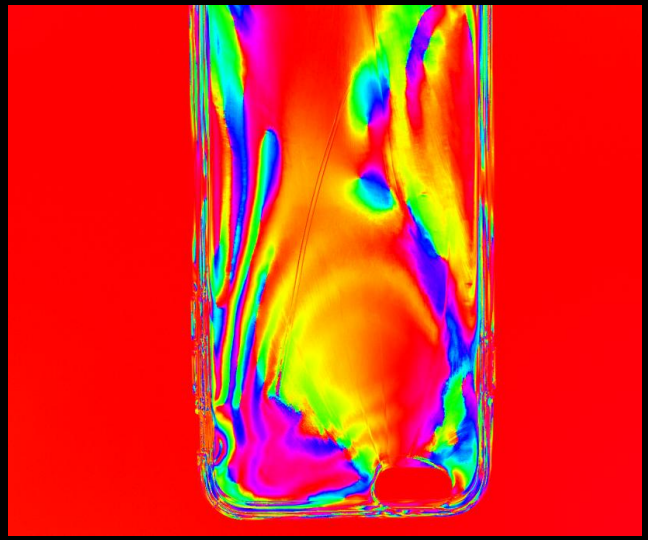
Polarized pixels | Sony

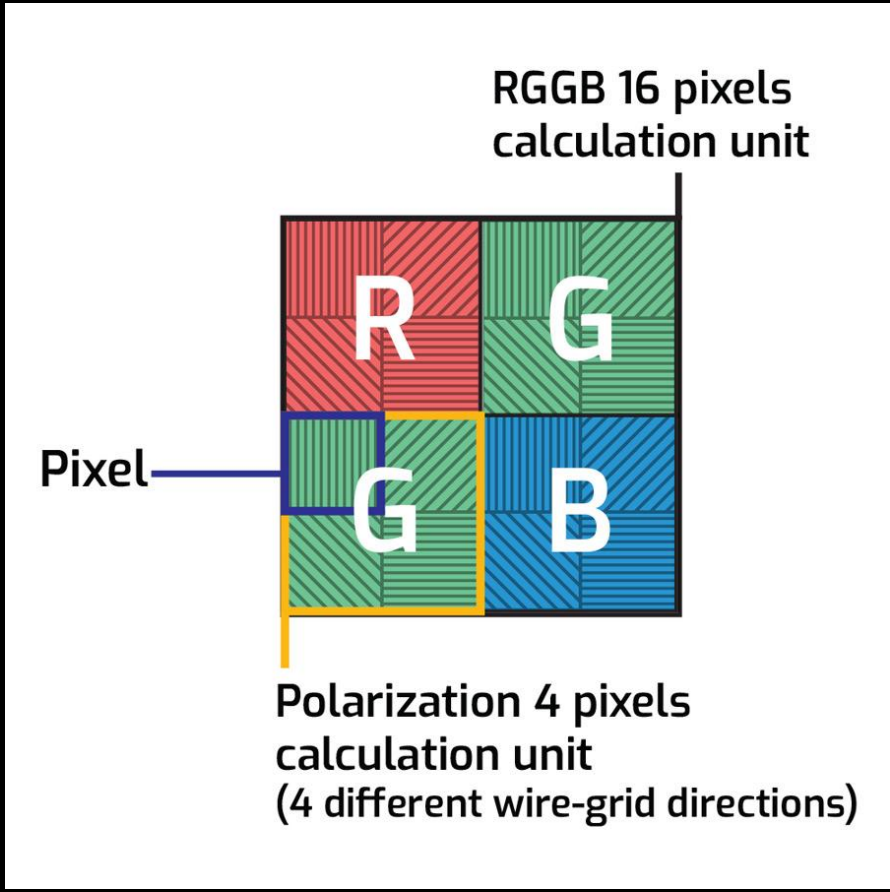




Calculation Unit
4 different directional polarizers







Polarized pixels | Sony

Pro:

4 different images in one capture.

Mono and color variants.

See more with reflections.

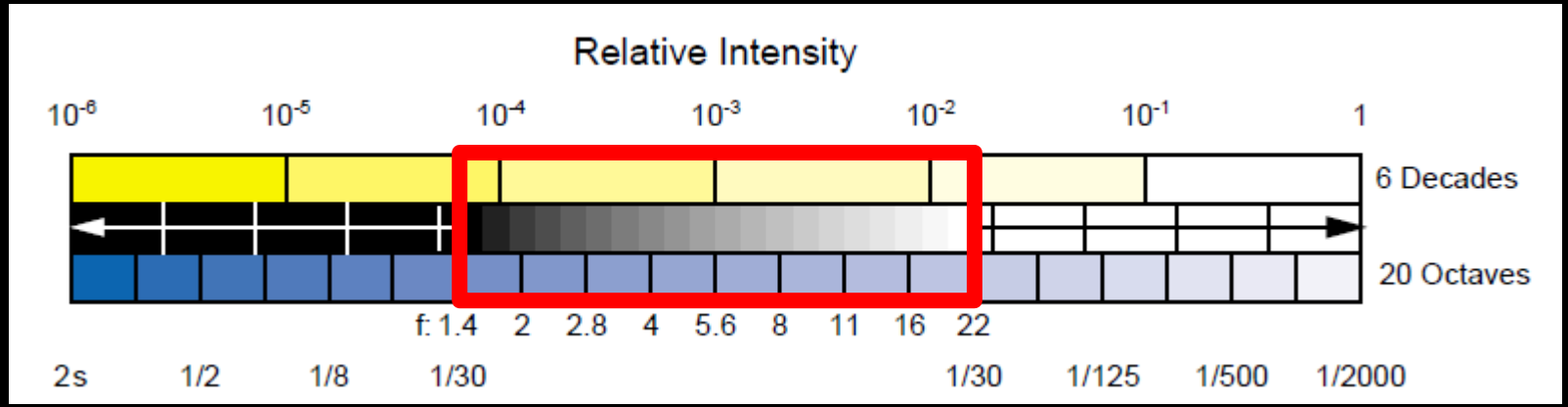
Con:

Not really more system dynamic.

Weak effect with stray light.

CLASSIC	NOT LINEAR	PHOTON	SPLIT
		Polarization	

Dynamic



Outdoor: ~ 160 dB

$$\text{Dynamic Range} = 20 \times \log \frac{\text{Fullwell Capacity}}{\text{Noise}}$$

Examples

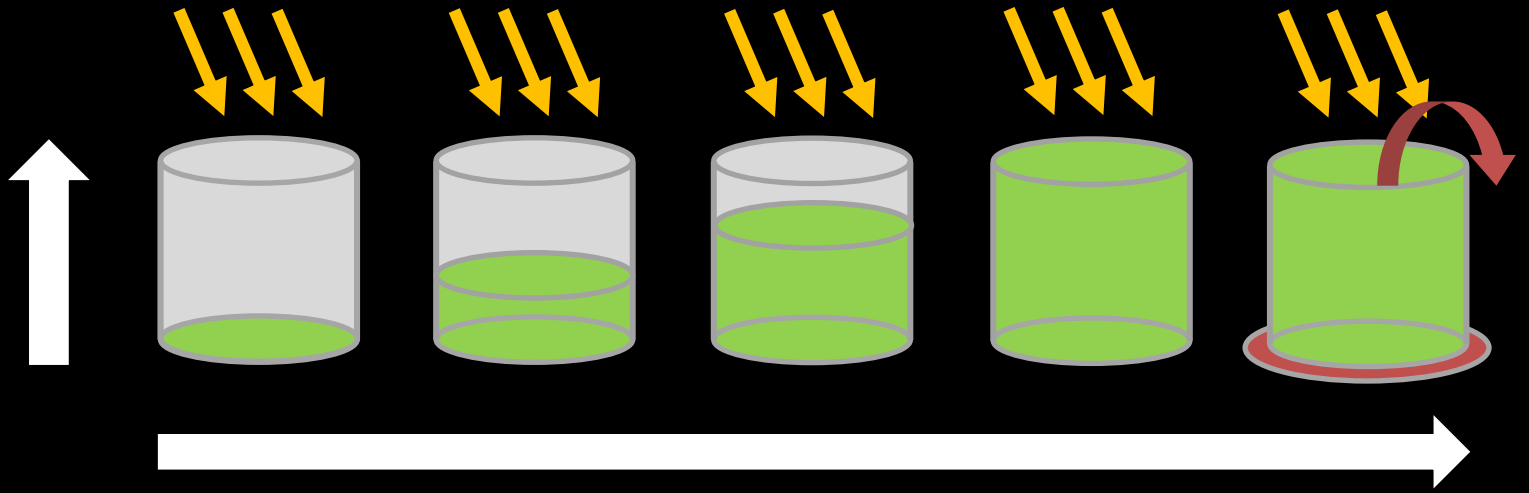
FW: 10.000 e- | Noise: 2e- | DR: 74 dB

FW: 100.000 e- | Noise: 1e- | DR: 100 dB

FW: 200.000 e- | Noise: 0.5e- | DR: 112 dB

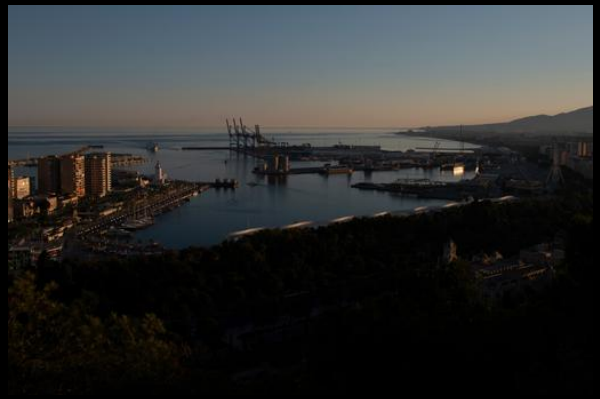
HDR

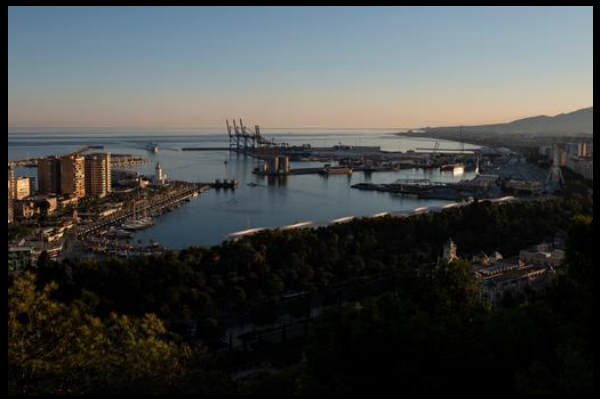
A linear pixel has limitations in its dynamic range. Always.



CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence		Polarization	

Sequencer





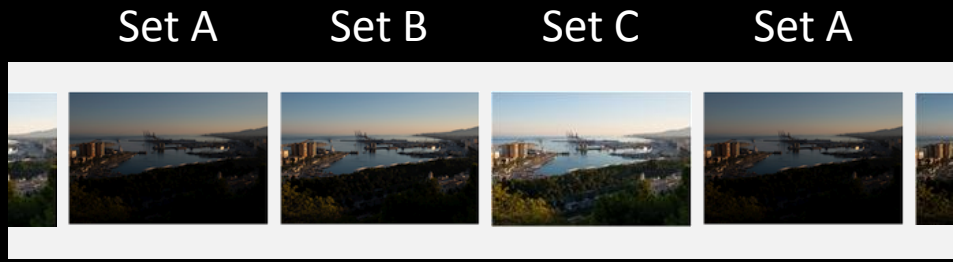
Sequencer

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

CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence		Polarization	
Interleave			

Single-frame multi-exposure

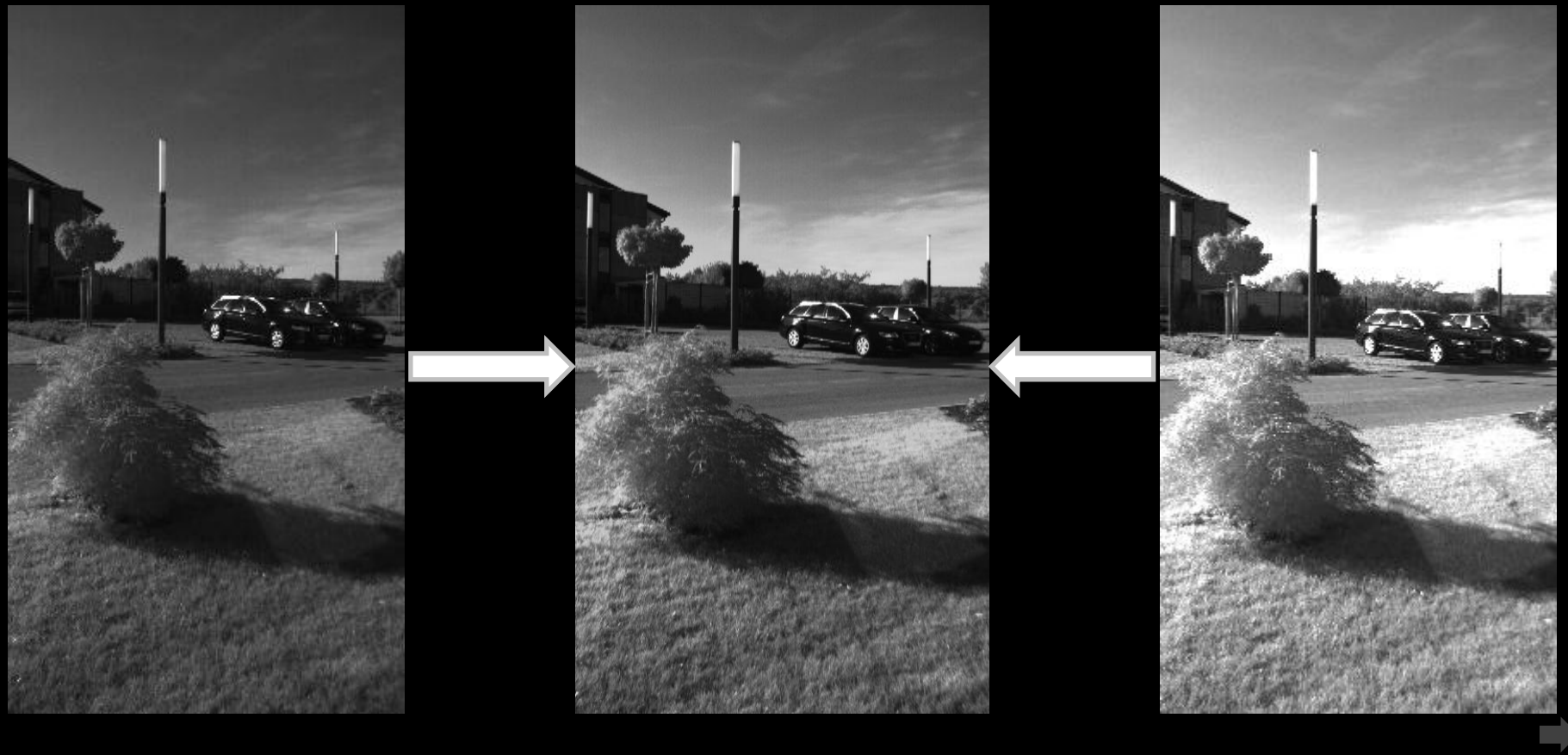
Example: Line wise

Short Exposure

Long Exposure

Single-frame multi-exposure

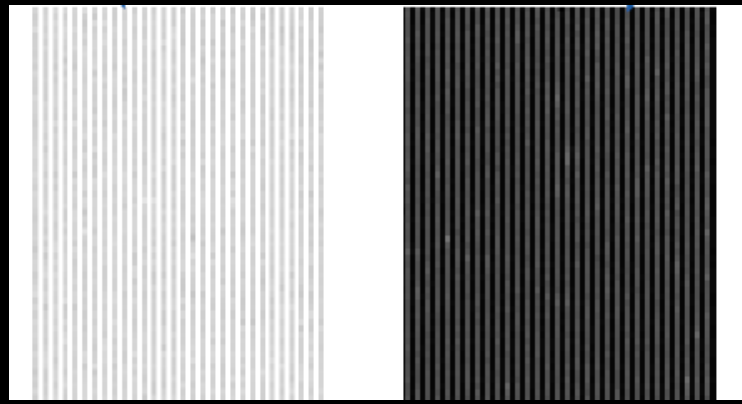
Single-frame multi-exposure



Single-frame multi-exposure

This is called Interleave HDR.

Line wise: Photonfocus | CMOSIS CMV | GPIXEL GMAX sensors.
Column wise: Teledyne e2v Snappy sensors.



The shorter exposure time starts later
by a longer pixel reset phase.
End by the charge transfer.

Pro: One image capture with 2 different images.
Con: Low resolution | weak HDR effect.
Different exposure start is difficult for moving objects.

CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence		Polarization	
Interleave			
Dual Exposure			

Dual exposure | triggering

Sony Pregius series | 3rd and 4th generation

Sensor is divided into two vertical regions with different exposure timings and gain settings

ROI: Upper part

ROI: Lower part

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

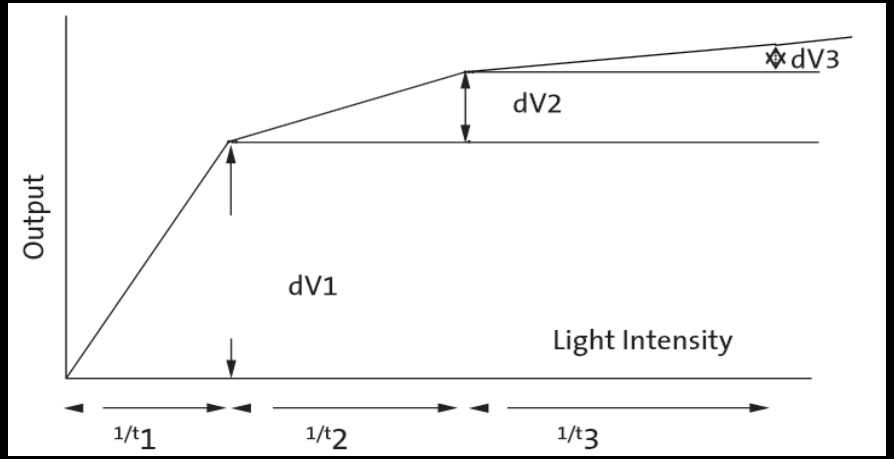
Multiple reset voltages & reset points

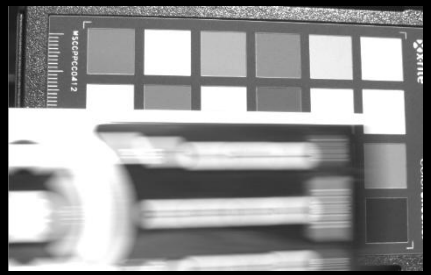
Called Kneepoint Mode or Piecewise Linear Pixel Response.

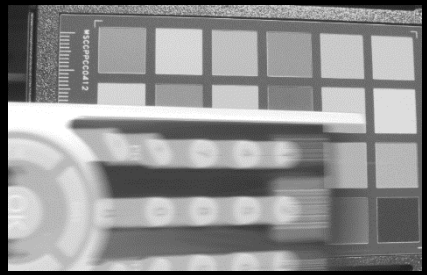
First example 2004: Micron MT9V022.

2 or 3 exposure phases.
Brighter pixels where reset to given level.
Then short exposure phase added
to saturate the pixels again.
And optional again.

Pro: One capture | One result.
Con: Moving bright objects | Color balance.



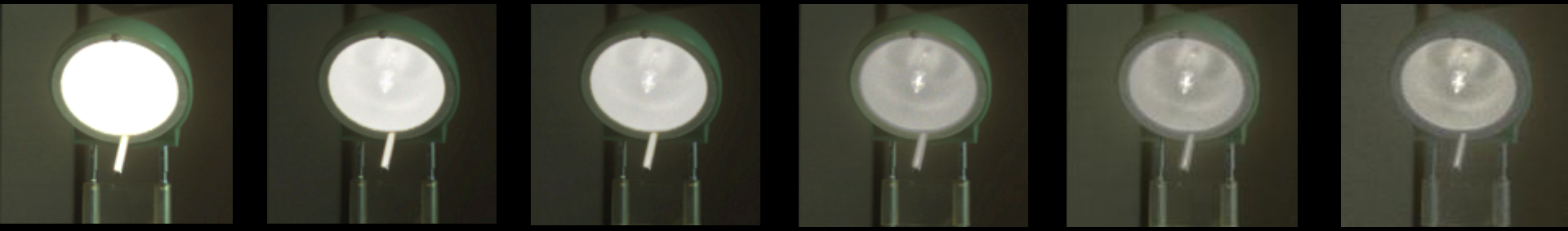




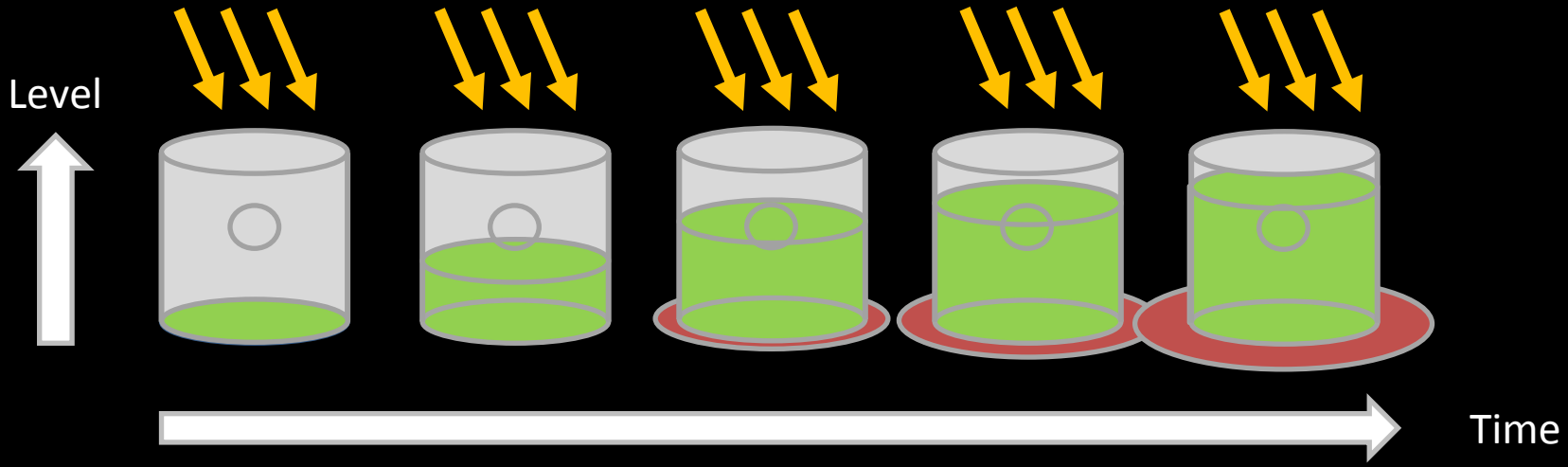
CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence	Antiblooming	Polarization	
Interleave			
Dual Exposure			
Piecewise linear			

Playing with the Antiblooming Voltage…

Only the bright parts are “damped”



“Drill a hole and spill out…”



LinLog | Photonfocus

Different Anti Blooming Voltages controls the offset of the “knee”.

Teledyne e2v: ev76c560 | ev76c570

Cons:

FPN around the kneepoint

Color Imaging

Not working with low light scenes

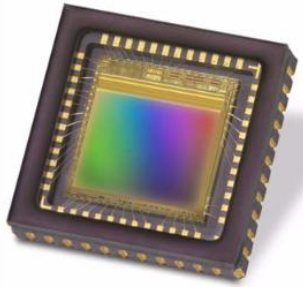
e2v

EV76C560
1.3 Mpixels B&W and Color CMOS Image Sensor

Datasheet

Features

- 1.3 million (1280 x 1024) pixels, 5.3 µm square pixels with micro-lens
- Optical format 1/1.8"
- 60 fps@ full resolution
- Embedded functions:
  - Image Histograms and Context output
  - Sub-sampling / binning
  - Multi-ROI (including 1 line mode)
  - Defective pixel correction
  - PLL with 5 to 50 MHz input frequency range (compatible with dithered master clock)
  - High dynamic range capabilities
  - Time to Read improvement (Abort image and Good first image)
- Timing modes:
  - Global shutter in serial and overlap modes
  - Rolling shutter allowing true CDS readout and global reset
- Output format 8 or 10 bits parallel plus synchronization



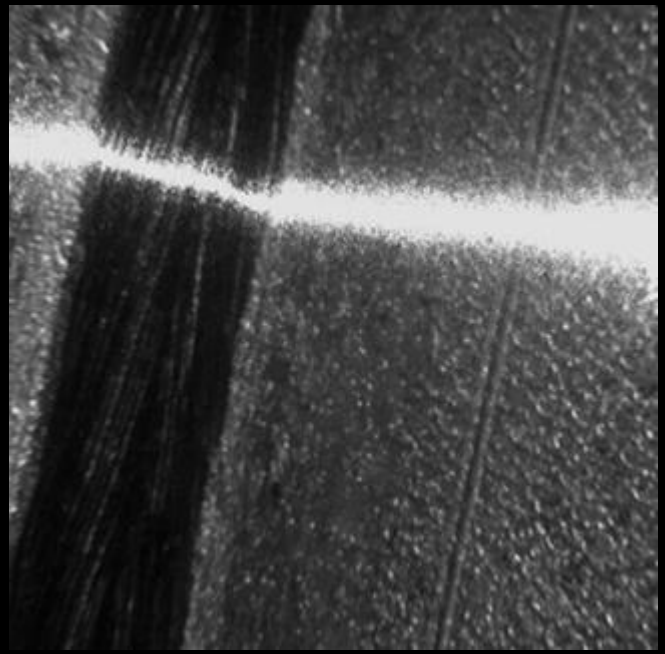
CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence	Antiblooming	Polarization	
Interleave	LinLog		
Dual Exposure			
Piecewise linear			

LinLog

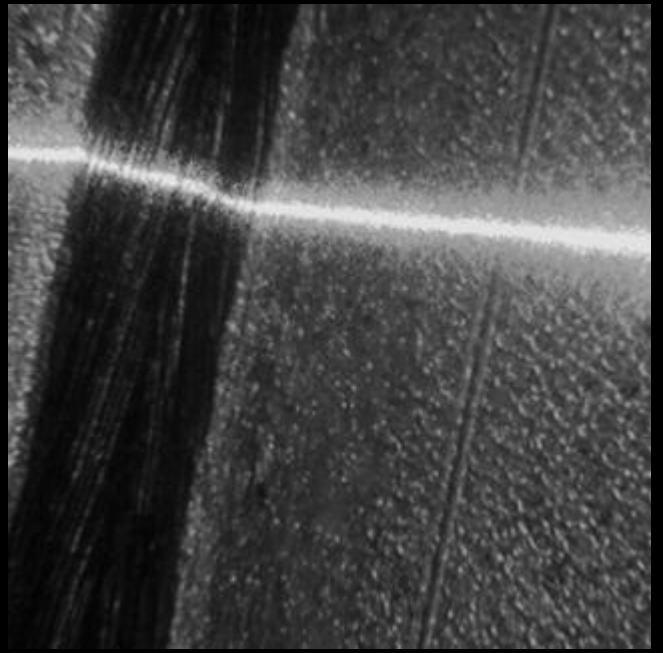
Only the bright parts are “damped”

LinLog

Inspection of a Welding Seam



CMOS camera
with linear response curve (<60dB)



CMOS camera
with LinLog (120dB)

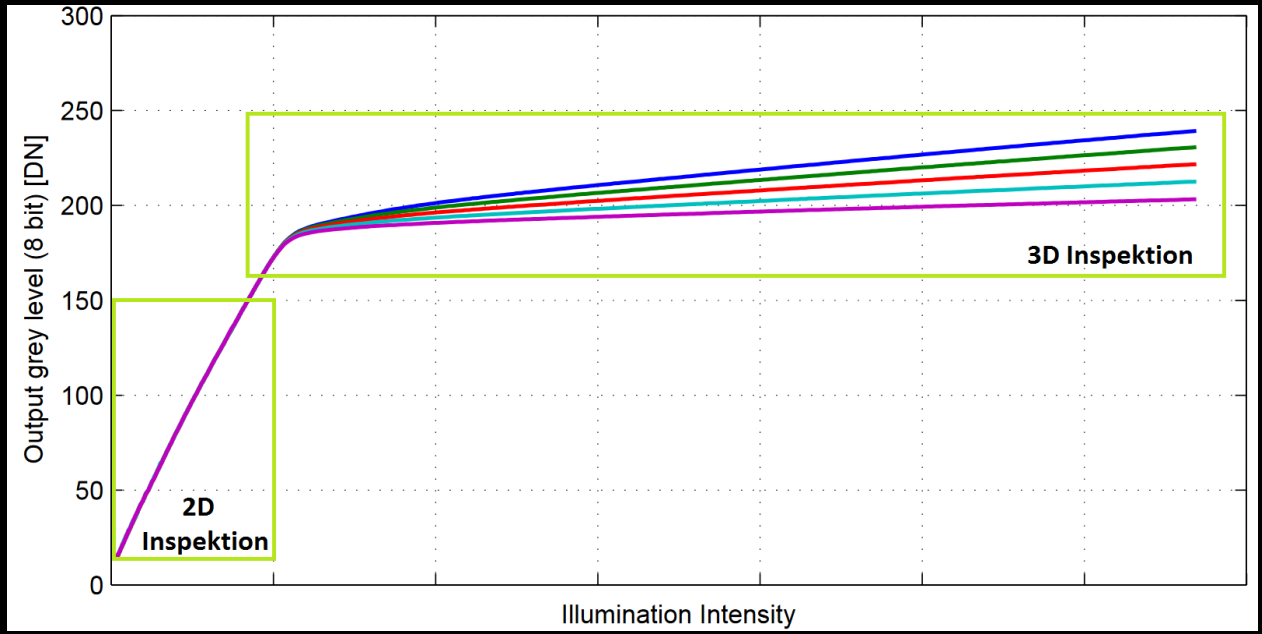
LinLog | Photonfocus & Log Mode | e2v

Different Anti Blooming Voltages

Called Kneepoints
Control offset and slope

LinLog (Photonfocus)
Offset and slope

LogMode (Teledyne e2v)
Offset

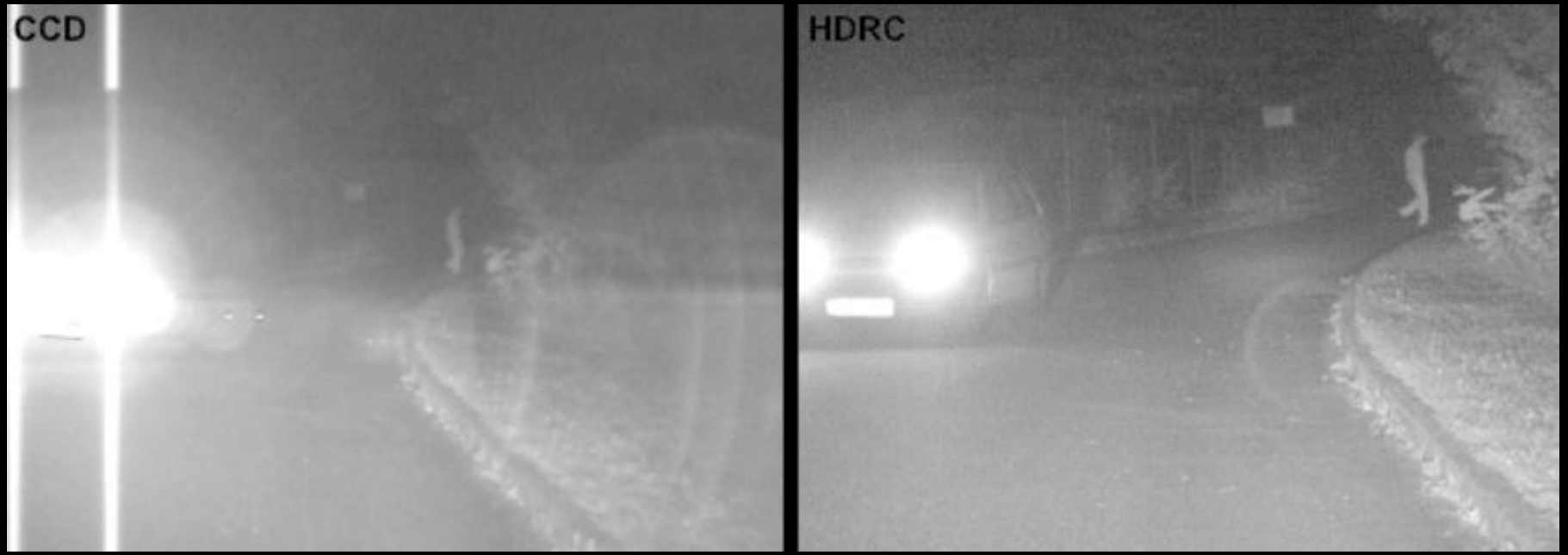


Con: FPN | Color Imaging | Motion artifacts with bright objects

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

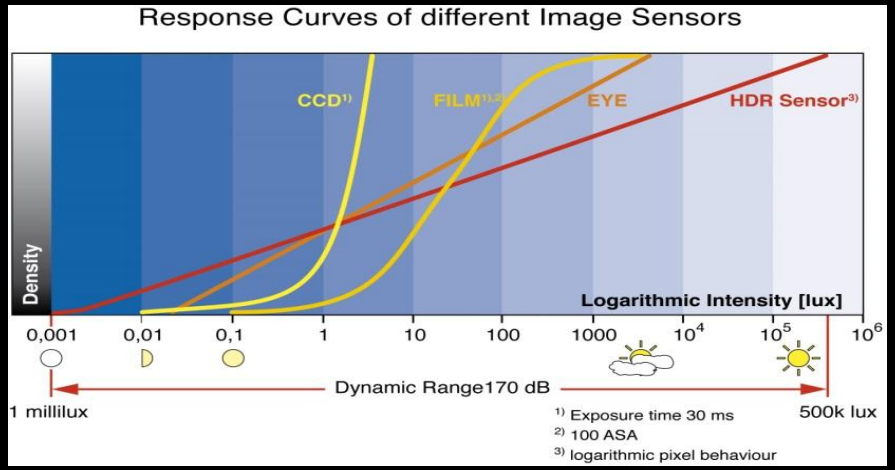
Full-logarithmic | IMS

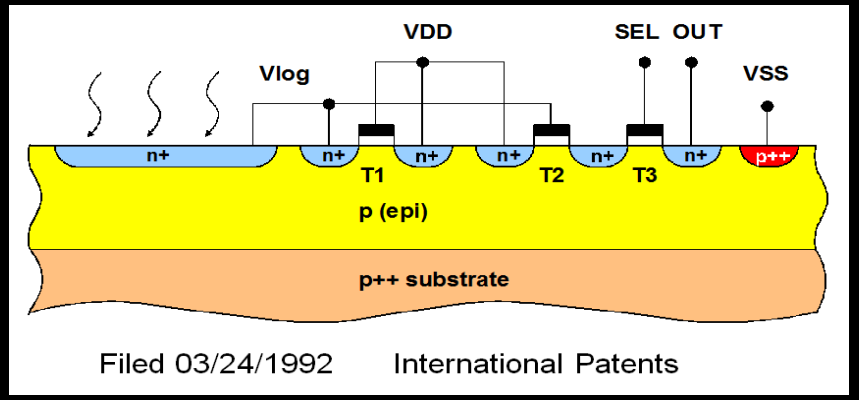
HDRC Imager

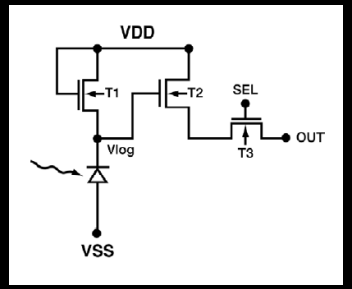


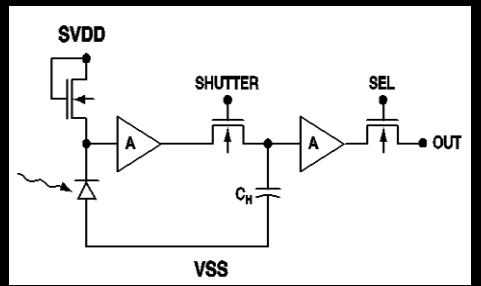
Full-logarithmic | IMS

HDRC (High Dynamic Range CMOS)









Pro: Real log Pixel

Con:
Complex DSNU & PRNU correction
Motion artifacts with bright objects

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

No integration | logarithmic | NIT

IMX 174

NSC1003

No integration logarithmic | NIT

WyDy | WDR – Wide Dynamic Range

Pro:

Solar cell pixel | actual light value

no integration | global readout

real log pixel

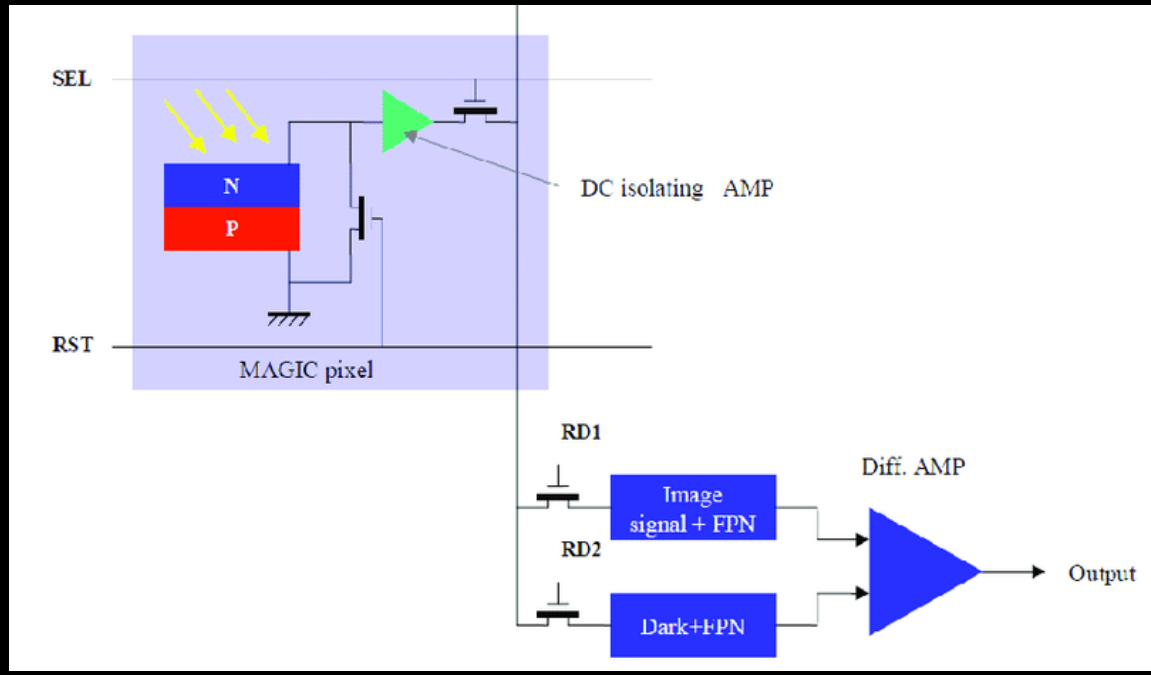
Con:

FPN

Image lag

black level drift (dark current)

analog output | timing like CCD



Conclusion

It depends – There is no winner. But a lot of inspiration for a modern pixel design!

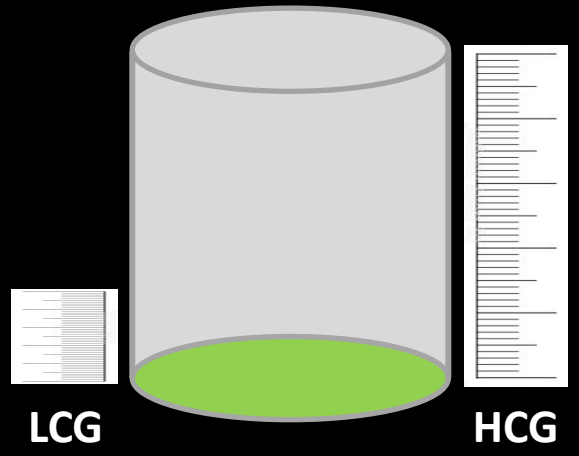
	HDR Effect	Image Prozessing	Moving objects	Camera implementation	Image quality
Polarized pixels	--	+	++	+	+
Sequencer	++	--	--	--	++
Interleave Exposure	-	--	-	-	+
LinLog	+	+	+	+	--
Kneepoint mode	+	+	+	+	--
Full-logarithmic Log	++	--	+	-	+
No integration Log	++	-	+	--	+

System | -- | - | + | ++

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

Dual conversion gain

Convert photons twice and different into electrons!



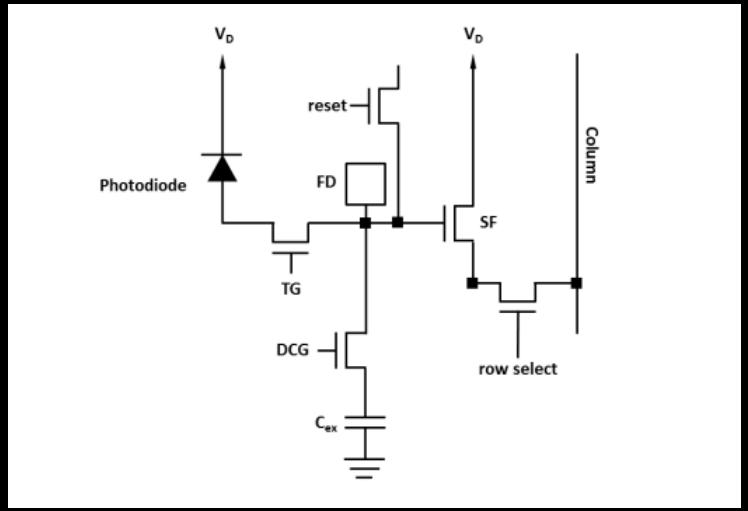
LCG – Low Conversion Gain

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.

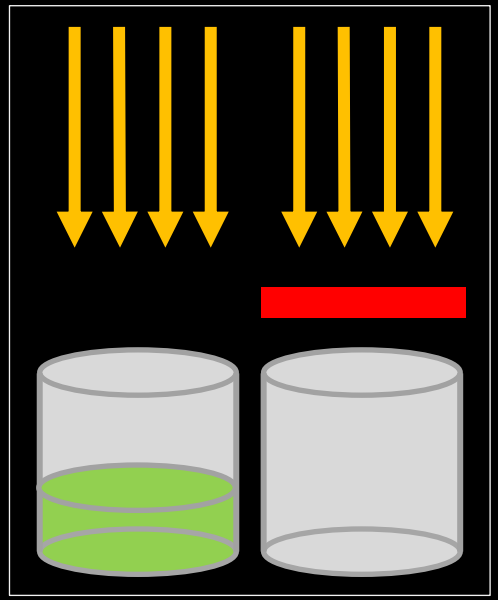
Factor 2 to 7 between LCG and HCG.
Combine on chip or with ISP!

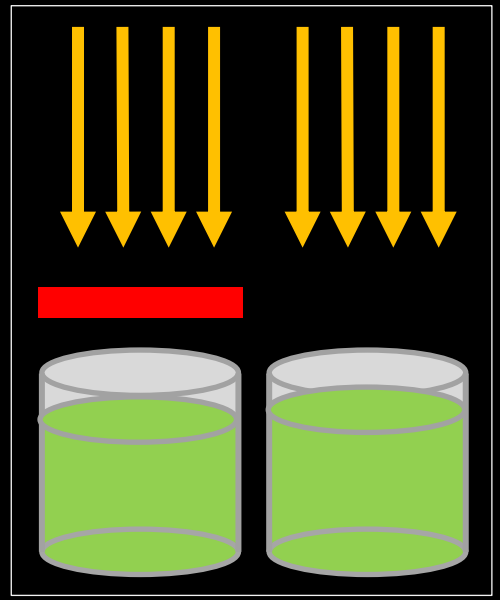


CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence	Antiblooming	Polarization	
Interleave	LinLog	Dual Conversion Gain	
Dual Exposure	Real Log	Dual Storage Node	
Piecewise linear	Solar Cell		

Pyxalis | STM: Dual storage node

One Global Shutter Pixel with 2 storage nodes





First: Short Exposure Time

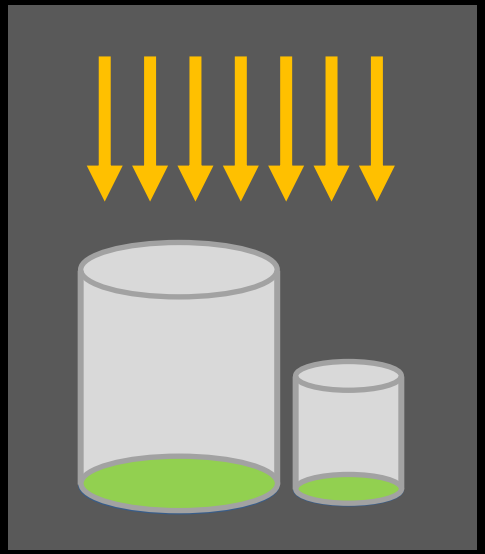
Second: Long Exposure Time

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

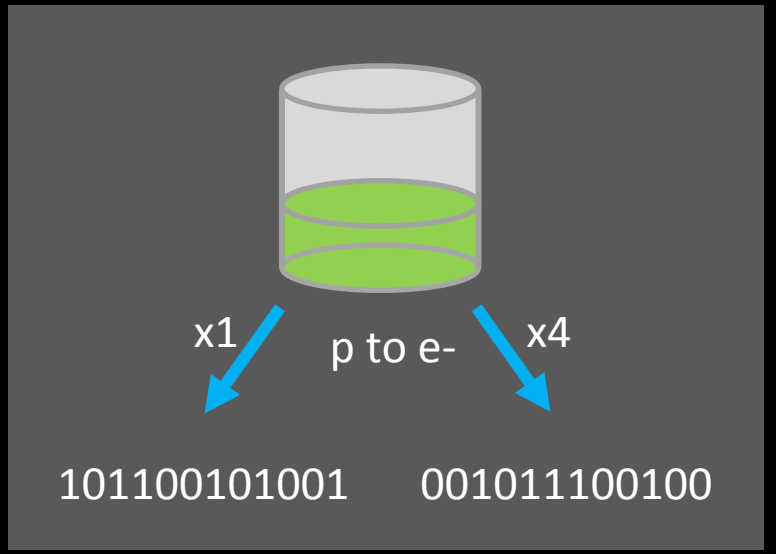
Split and Dual in combination

Split Photodiode

Large – LPD | Small – SPD



Dual Conversion Gain




life.augmented


70


70

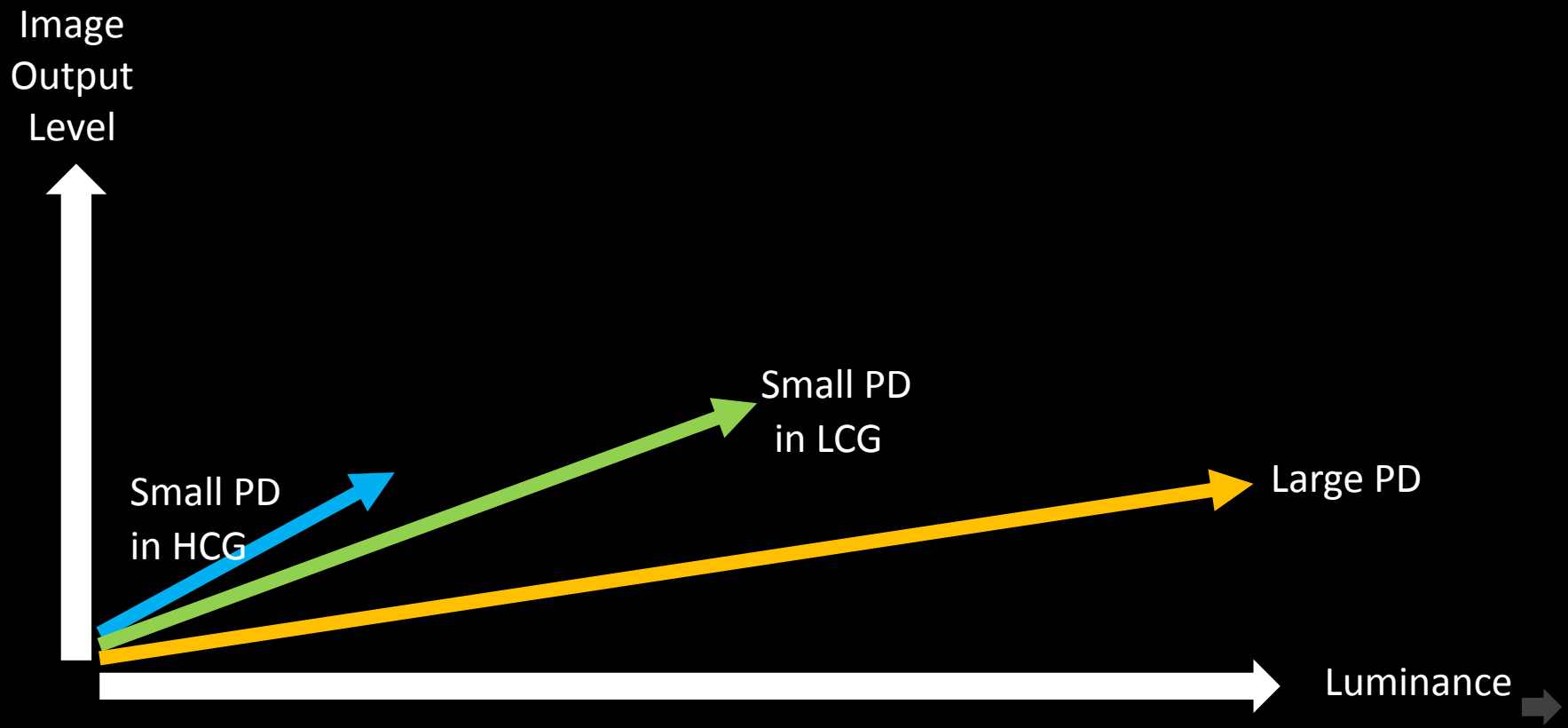

70

CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence	Antiblooming	Polarization	Sony IMX390
Interleave	LinLog	Dual Conversion Gain	
Dual Exposure	Real Log	Dual Storage Node	
Piecewise linear	Solar Cell		

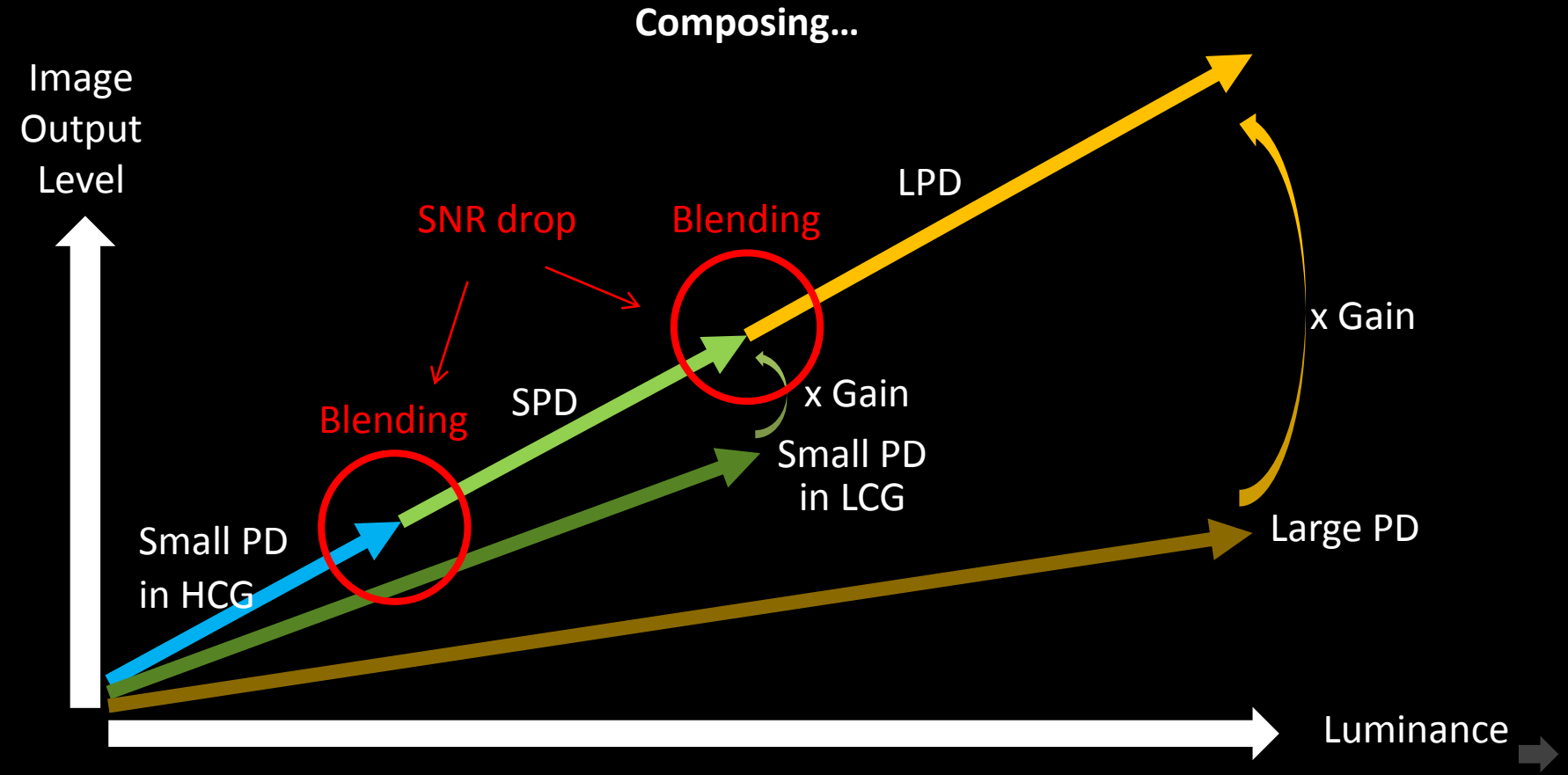
Sony Semiconductor IMX390

Sony Semiconductor IMX 390

One capture – three interleave readouts



Sony Semiconductor IMX 390



Sony Semiconductor

Sony	IMX390CQV-W
Sensor	2.3 MP | 1920 x 1200 | 50 fps | Color | RS
Pixelarray	Dual PD | 1:31? | 3.0µm | 1/2.7“ | 21° CRA
Exposure / Images	1 / 3
Conversion gain	Dual for Small Pixel | 1:3.6
HDR	110 / 120 dB | On Board | 12 - 24 Bit | RAW | Combined | Compressed
Anti flicker	Yes
Features	LUT | BLC | DNR | Shading | DPC
Output	MIPI CSI-2 | 4-lane

Sony Semiconductor

IMX390

2 MP class

3 readouts

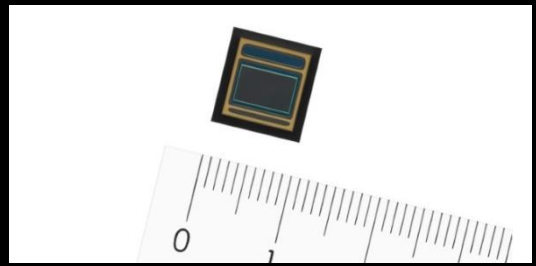
IMX490

5.4 MP | 3k x 2k class | 3µm | 10.3mm diag

4 readouts (Dual Pixel, twice dual conversion gain)

Further family extension planned 2020 / 2021

with a 3 MP and a 2 MP sensor



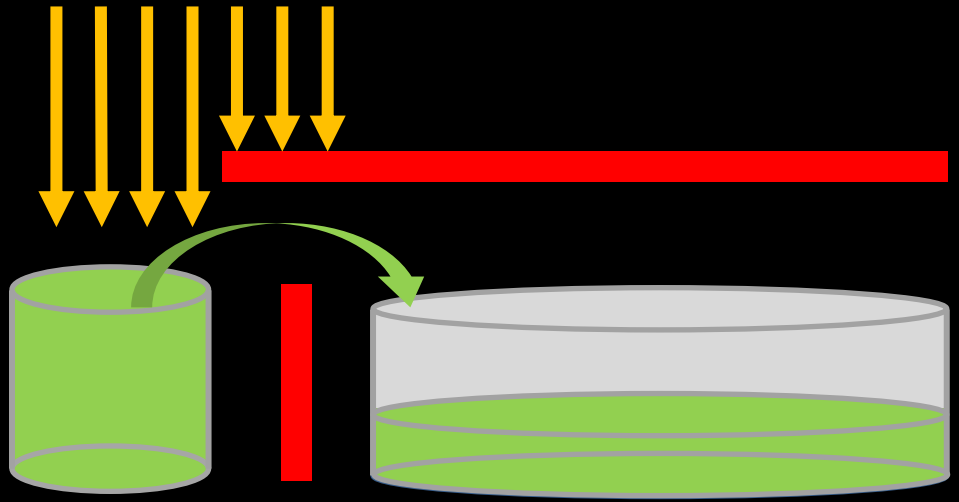
CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence	Antiblooming	Polarization	Sony IMX390
Interleave	LinLog	Dual Conversion Gain	On Semi AR0233
Dual Exposure	Real Log	Dual Storage Node	
Piecewise linear	Solar Cell		

On Semiconductor AR0233

On Semiconductor

Single PD with additional local overflow „Area“

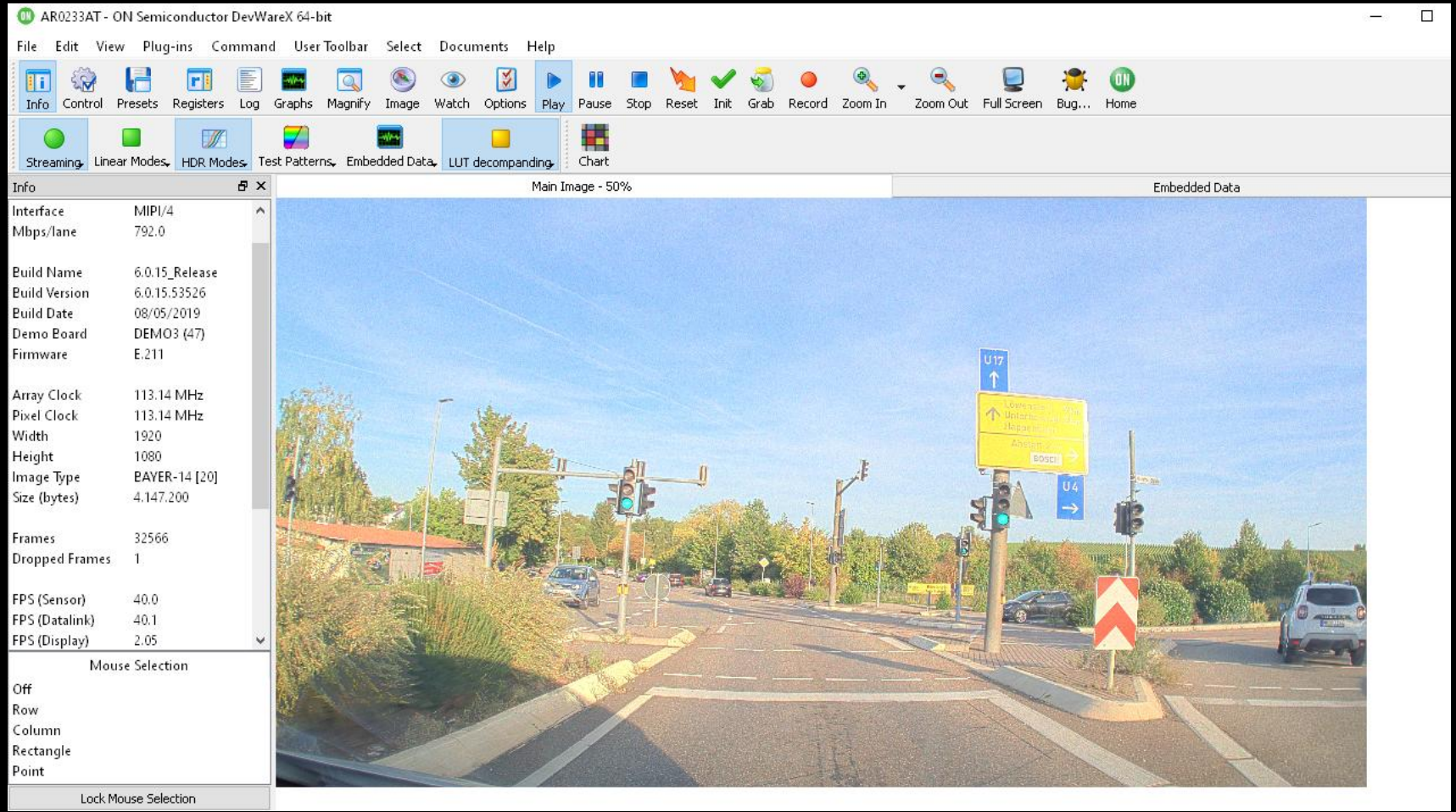
Dual CG | 4 readouts to combine



On Semiconductor

On Semiconductor	AR0233
Sensor	2.65 MP | 2064 x 1288 | 45 fps | Color | RS
Pixelarray	Single PD | 3.0µm | 1/2.5“ | 17° CRA
Exposures / Images	2 / 4
Conversion gain	Dual on PD | +Overflow
HDR	140 dB | On Board Processing | 24 Bit RAW | …
Anti flicker	Yes
Features	…
Output	MIPI CSI-2 | 4-lane

On Semiconductor



On Semiconductor

AR0233

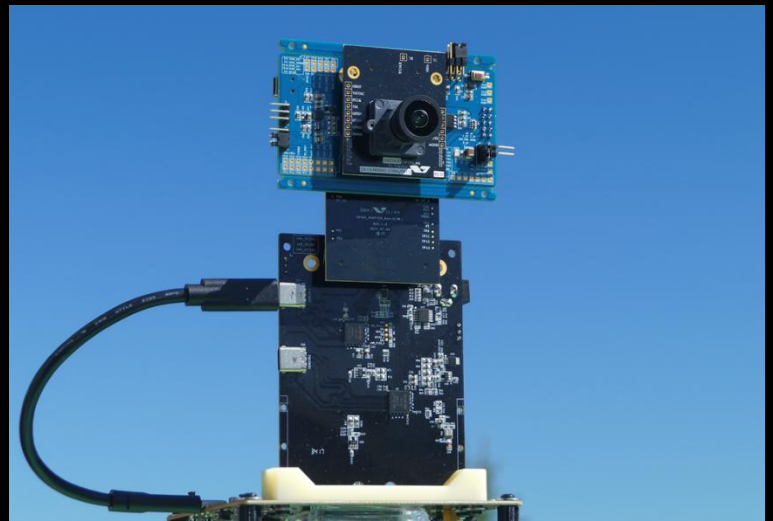
2.6 MP | Single PD | Dual storage | Dual CG on PD

AR0820

8 MP | 4k x 2k | 2.1µm | 1/2” | Dual PD | Dual CG

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		

Omnivision OX02A10



Omnivision

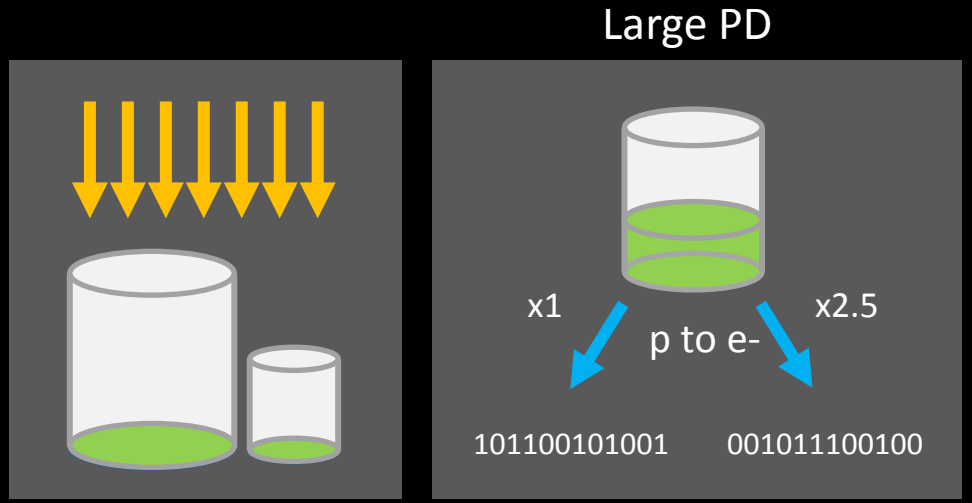
Exposure

Short Exposure Time → Small PD

Long Exposure Time → Large PD

Readout

1. Small PD
2. Large PD with HCG
3. Large PD with LCG



Omnivision

OmniVision	OX02A10
Sensor	1.7 MP | 1824 x 940 | 60 fps | Color | RS
Pixelarray	Dual PD | 4.2µm | 1/2.1“ | 19° CRA
Exposure / Images	2 / 3
Conversion gain	Dual at LPD | 1:2.5
HDR	110 – 120 dB | On Board | 20 Bit linear comb. | RAW | YUV
Anti flicker	Yes
Features	LENC, DPC, DNR, ToneMap, AWB, AEC, AGC, BLC, LUT
Output	12 Bit Parallel | MIPI CSI-2 with 4-lanes

Omnivision

OX02A10

1.7 MP | Dual PD | Dual Gain on one PD

OX03A10

2.46 MP | Single PD | Dual Gain | 120dB | 50 fps

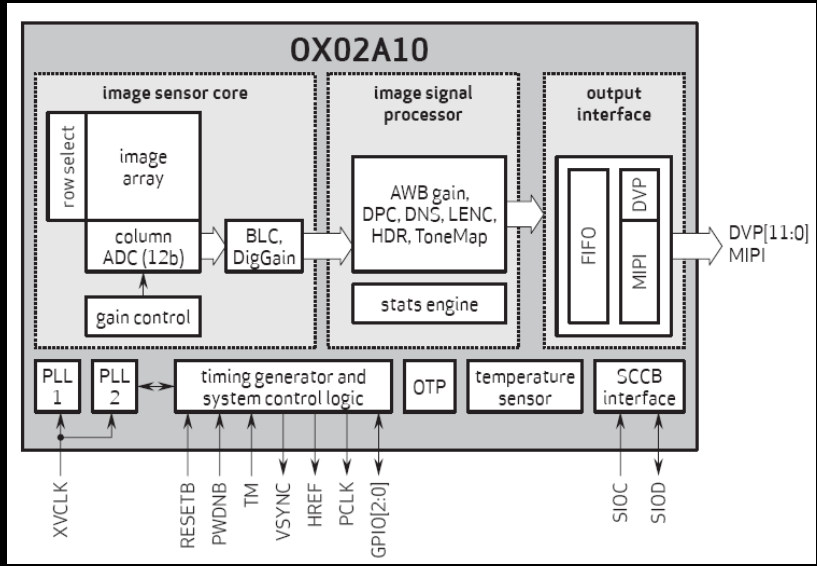
OX01D10

1.2 MP | Dual PD | Dual Gain on one PD

OX01B40

1.3 MP | Dual PD | Dual Gain on one PD

+ 120 dB with stacked ISP



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		STM VC 6768

ST Microelectronics VG6768

ST Microelectronics

Traditional 3 exposure times in a sequence is not bad

Issues with LED light sources

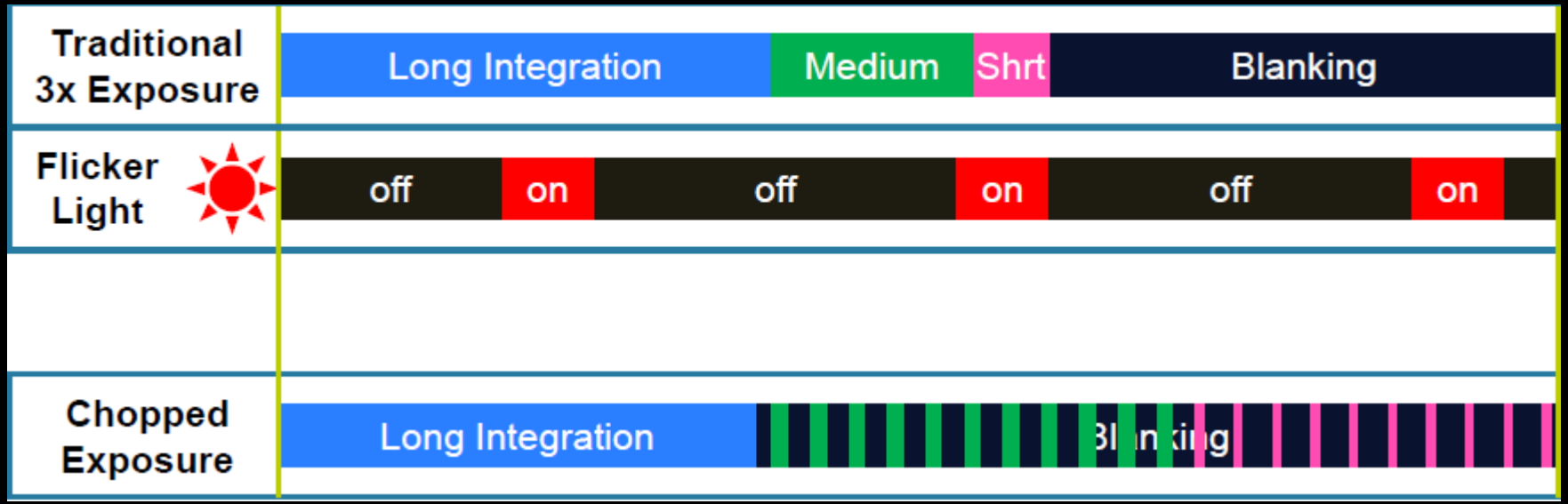
Issues with motion

ST Microelectronics

Chopping the exposure is the right direction.

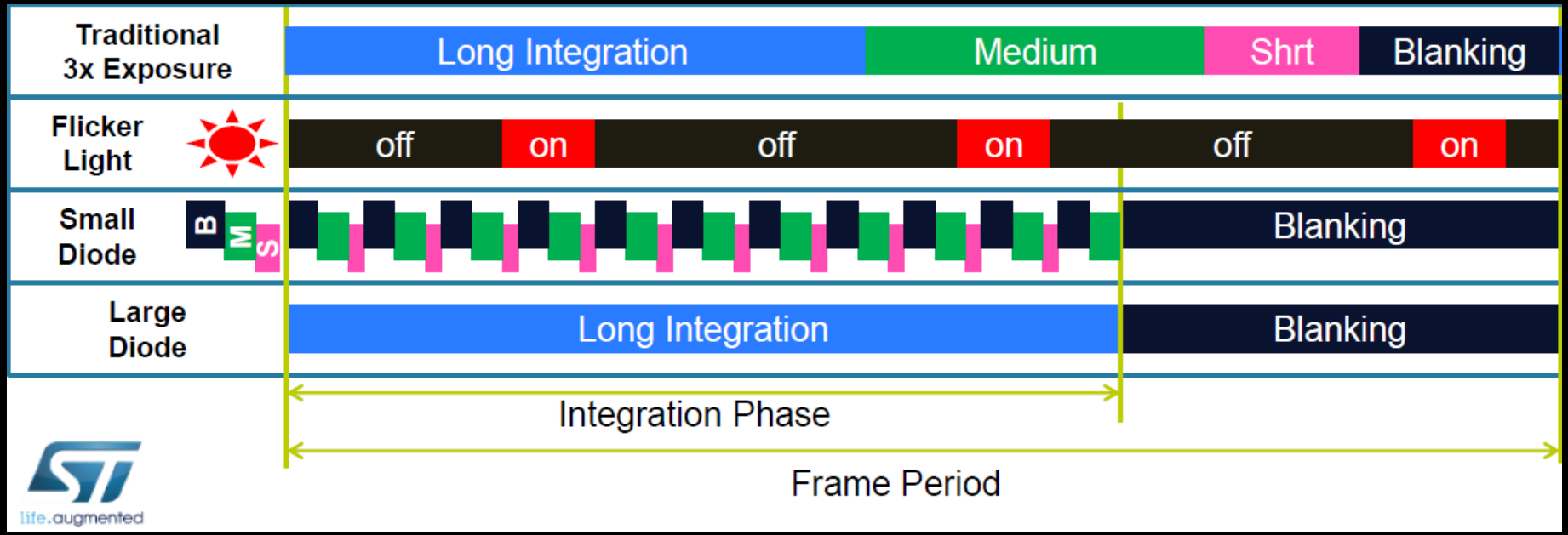
Catch LED Illumination correct.

But with moving objects it gets much more worse.



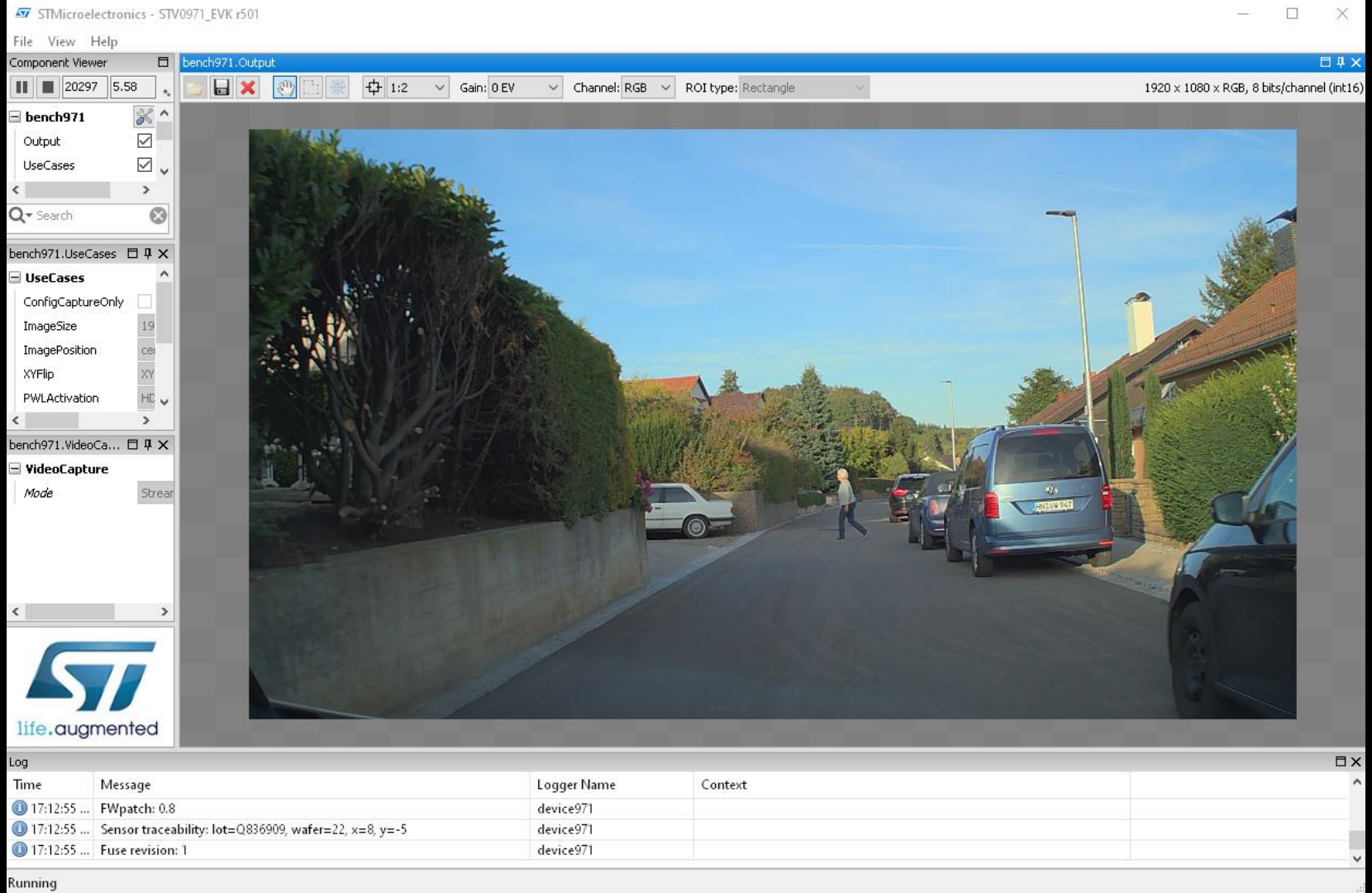
ST Microelectronics

Interleave parallel in 2 photodiodes is faster



ST Microelectronics

ST Microelectronics	VG6768
Sensor	2.5 MP | 1928 x 1288 | 60 fps | Color | RS
Pixelarray	Dual PD | 1:4 | 3.2µm | 1/2.1“ | 15° CRA
Exposure / Images	1 / 3
Conversion gain	Dual | 1:3
HDR	145 dB | 14 + 11 + 11 Bit | Merge
Anti flicker	Yes
Features	BLC | DPC | DNR | LUT
Output	MIPI CSI-2 | 4-lane


STMicroelectronics - STV0971_EVK r501
File View Help
Component Viewer
20297 5.58
bench971
Output
UseCases
Search
bench971.UseCases
UseCases
ConfigCaptureOnly
ImageSize
ImagePosition
XYFlip
PWLActivation
bench971.VideoCa...
VideoCapture
Mode
life.augmented
bench971.Output
1:2
Gain: 0 EV
Channel: RGB
ROI type: Rectangle
1920 x 1080 x RGB, 8 bits/channel (int16)
Log
Time
Message
Logger Name
Context
17:12:55 ... FWpatch: 0.8 device971
17:12:55 ... Sensor traceability: lot=Q836909, wafer=22, x=8, y=-5 device971
17:12:55 ... Fuse revision: 1 device971
Running

Summary

	Sony IMX390	ST Micro VG6768	OVT OX02A10	On Semi AR0233
PD per Pixel	Dual	Dual	Dual	Single
Exposure / Images	1	1	2 (sim)	2 (seq)
Conversion gain / readout	Dual for SPD	Dual for LPD	Dual for LPD	Dual for PD
Resulting images	3	3	3	4

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

SPAD / QIS

Say „hello“ to a single photon!

Single Photon Avalance Diode in an 2D-Array

Quanta Image Sensor

100 – 150 ps timing resolution

Digital counting

130 - 150 dB DR

Promising? Trend?

Summary

- Forget linear cameras with single conventional pixel
- The classic methods shows the direction
- The new pixel designs are the right way

- All 4 modern HDR sensors are doing a great job
- The HDR image quality is near perfect

- The overall image quality is better with an external ISP
- The Implementation is easy (SW / HW)

- And take care of lenses and IR-cut filter

High Dynamic Range Imaging

A short summary

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