

Dana Diezemann

High Dynamic Range Imaging | HDR

A short summary

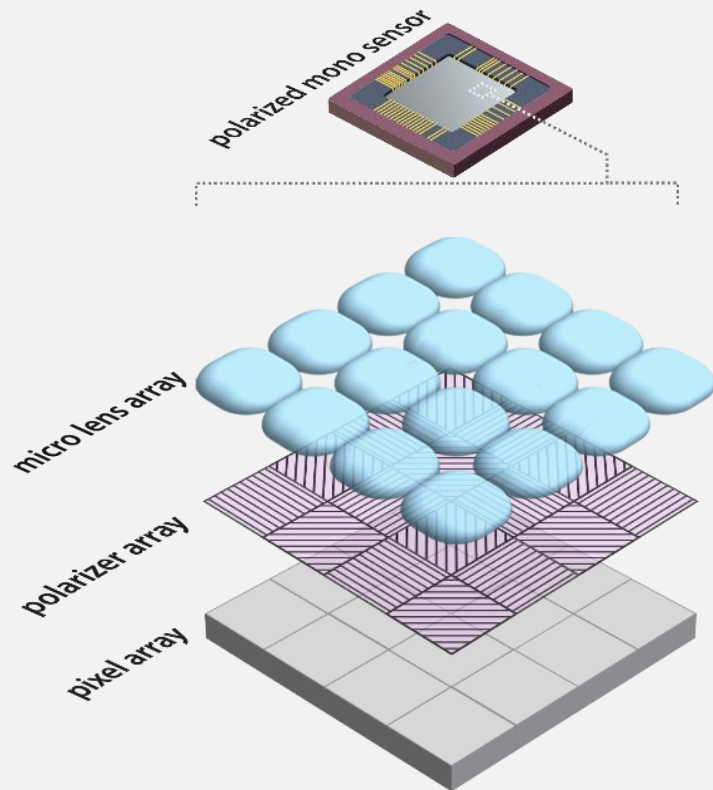
Image Sensors Europe | 12. 03. 2020



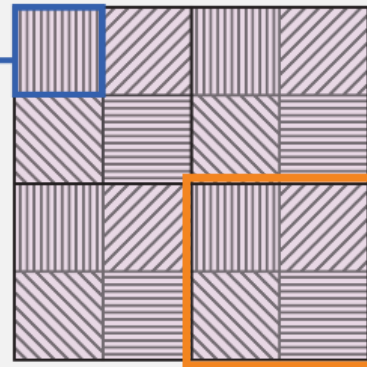
Polarized Pixels | Sony



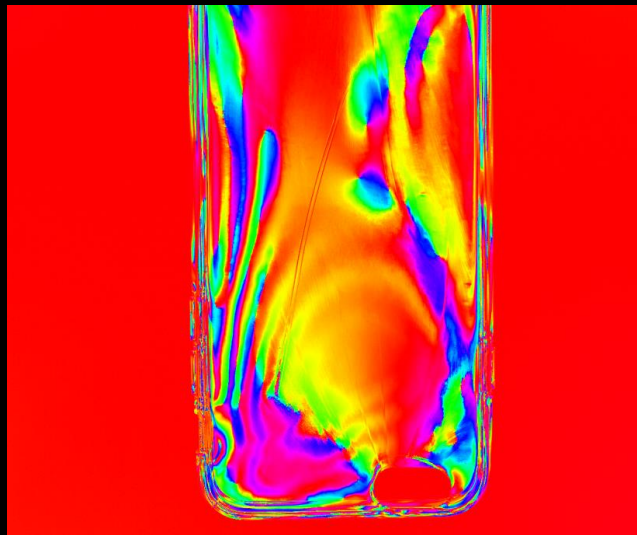
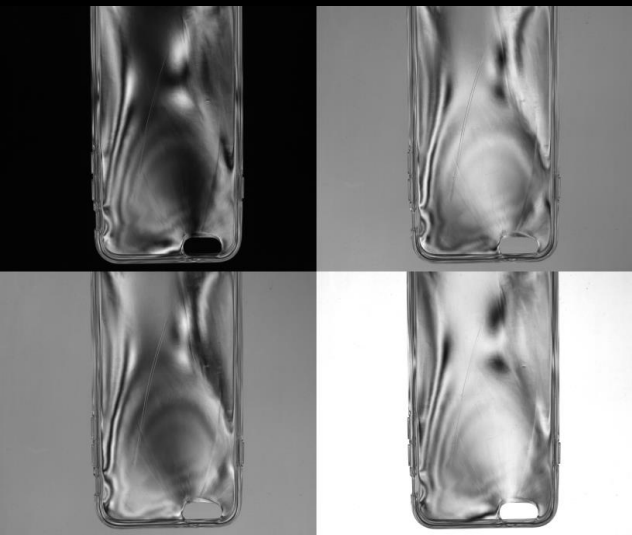
Polarized pixels | Sony

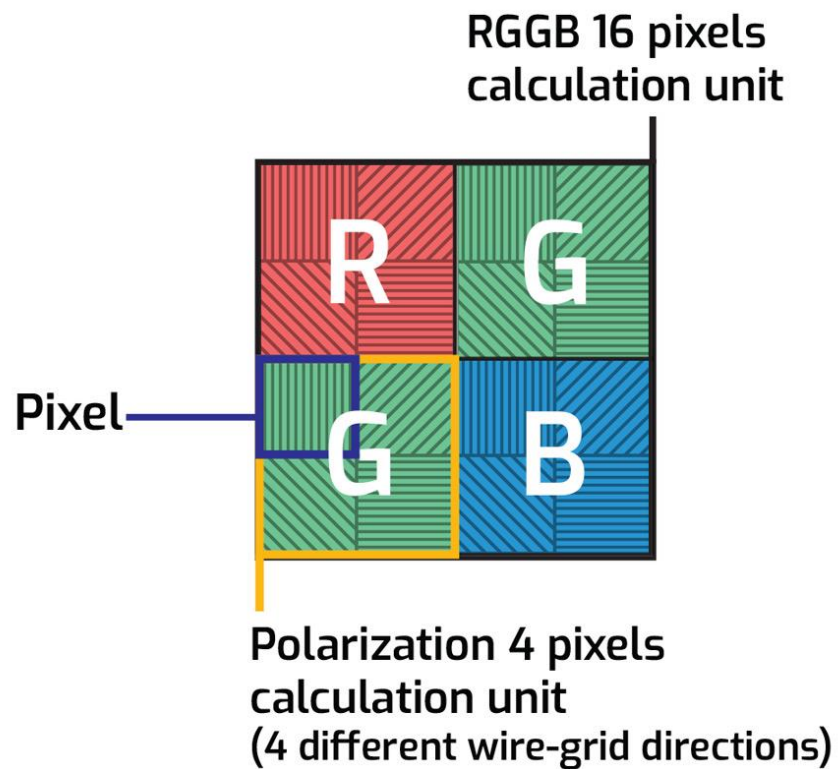
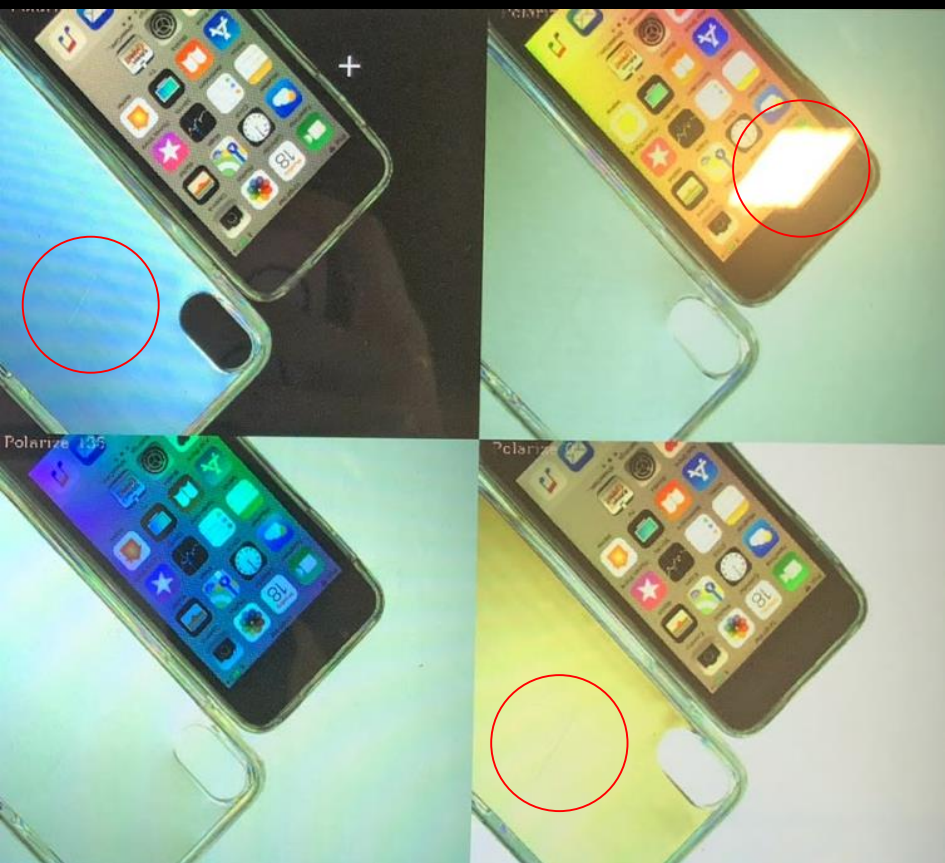


Pixel



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:

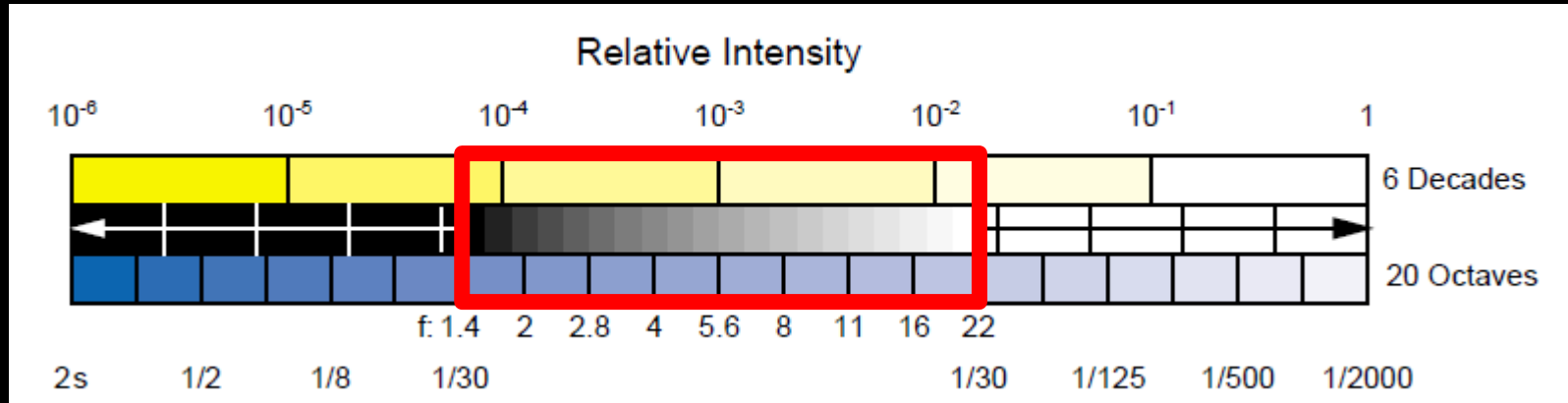
Not really more system dynamic.

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

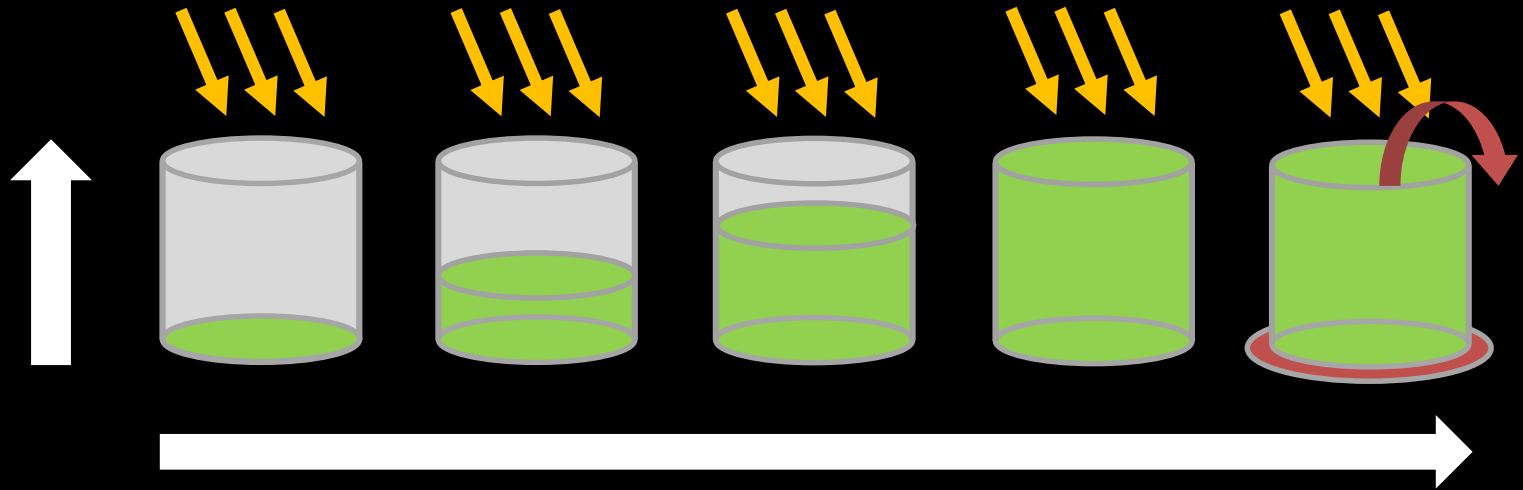
FW: 100.000 e- | Noise: 1e- | DR: 100 dB

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



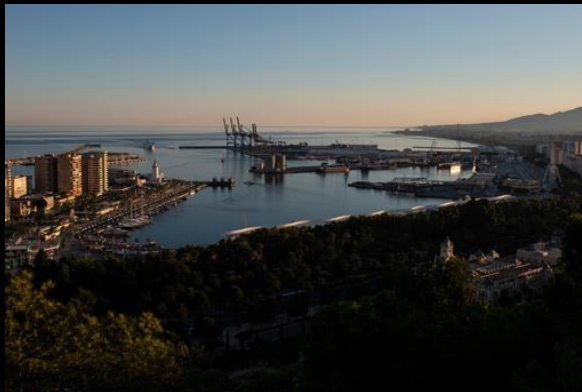
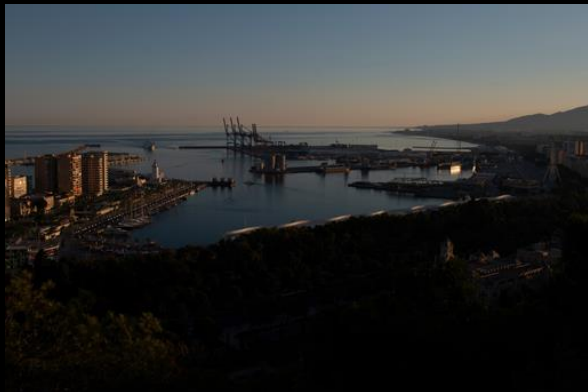
HDR

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



CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence		Polarization	

Sequencer



Sequencer

Sequencer

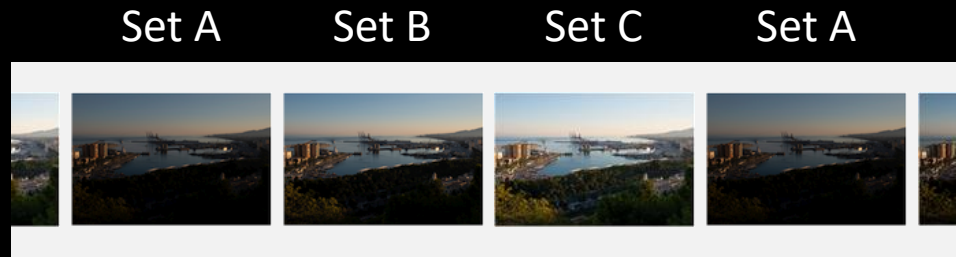
Set of different settings (Exposure time, Gain), individual frame by frame

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.

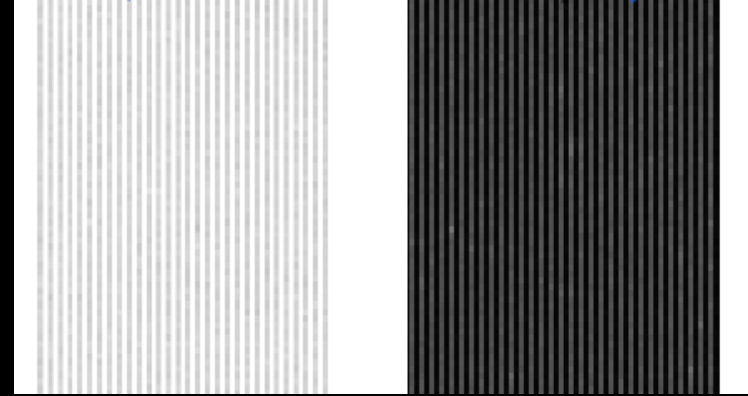
Column wise: Teledyne e2v Snappy sensors.

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

Datum / Zeit	Limit PKW	Limit LKW	Geschw.	Klasse	Richtung
11.03.2018 14:40:23	100 km/h		163 km/h	PKW	ankommend



System	Bildnummer	Ort
PS6635799	1603111253 - 150 - 1	Gem. Kirchheim - A4, km 384,250 - Kirchheimer Dreieck - Dresden

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.

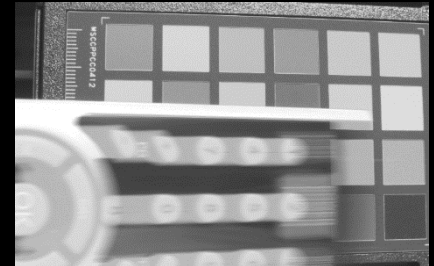
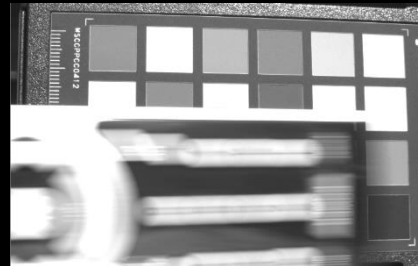
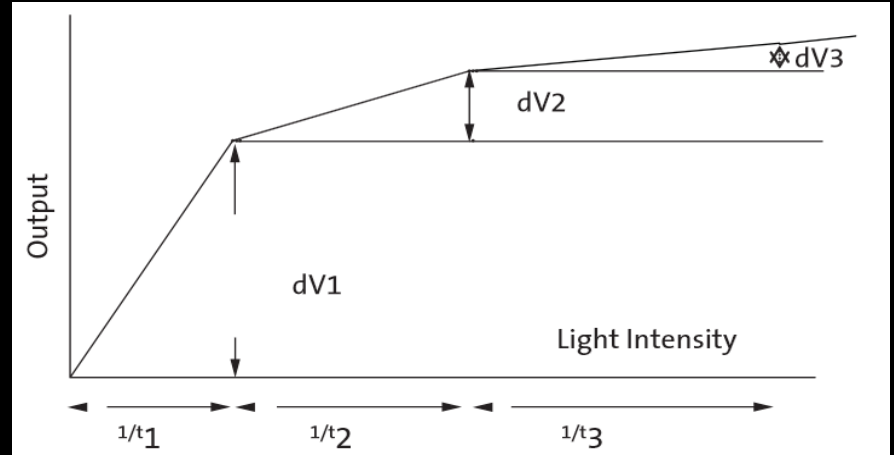
Brighter pixels where reset to given level.

Then short exposure phase added
to saturate the pixels again.

And optional again.

Pro: One capture | One result.

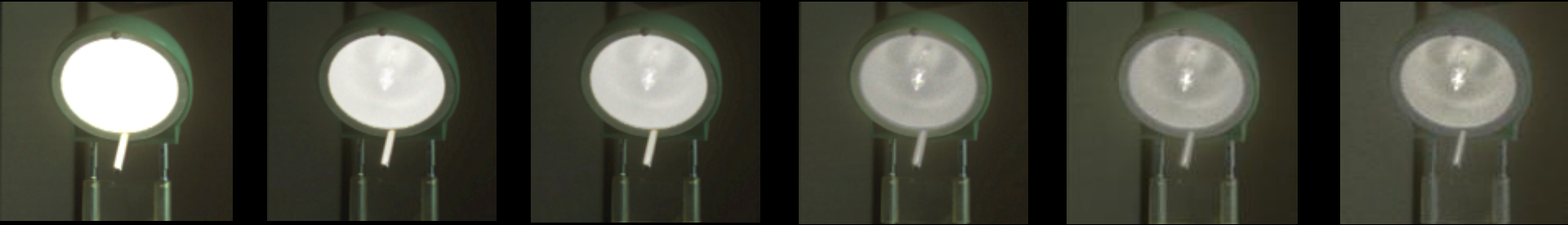
Con: Moving bright objects | Color balance.



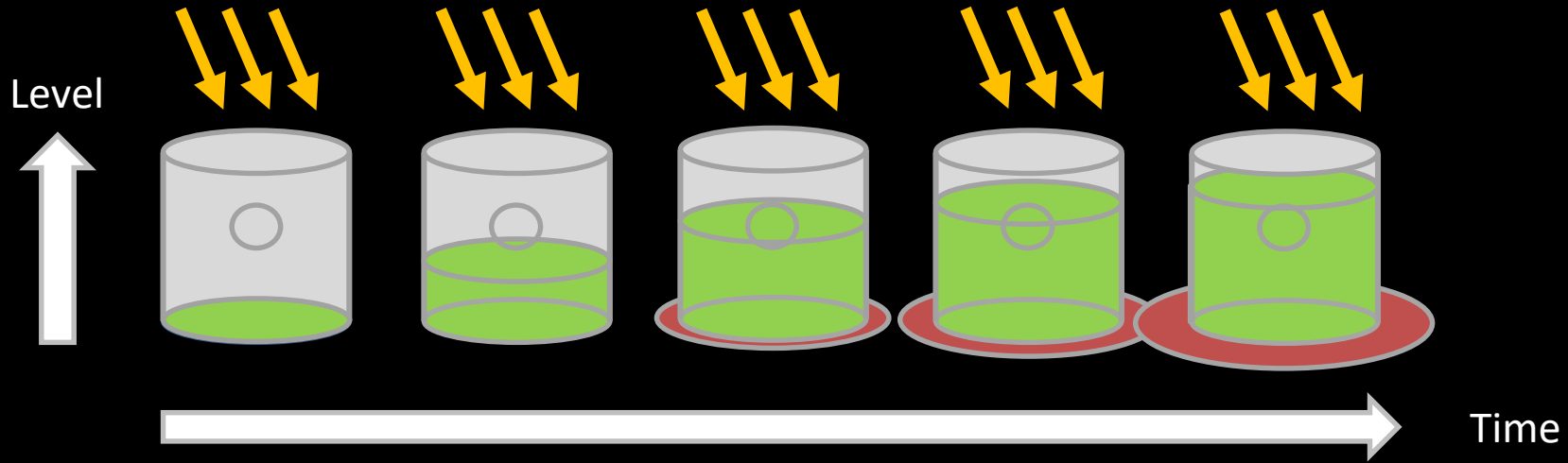
CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence	Antiblooming	Polarization	
Interleave			
Dual Exposure			
Piecewise linear			

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

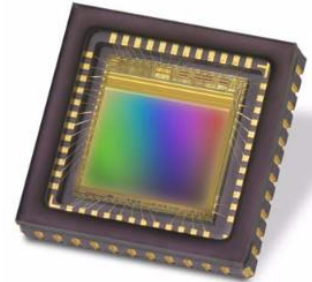
EV76C560

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			

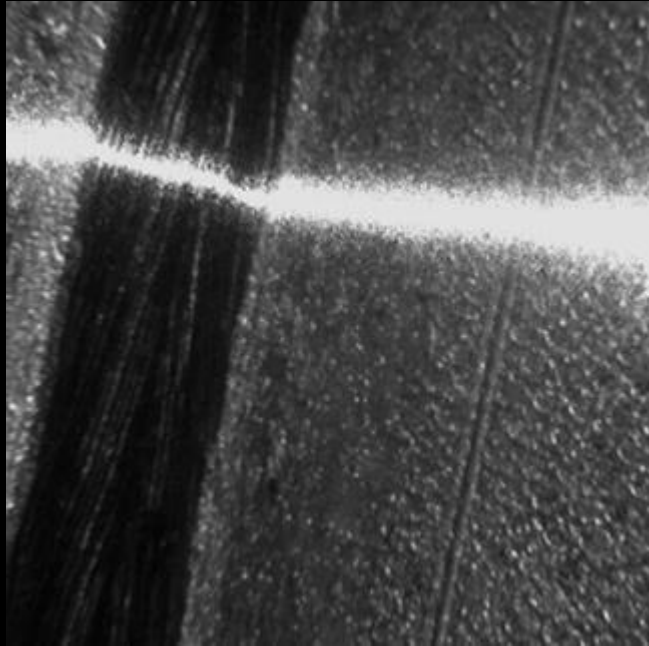
LinLog

Only the bright parts are “damped”

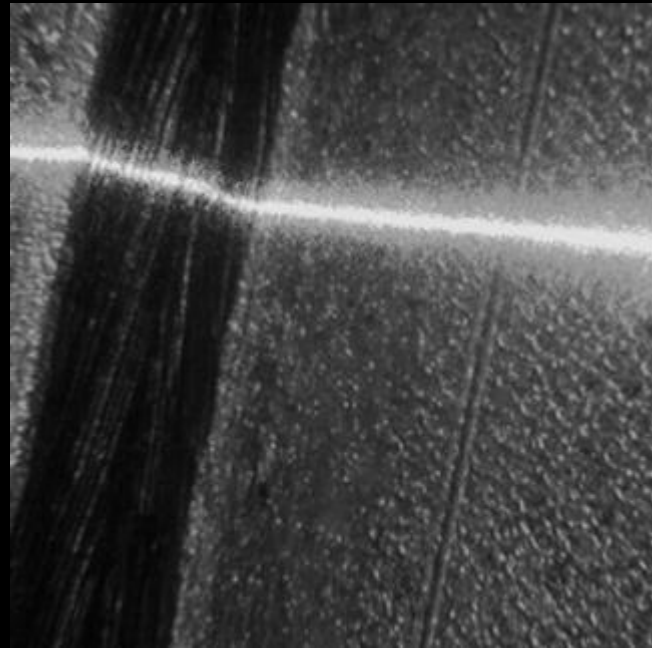


LinLog

Inspection of a Welding Seam



CMOS camera
with linear response curve (<60dB)



CMOS camera
with LinLog (120dB)



LinLog | Photonfocus & Log Mode | e2v

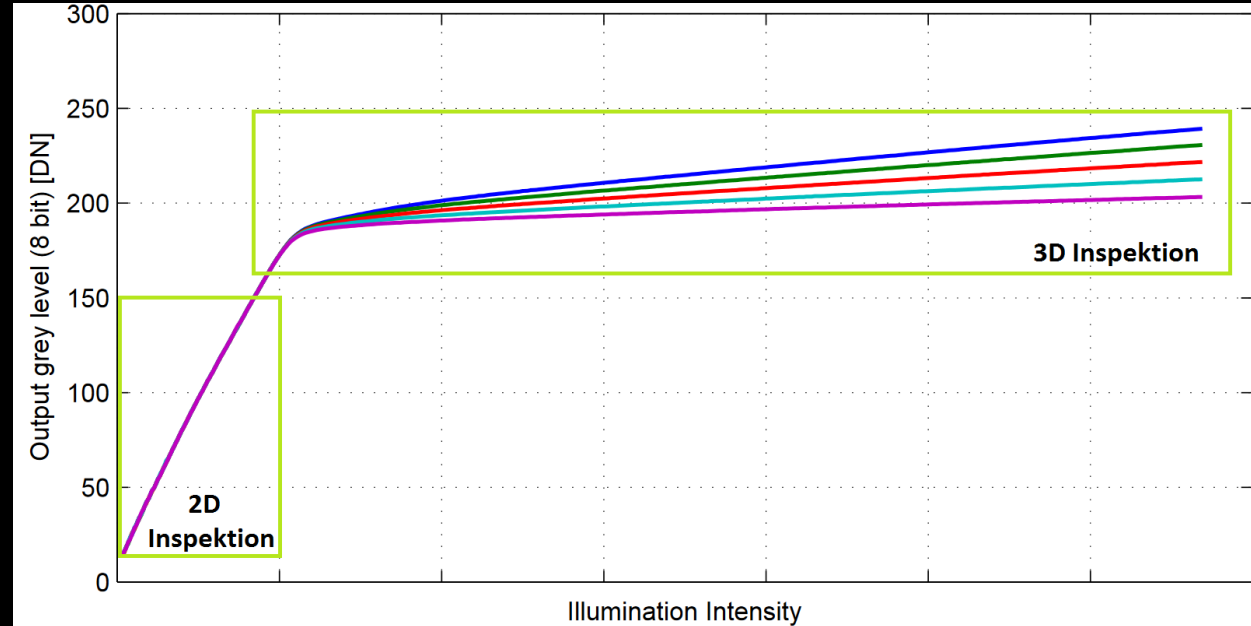
Different Anti Blooming Voltages

Called Kneepoints
Control offset and slope

LinLog (Photonfocus)
Offset and slope

LogMode (Teledyne e2v)
Offset

Con: FPN | Color Imaging



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

Full-logarithmic | IMS

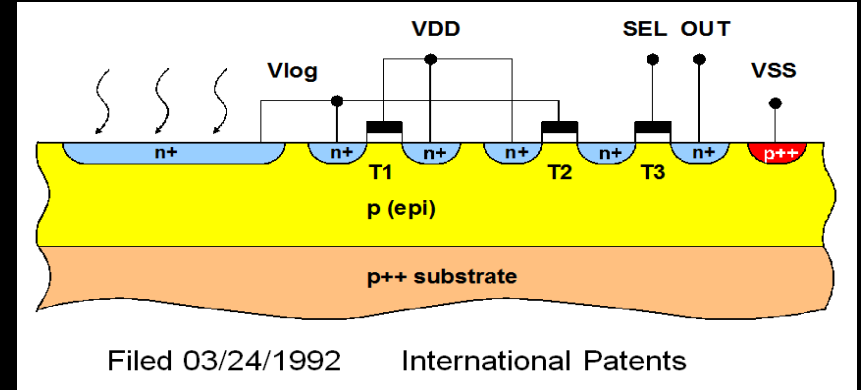
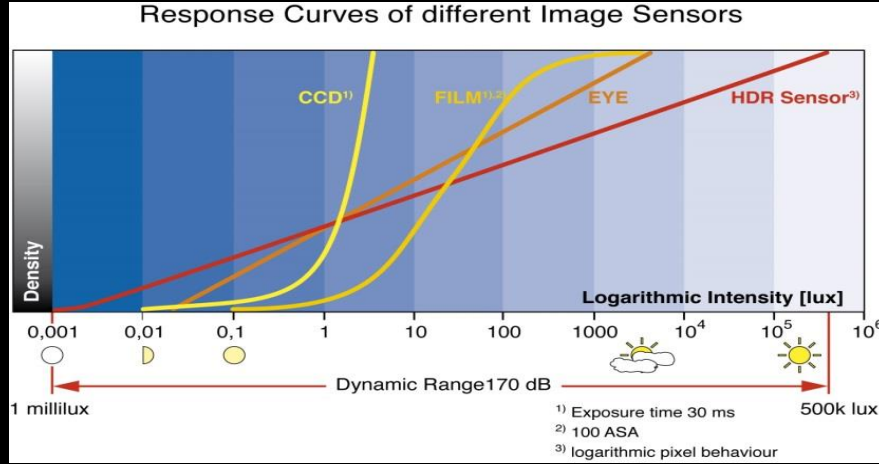
HDRC Imager



Full-logarithmic | IMS

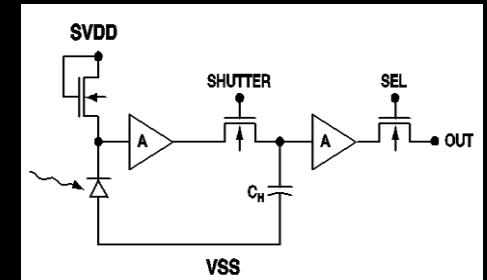
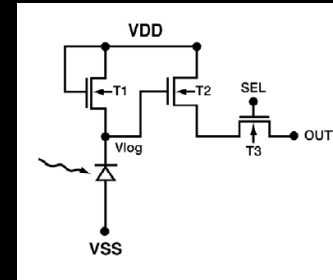


HDRC Imager



Pro: Real log Pixel

Con: Complex DSNU & PRNU correction



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

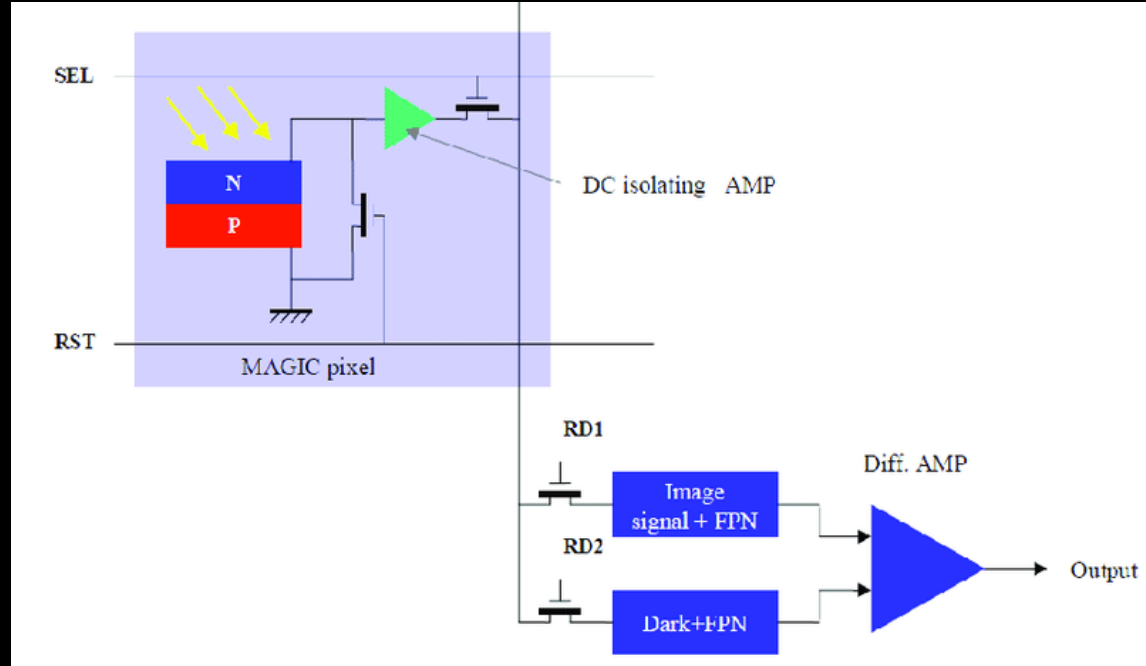
Con:

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.

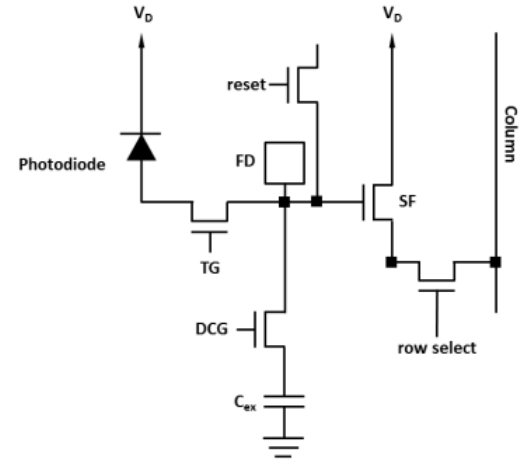
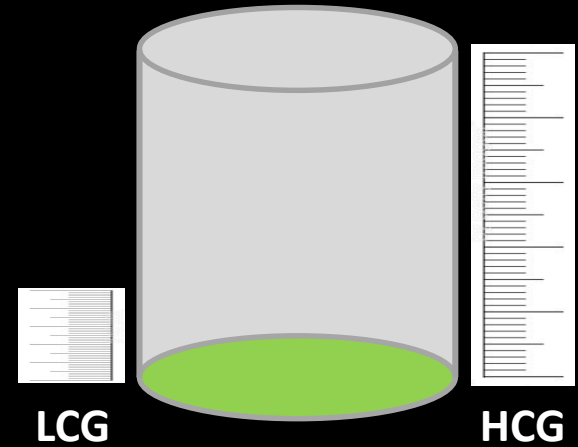
HCG – High Conversion Gain

Advantage in SNR at low illuminance levels.

For dark parts in the image.

Factor 2 to 7 between LCG and HCG.

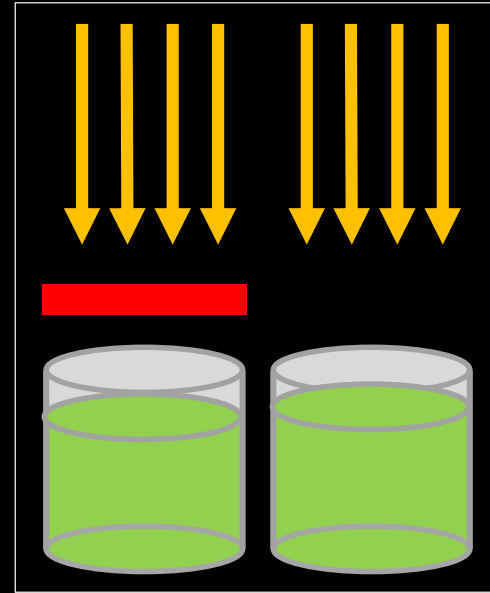
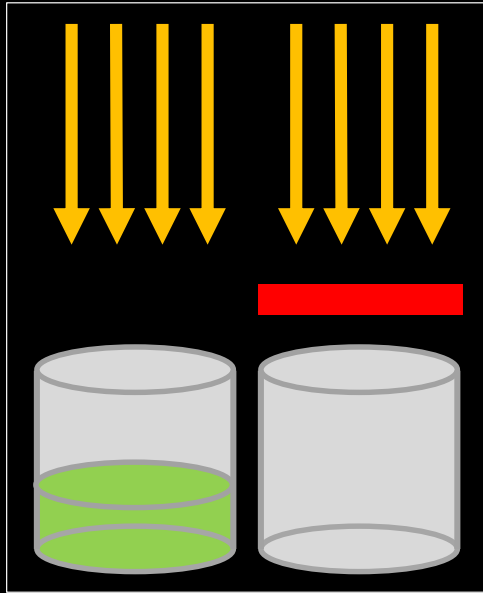
Combine on chip or with ISP!



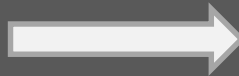
CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence	Antiblooming	Polarization	
Interleave	LinLog	Dual Conversion Gain	
Dual Exposure	Real Log	Dual Storage Node	
Piecewise linear	Solar Cell		

Pyxalis | STM: Dual storage node

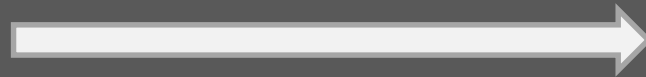
One Global Shutter Pixel with 2 storage nodes



First: Short Exposure Time



Second: Long Exposure Time

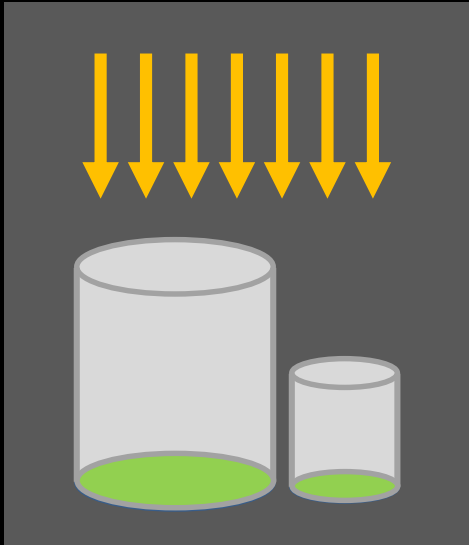


CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence	Antiblooming	Polarization	???
Interleave	LinLog	Dual Conversion Gain	
Dual Exposure	Real Log	Dual Storage Node	
Piecewise linear	Solar Cell		

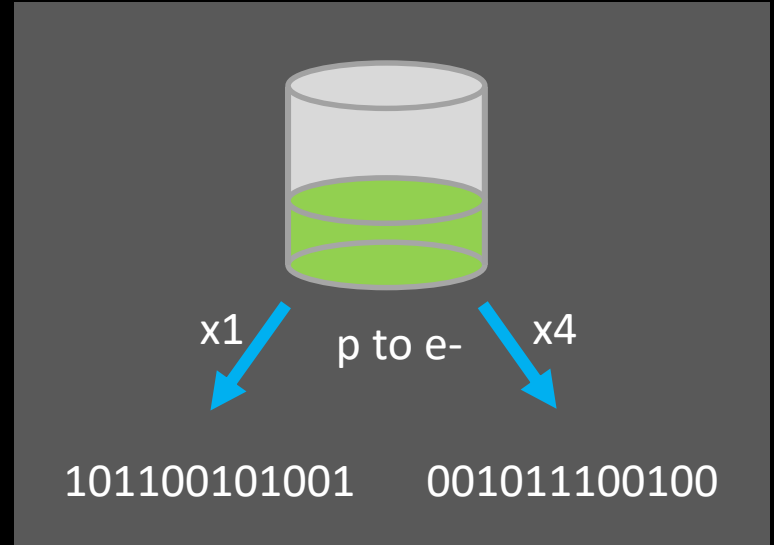
Split and Dual in combination

Split Photodiode

Large – LPD | Small – SPD



Dual Conversion Gain









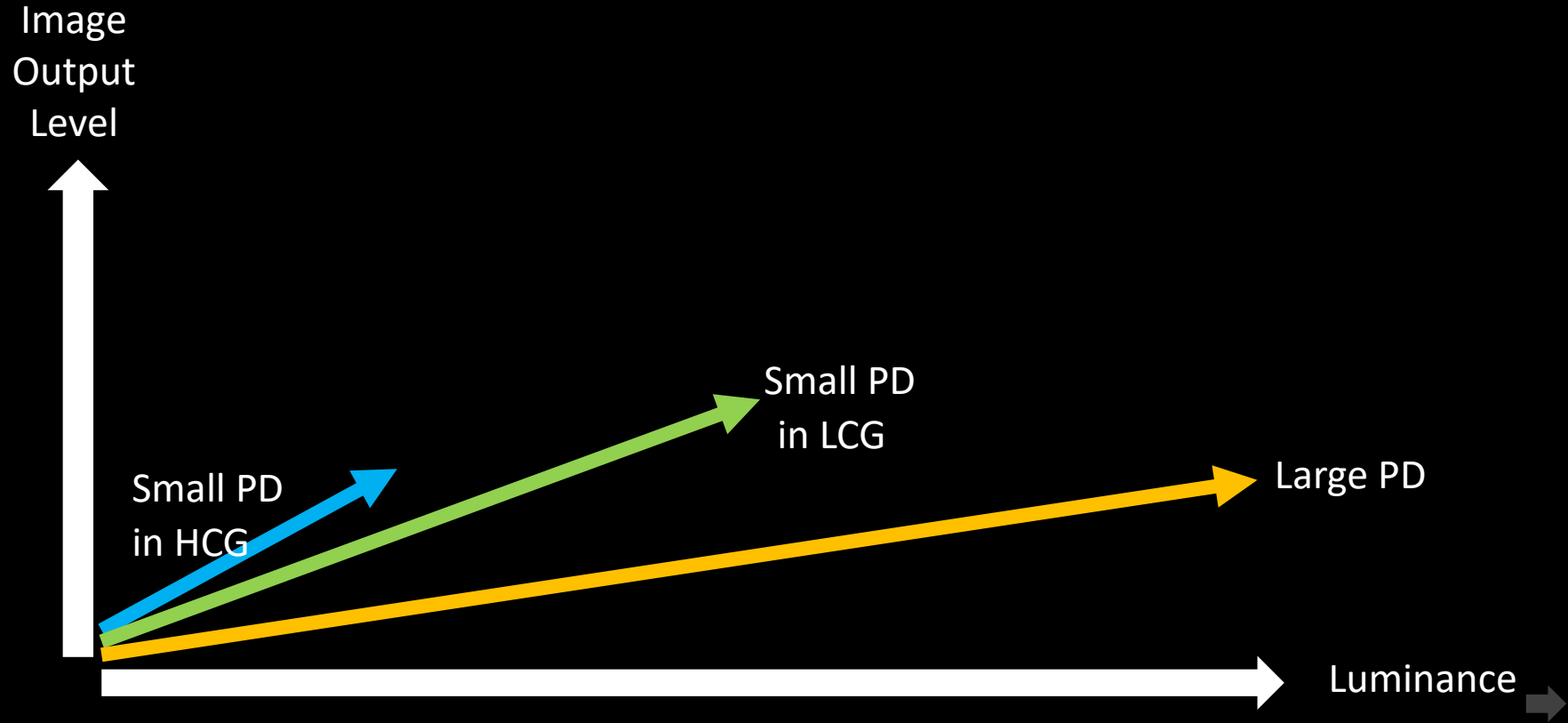
CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence	Antiblooming	Polarization	Sony IMX390
Interleave	LinLog	Dual Conversion Gain	
Dual Exposure	Real Log	Dual Storage Node	
Piecewise linear	Solar Cell		

Sony Semiconductor IMX390

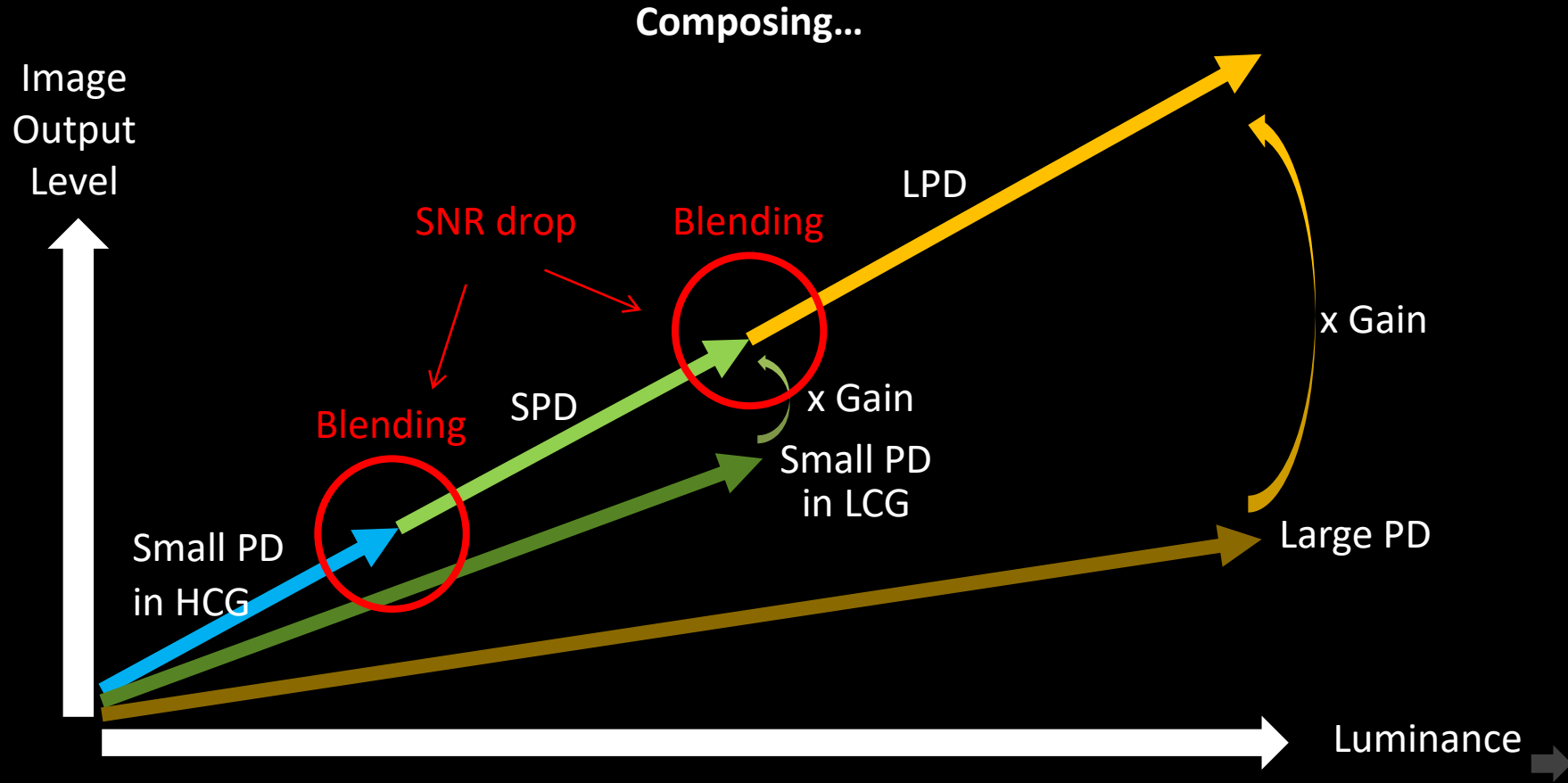


Sony Semiconductor IMX 390

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



IMX390

2 MP class

3 readouts

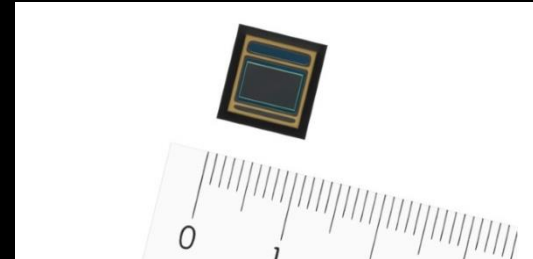
IMX490

5.4 MP | 3k x 2k class | 3 μ m | 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 ARO233
Dual Exposure	Real Log	Dual Storage Node	
Piecewise linear	Solar Cell		

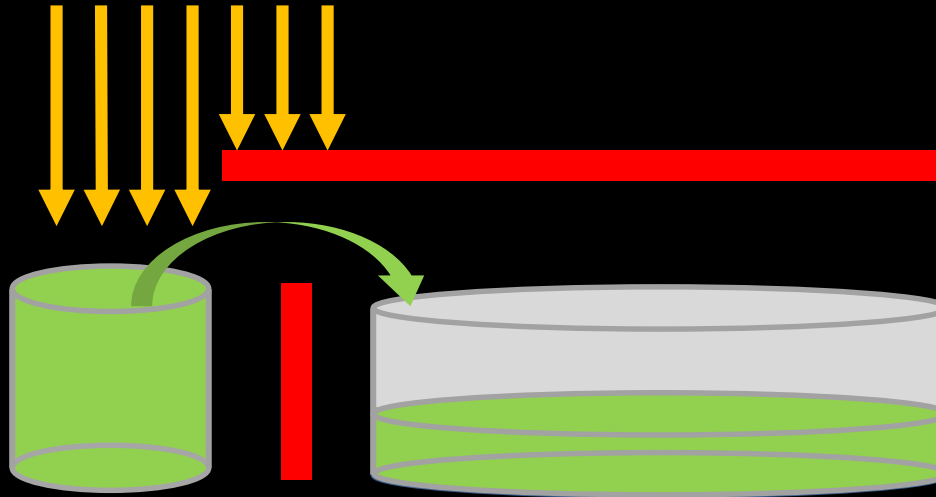
On Semiconductor AR0233



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

AR0233AT - ON Semiconductor DevWareX 64-bit

File Edit View Plug-ins Command User Toolbar Select Documents Help

Info Control Presets Registers Log Graphs Magnify Image Watch Options Play Pause Stop Reset Init Grab Record Zoom In Zoom Out Full Screen Bug... Home

Streaming Linear Modes HDR Modes Test Patterns Embedded Data LUT decompanding Chart

Info Main Image - 50% Embedded Data

Interface	MIPI/4
Mbps/lane	792.0
Build Name	6.0.15_Release
Build Version	6.0.15.53526
Build Date	08/05/2019
Demo Board	DEMO3 (47)
Firmware	E.211
Array Clock	113.14 MHz
Pixel Clock	113.14 MHz
Width	1920
Height	1080
Image Type	BAYER-14 [20]
Size (bytes)	4,147,200
Frames	32566
Dropped Frames	1
FPS (Sensor)	40.0
FPS (Datalink)	40.1
FPS (Display)	2.05

Mouse Selection

Off

Row

Column

Rectangle

Point

Lock Mouse Selection



On Semiconductor

AR0233

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

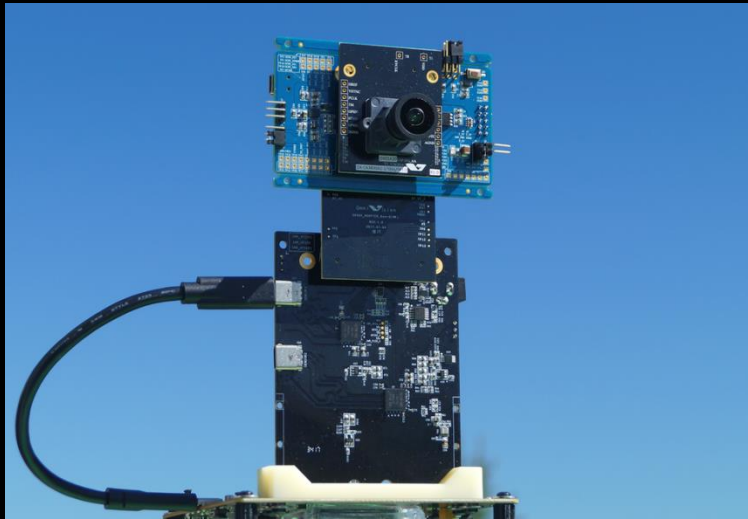
AR0820

8 MP | 4k x 2k | 2.1 μ m | 1/2" | Dual PD | Dual CG



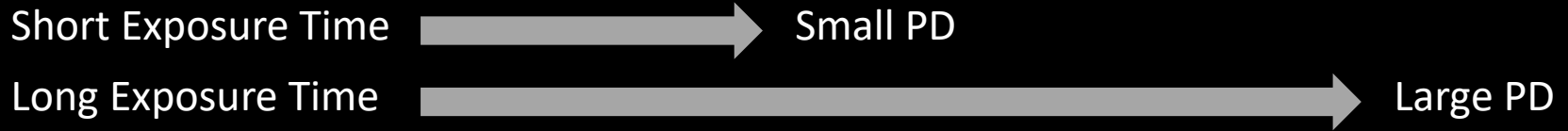
CLASSIC	NOT LINEAR	PHOTON	SPLIT
Sequence	Antiblooming	Polarization	Sony IMX390
Interleave	LinLog	Dual Conversion Gain	On Semi AR0233
Dual Exposure	Real Log	Dual Storage Node	OVT OX02A10
Piecewise linear	Solar Cell		

Omni**V**ision OX02A10



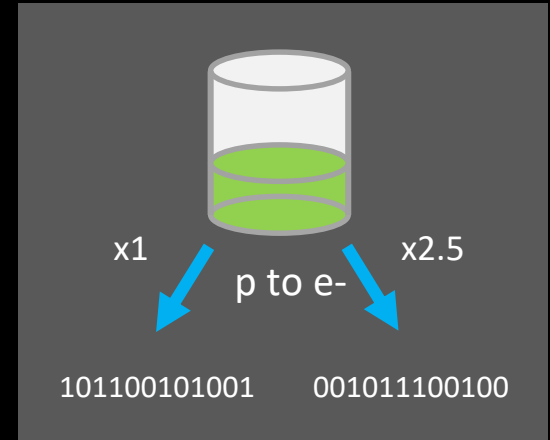
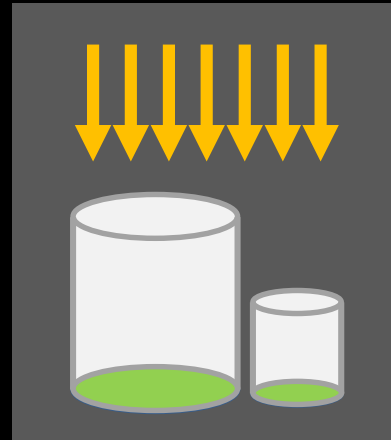
Omnivision

Exposure



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

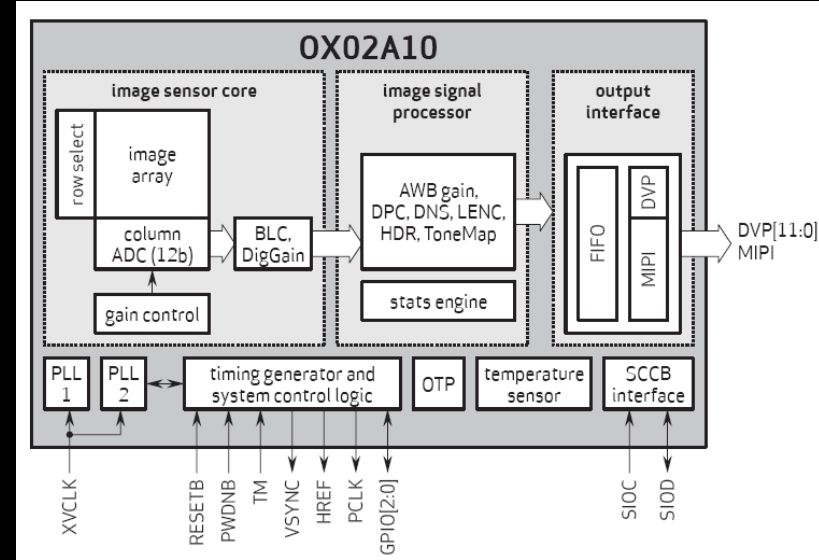
2.46 MP | Single PD | Dual Gain | 120dB | 50 fps

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



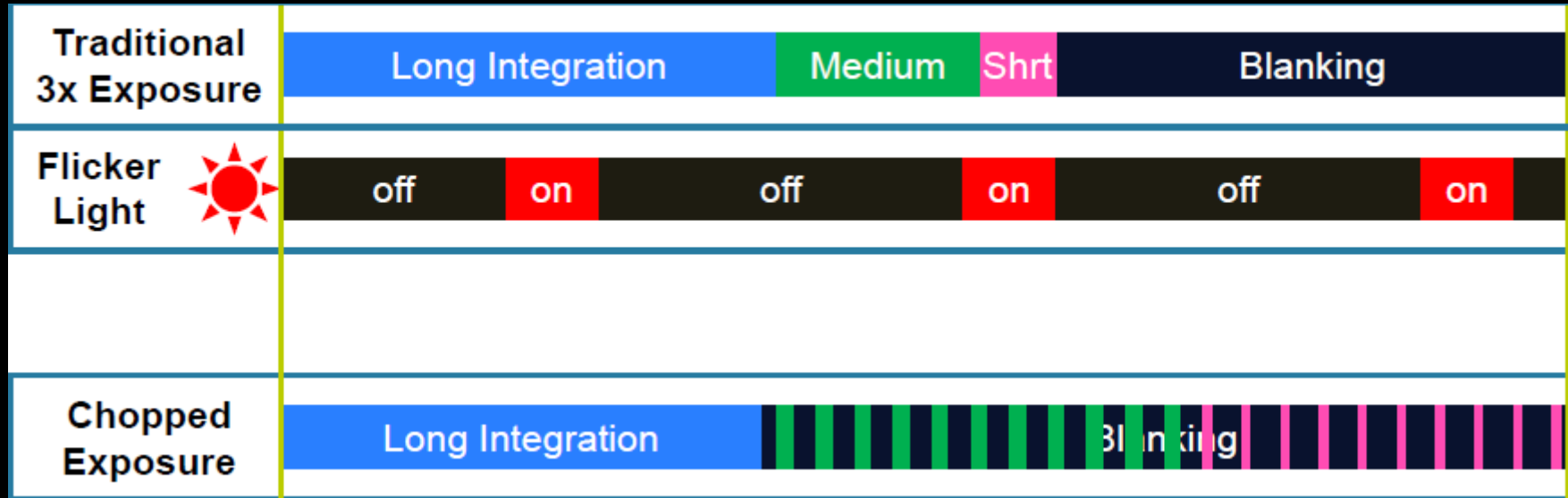
Traditional 3x Exposure	Long Integration					Medium	Shrt	Blanking	Long
Flicker Light 	off	on	off	on	off	on	on	off	off

ST Microelectronics

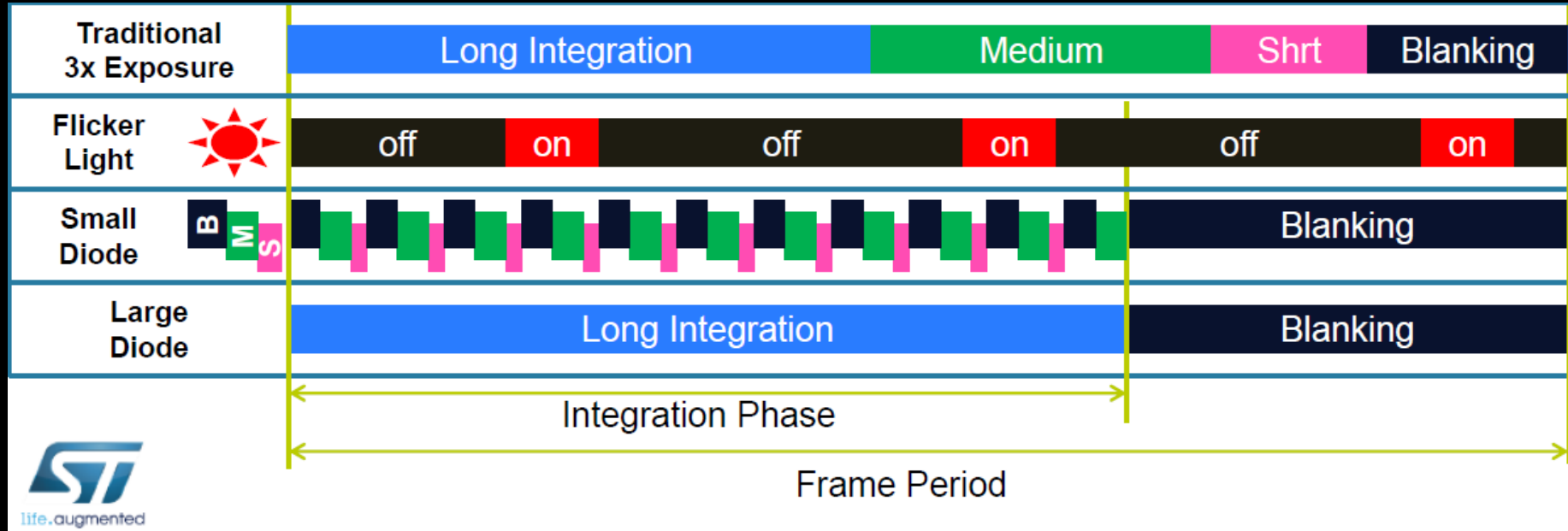
Chopping the exposure is the right direction.

Catch LED Illumination correct.

But with moving objects much more worse.



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



20297 5.58

bench971

Output

UseCases

Search

bench971.UseCases

UseCases

ConfigCaptureOnly

ImageSize

ImagePosition

XYFlip

PWLActivation

bench971.VideoCa...

VideoCapture

Mode

Stream



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

bench971.Output

Gain: 0 EV Channel: RGB ROI type: Rectangle

1920 x 1080 x RGB, 8 bits/channel (int16)



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 Avalanche 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

Dana Diezemann

Senior Strategical Product Manager

ddiezemann@isravisision.com

+49 6151 948 278 | +49 172 2980 278

isravisision.com | photonfocus.com

The logo for ISRA VISION, with "ISRA" in large grey letters and "VISION" in smaller red letters below it.The logo for photon focus, featuring the word "photon" in black and "focus" in red, with a red swoosh underline.