ams OSRAM

A 0.5Mpixel global-shutter image sensor with NIR QE enhancement, 20mW power consumption and smart event detection modes

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Agenda

1. Introduction
2. Sensor architecture
3. HDR
4. Special features
5. Char results
6. Conclusion

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Hot applications for global shutter image sensors

AR/VR & wearables

- Eye tracking
- Head tracking
- hand tracking

Robots & drones

- Obstacle avoidance
- SLAM navigation solutions*

*SLAM - simultaneous location & mapping

Mobile, consumer & computing

- Biometric access control
- Eye tracking
- Face tracking

Industrial, home & building automation

- Presence detection
- Smart door access control
- Flow control, pick & place, object detection
- Barcode readers in logistics

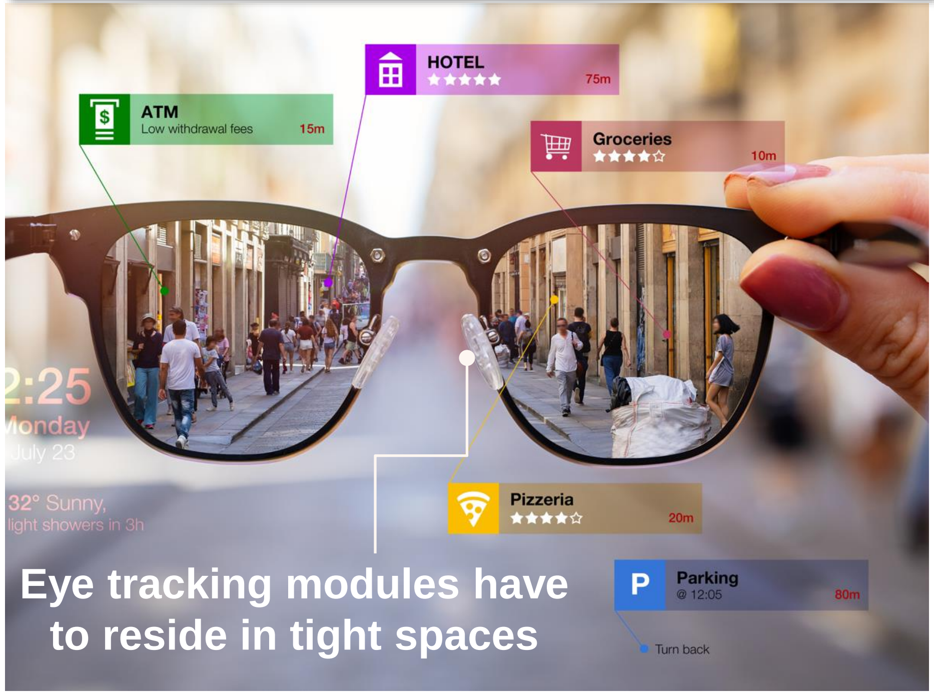
Hot applications for global shutter image sensors

Desired features

- Global shutter
- Small footprint
- Low cost
- Low power
- High QE at both visible and NIR

Looking closely at AR/VR APPS

Products have to fit in tight spaces which makes integration difficult

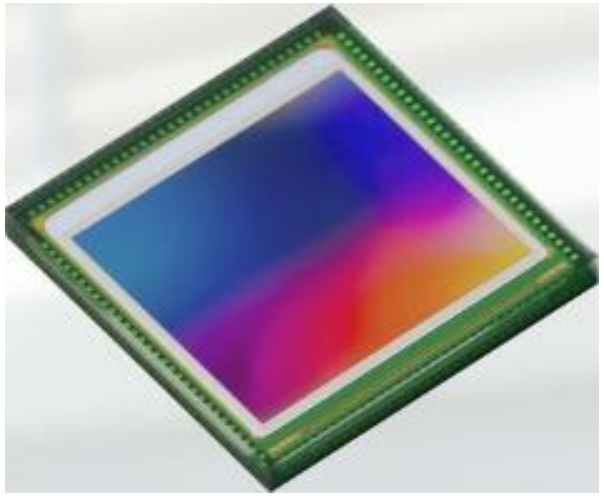


Most critical requirement

- **Smallest footprint:** (packaged sensor placed on thin glasses frame)
- **Low power: sensor power + system power (via global shutter operation)**

MIRA050 design aiming:

1. **Ultra-low system power consumption**
2. **Smallest die size global shutter sensor**



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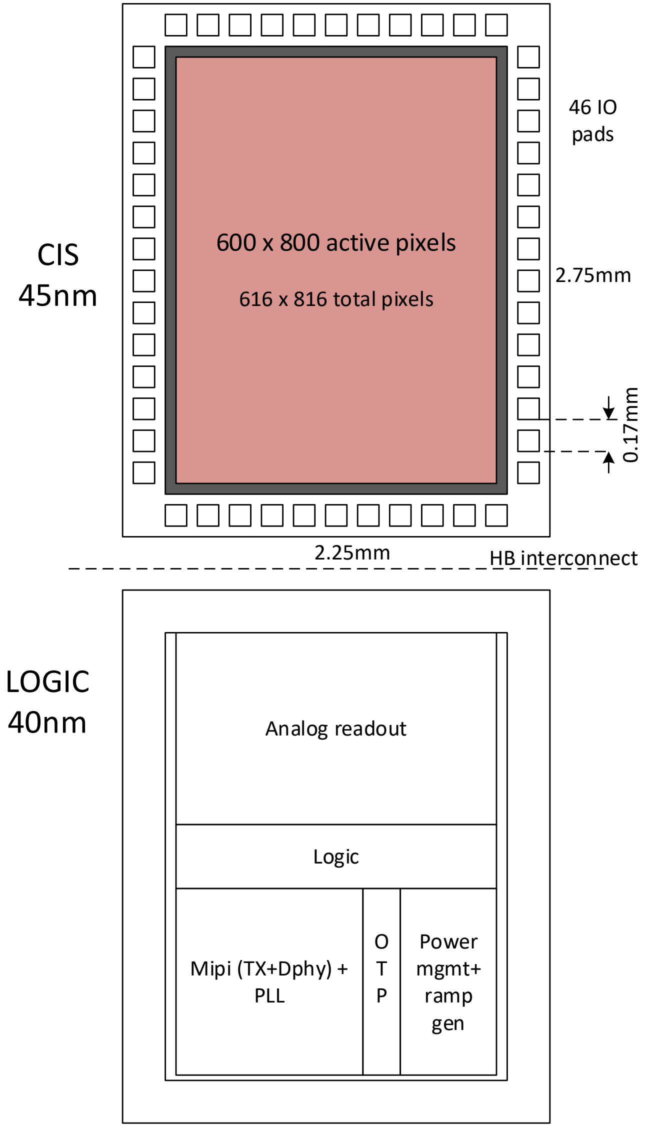
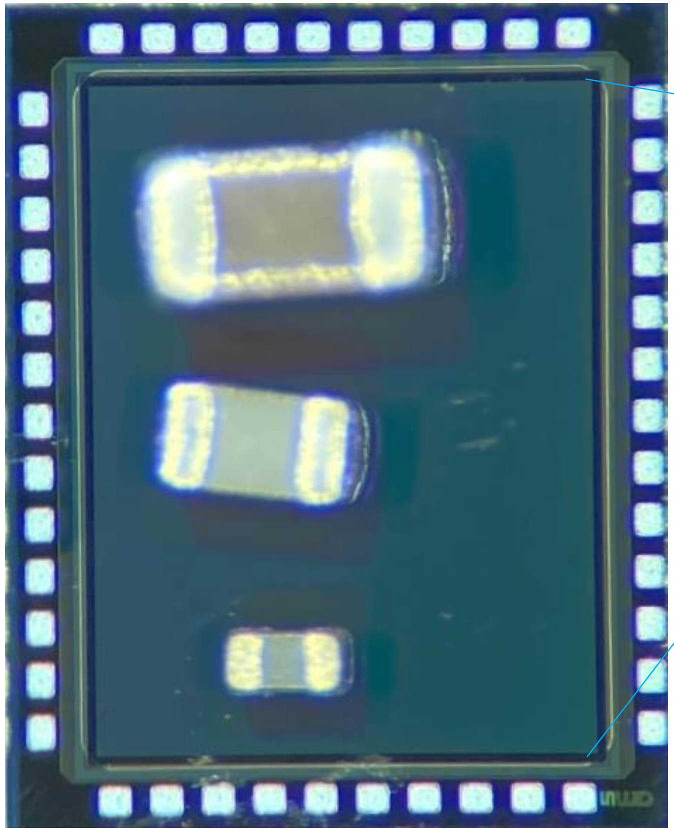
Sensor architecture



Based on consumer sensor requirements, especially AR/VR applications, ams OSRAM designed the **Mira050** CMOS image sensor with:

- 600 x 800 active pixels resolution (**0.5MP**)
- **2.3mm x 2.8mm** CSP packaged size
- 3D stacked **45nm CIS + 40nm logic** with HB interconnect
- **2.79um GS BSI**, voltage domain pixels with > 90% visible QE and >36% 940nm QE
- Ultra compact readout IP

Sensor footprint



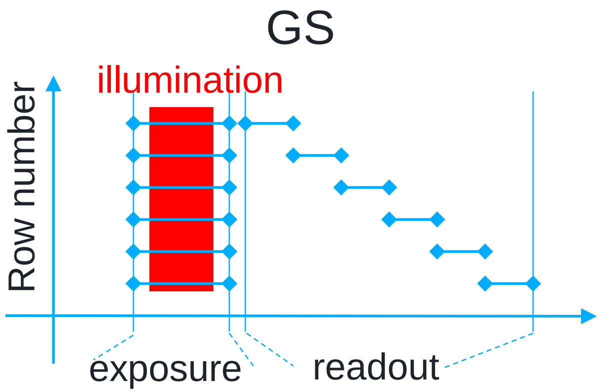
Despite miniaturized size

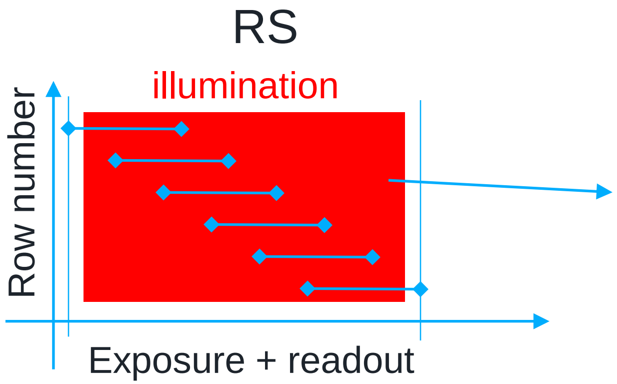
- Optimal usage of silicon area for pixel array squeezing maximum possible sensitivity
- Includes all modern features required by consumer sensors such as MIPI interface, smart event detection, smart power down modes, etc

Ultra-low system power consumption(1): global shutter

Global shutter has 2 major advantages over rolling shutter sensors in AR VR apps:

1. Much lower illuminator power required: all global shutter pixels are exposed at once



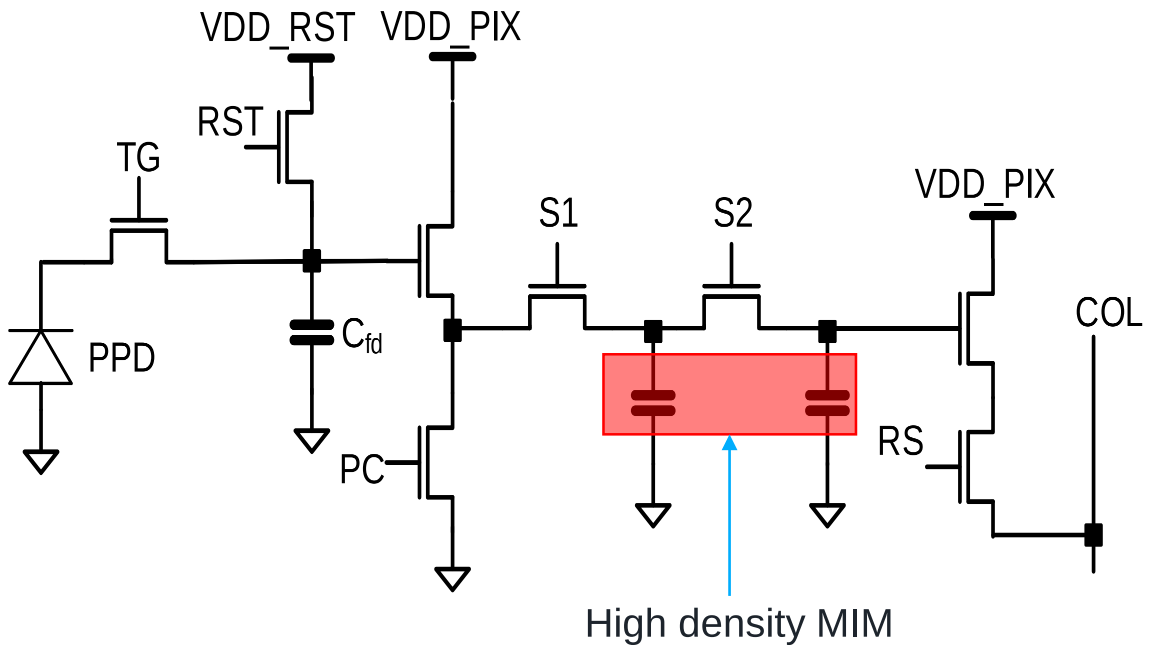


RS rows are exposed and read sequentially, requiring VCsel to illuminate for the full frame duration

2. Lower frame rate needed due to lack of rolling shutter image distortion (jello effect)
   → Also critical for power consumption

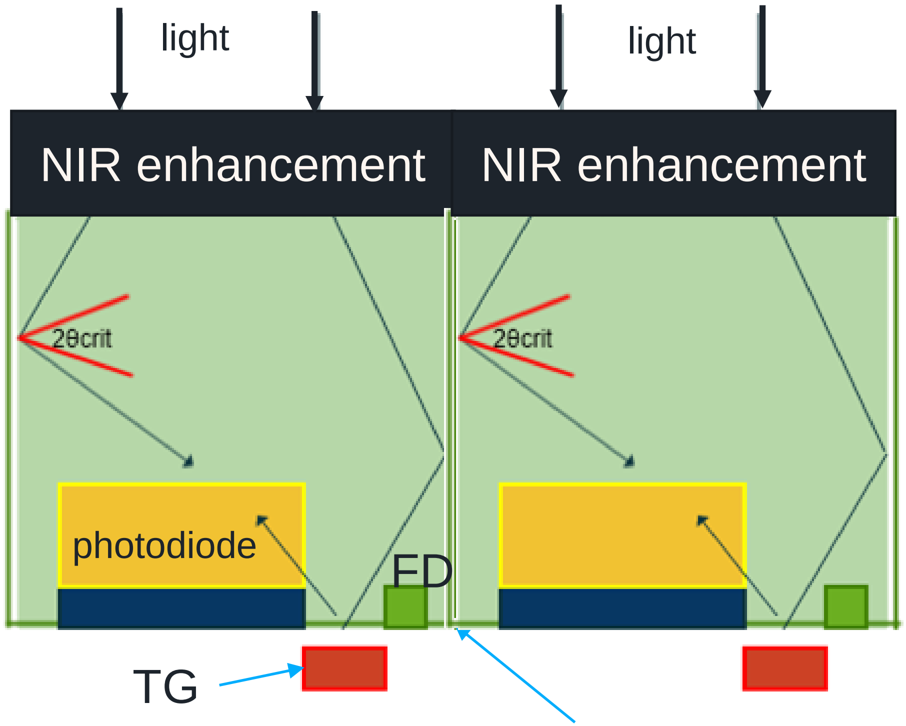
Henri Lartigue, “Race Car”, 1912

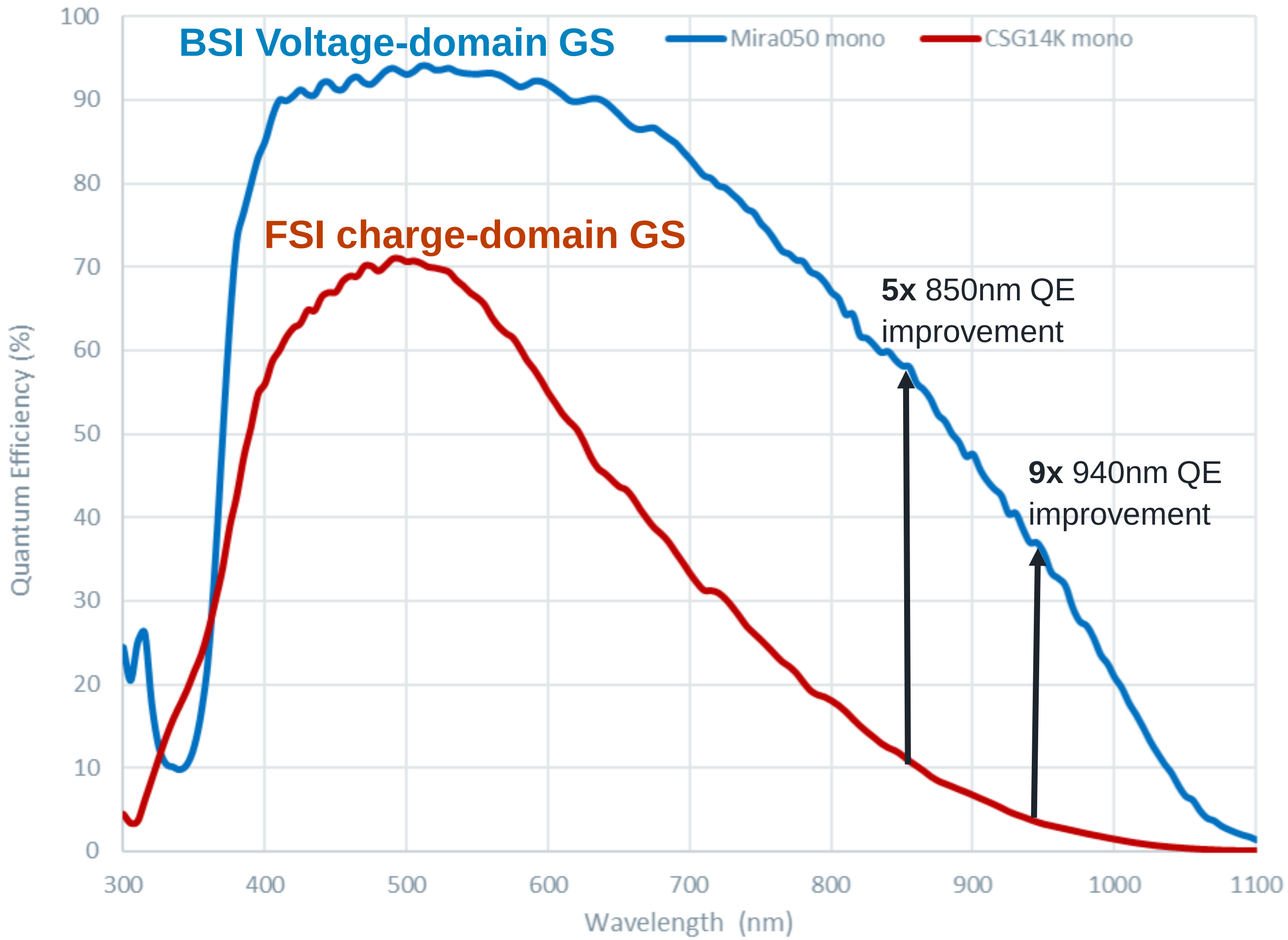
Ultra-low system power consumption(2): 8T voltage domain GS pixel with high QE



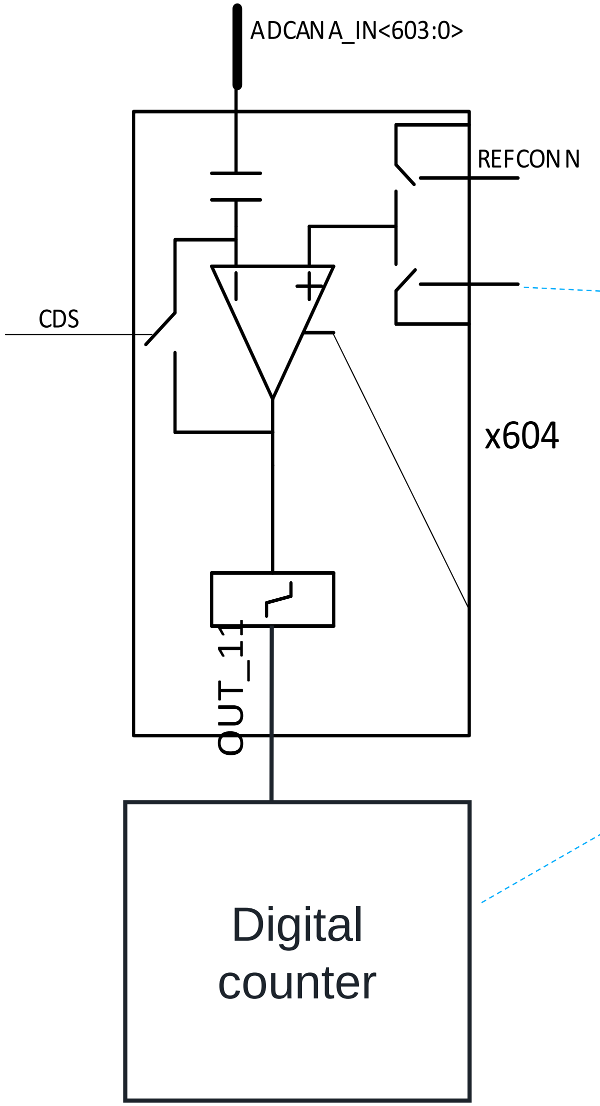
- Voltage domain is important for BSI + NIR extension due to PLS performance
- Less noise competitive with charge domain but improving

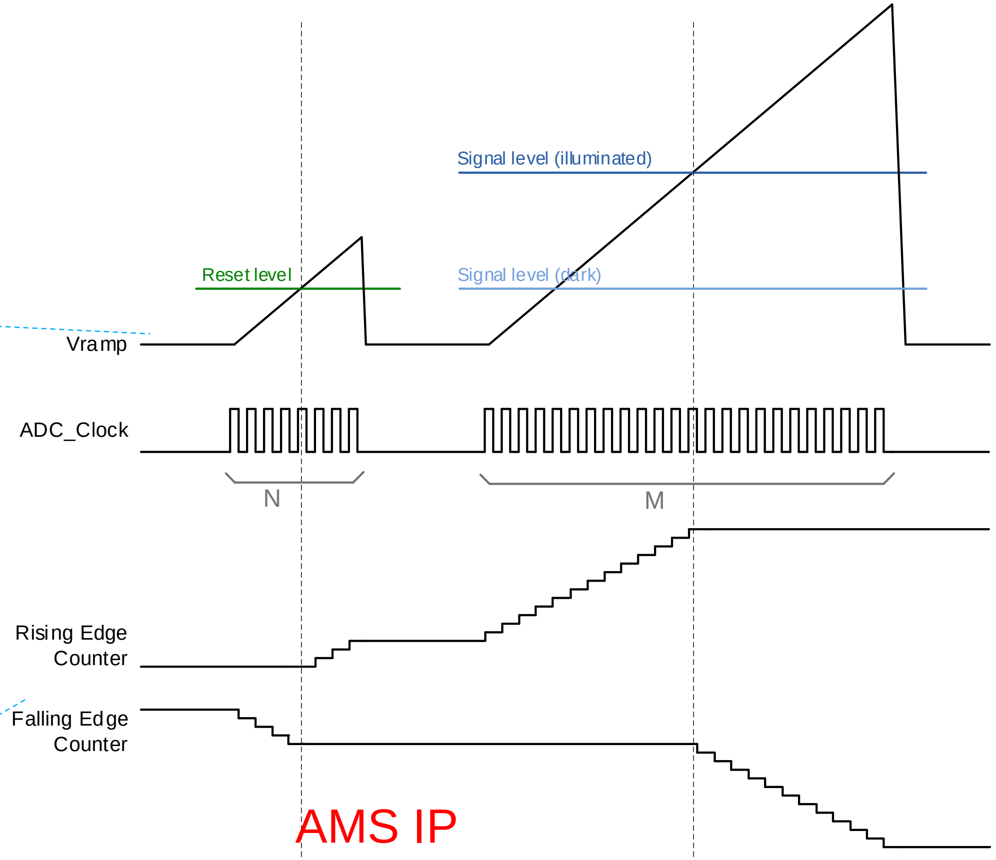
Ultra-low system power consumption(2): 8T voltage domain GS pixel with high QE





Ultra-low system power consumption(3): mostly digital ADC

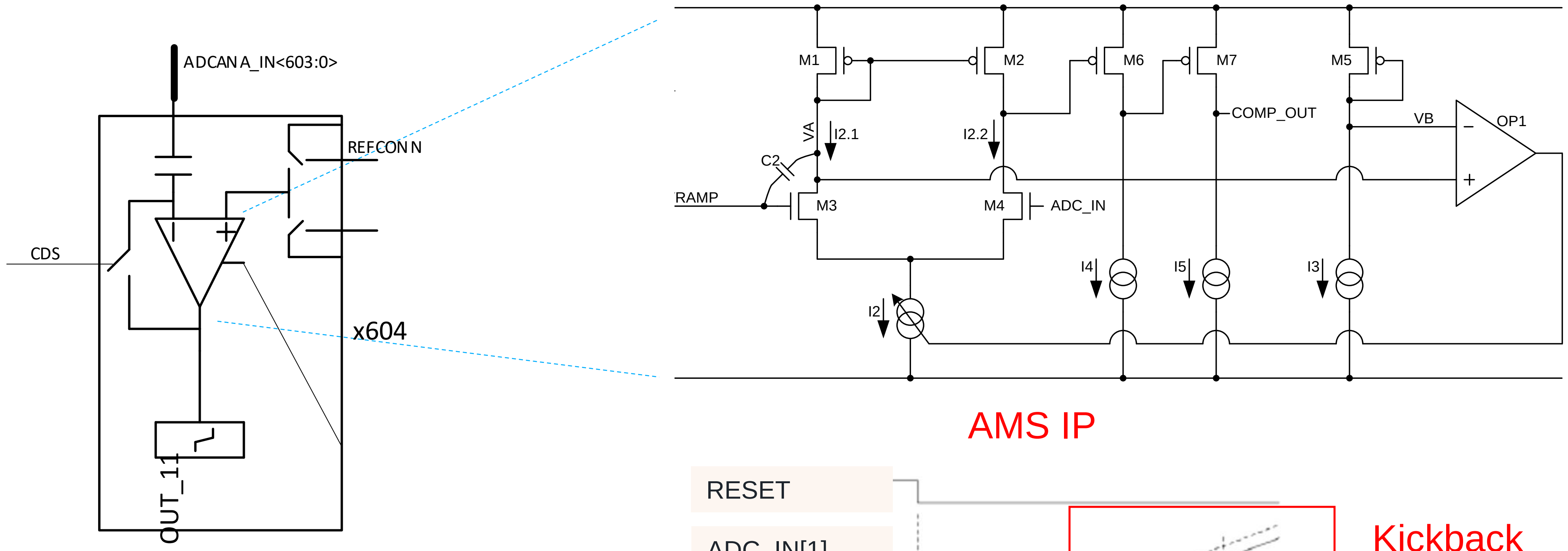




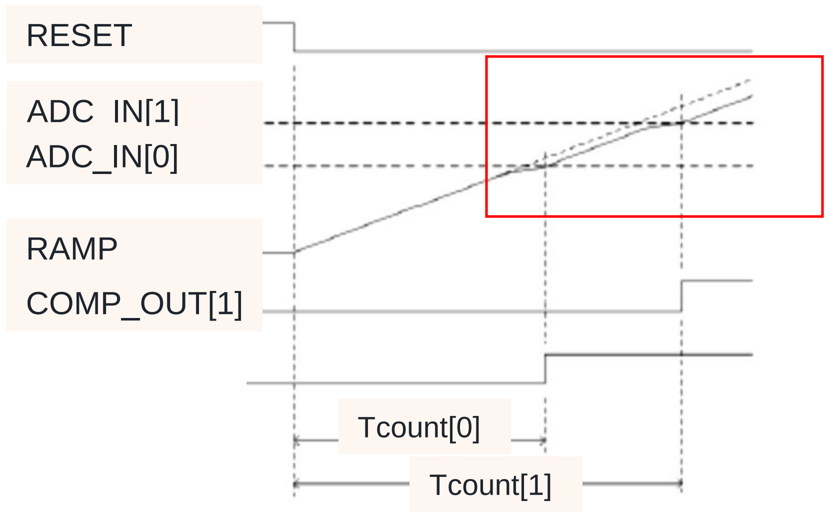
- Constant current consumption → reduced banding
- 1 bit resolution increase

Ultra-low system power consumption(4): Mostly digital ADC

ADC ramp capacitance size reduction via kickback cancellation circuit



AMS IP



Kickback removed

Kickback cancellation circuit drastically improves

- ramp **power consumption**
- **die size**

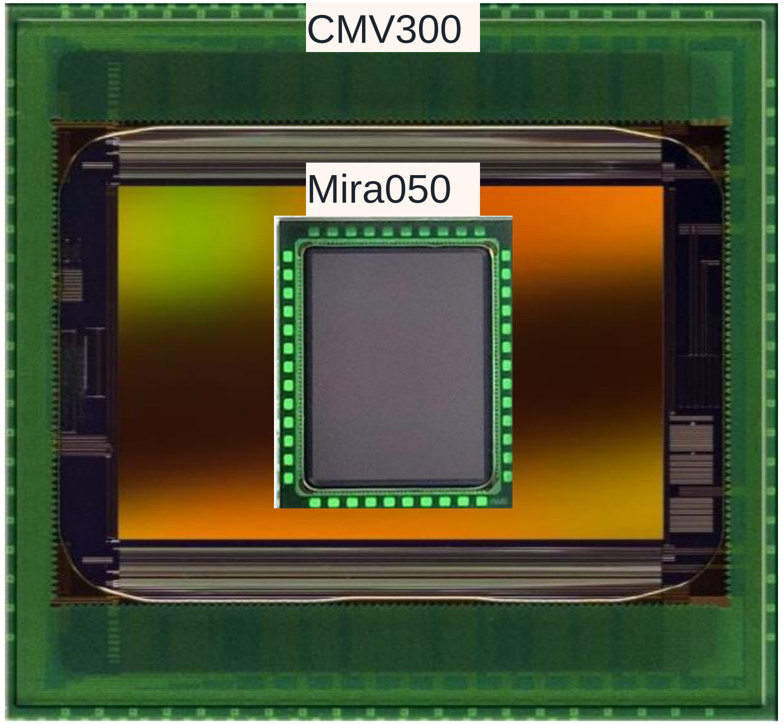
Ultra-low system power consumption(5): tech node scaling

- Exchange analog for more digital
- Use of scaled technology node (40nm)

↓

Drastic overall power reduction

item	Ams OSRAM Mira 050 SVGA, 0.5MP	Ams OSRAM CMV 300 VGA, 0.3MP
Power 30fps, 10bit	18.5mW	700mW
Power 60fps, 10bit	30mW	
Power 120fps, 10bit	53mW	
Power 200fps, 10bit	75mW	



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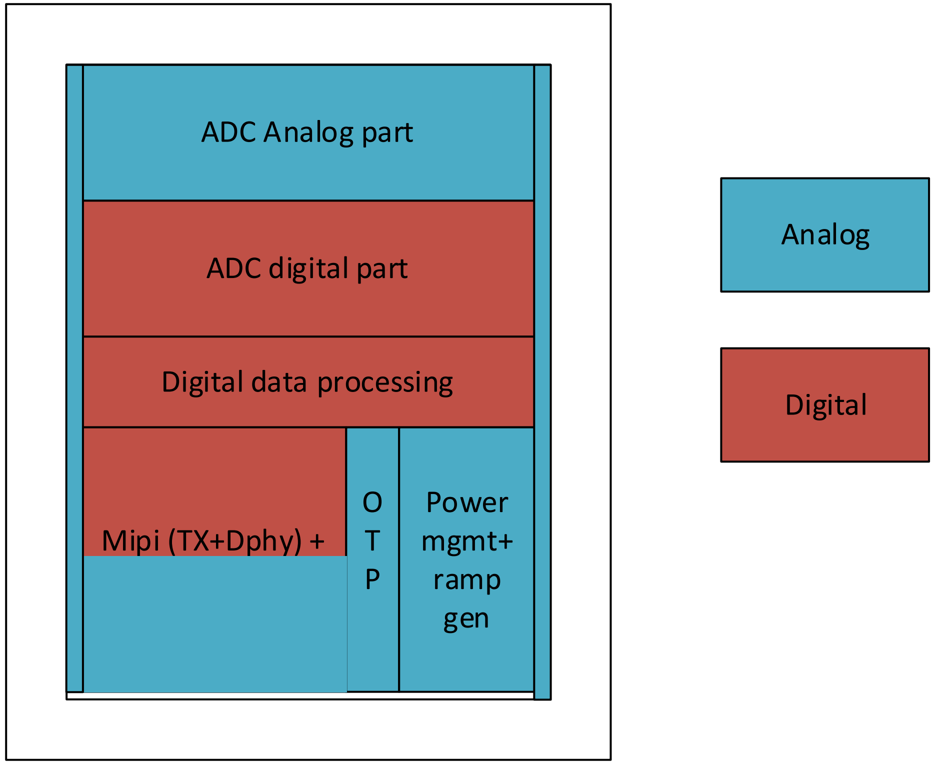
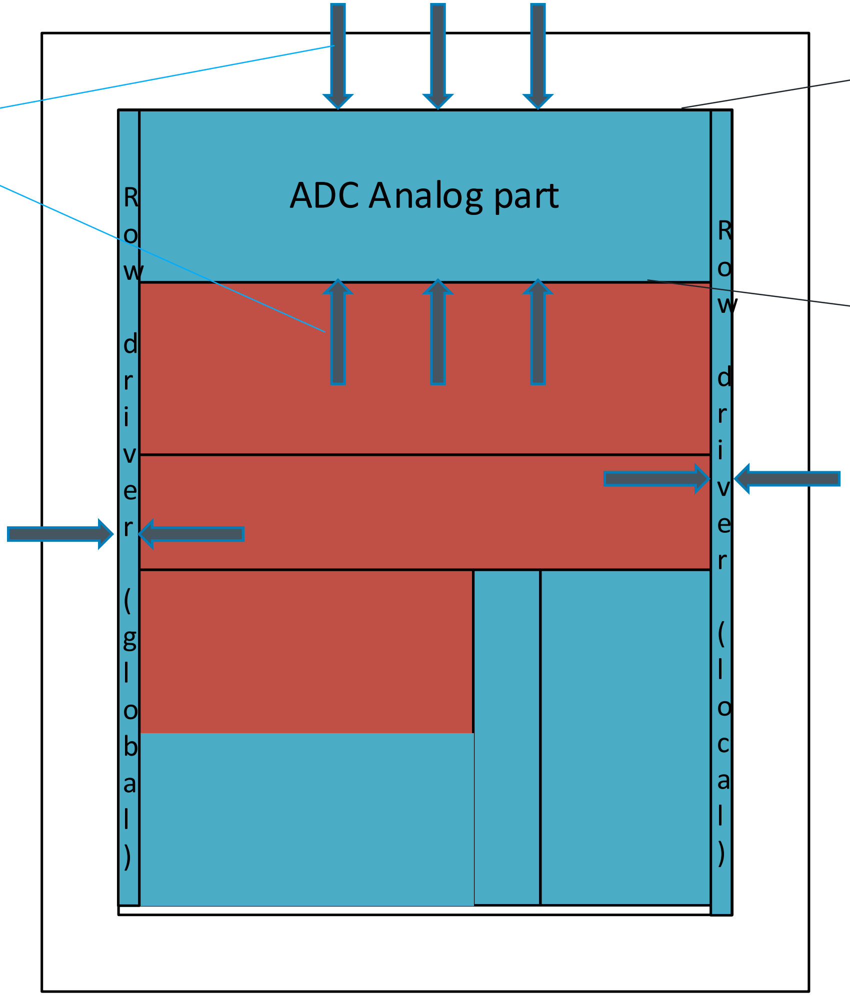
Footprint reduction (1): focus on logic layer

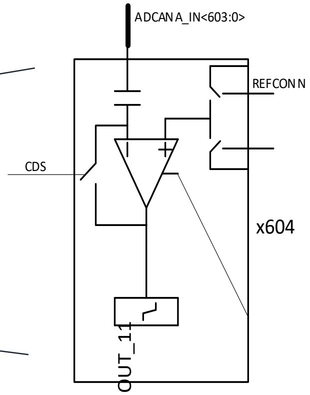


1. Reduce and area-optimize analog blocks
2. Use scaled tech node (40nm) for digital

Footprint reduction (2): focus on logic layer

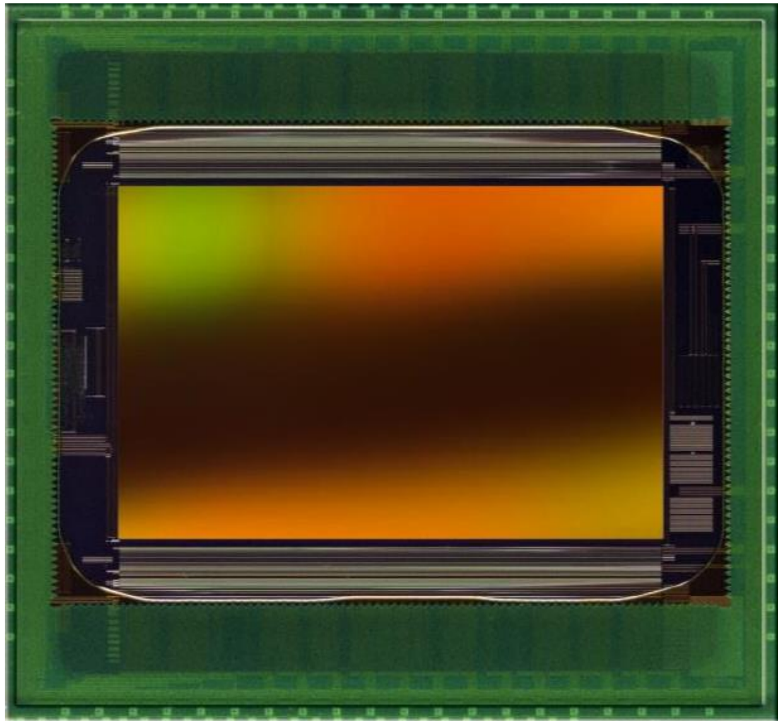
1. Squeeze ADC size by simplifying comparator schematic and by removing column S&H scheme
2. Reduce ramp cap size by kickback cancellation technique





Squeeze row driver size (20um width on left and right side) by sharing bias blocks and exploiting metal spacing capabilities of 40nm tech

Footprint reduction (3): ams OSRAM's size reduction



ams OSRAM CMV300
GS, VGA (640 x 480 pixels)

ams OSRAM Mira050,
GS, SVGA (600 x 800 pixels)

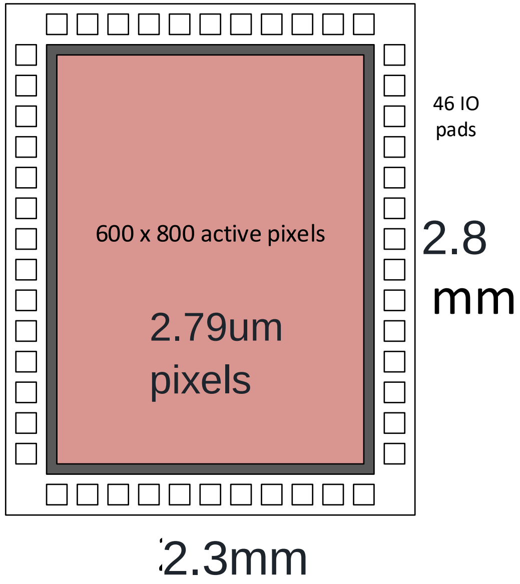
Footprint comparison with state of the art consumer GS sensors

- Optical area is critical for sensitivity hence system power consumption - A
- Total package area is critical for system footprint - B

Efficiency ratio defined as: optical area/total package area (Area A/ Area B)

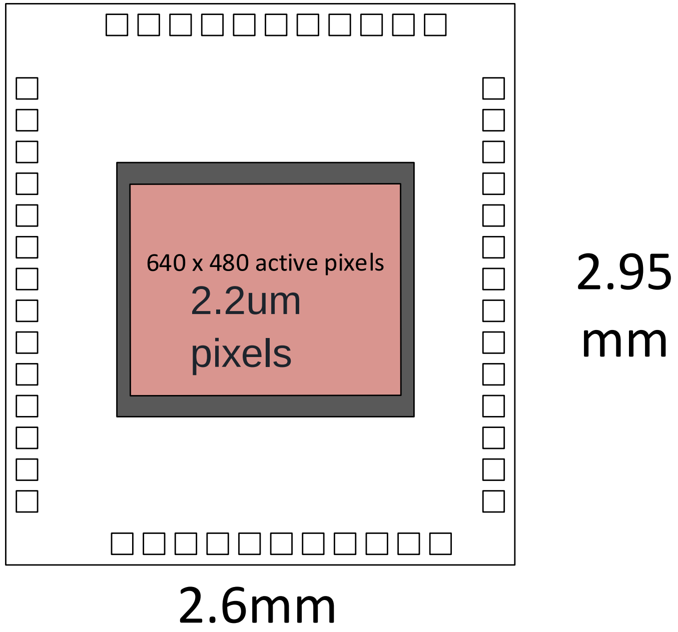
Footprint comparison with state of the art consumer GS sensors

This work



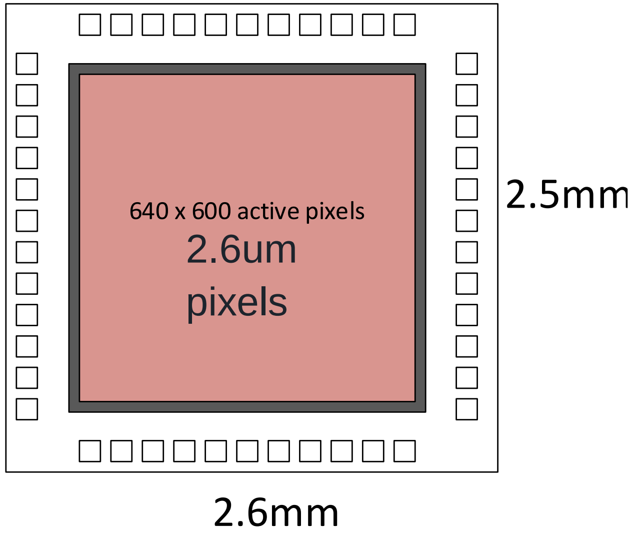
Total Area= 6.44mm2
Optical Area= 3.74mm2
Efficiency ratio = 58%

Competitor 1



Total Area= 7.67mm2
Optical Area= 1.48mm2
Efficiency ratio = 19.2%

Competitor 2



Total Area= 6.5mm2
Optical Area= 2.58mm2
Efficiency ratio = 39%

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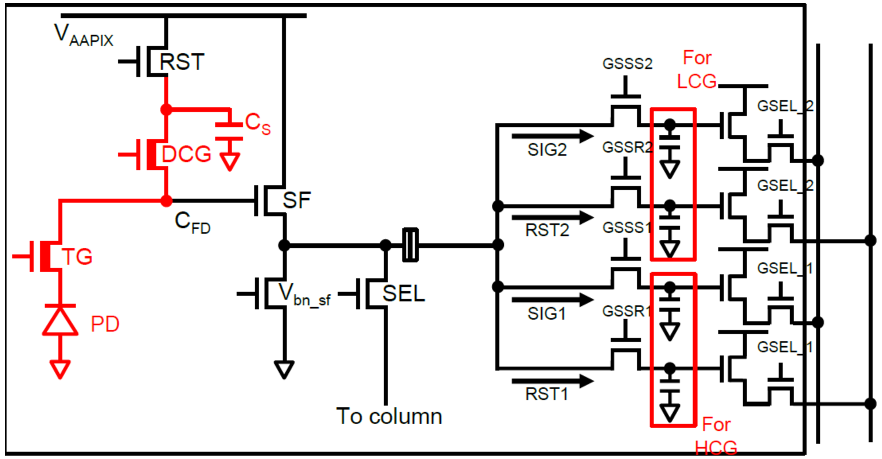
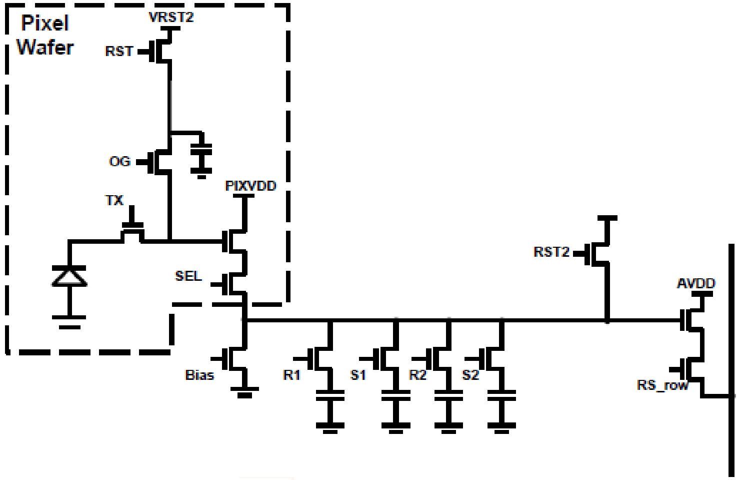
HDR Prior art



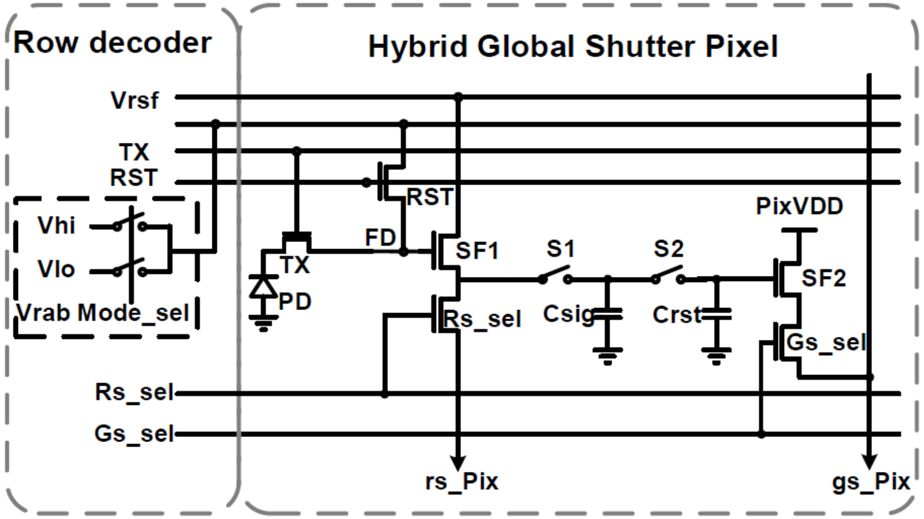
Miyauchi, IISW'21

>= 4x HD MIM caps / pixel



Fowler, Autosens'21

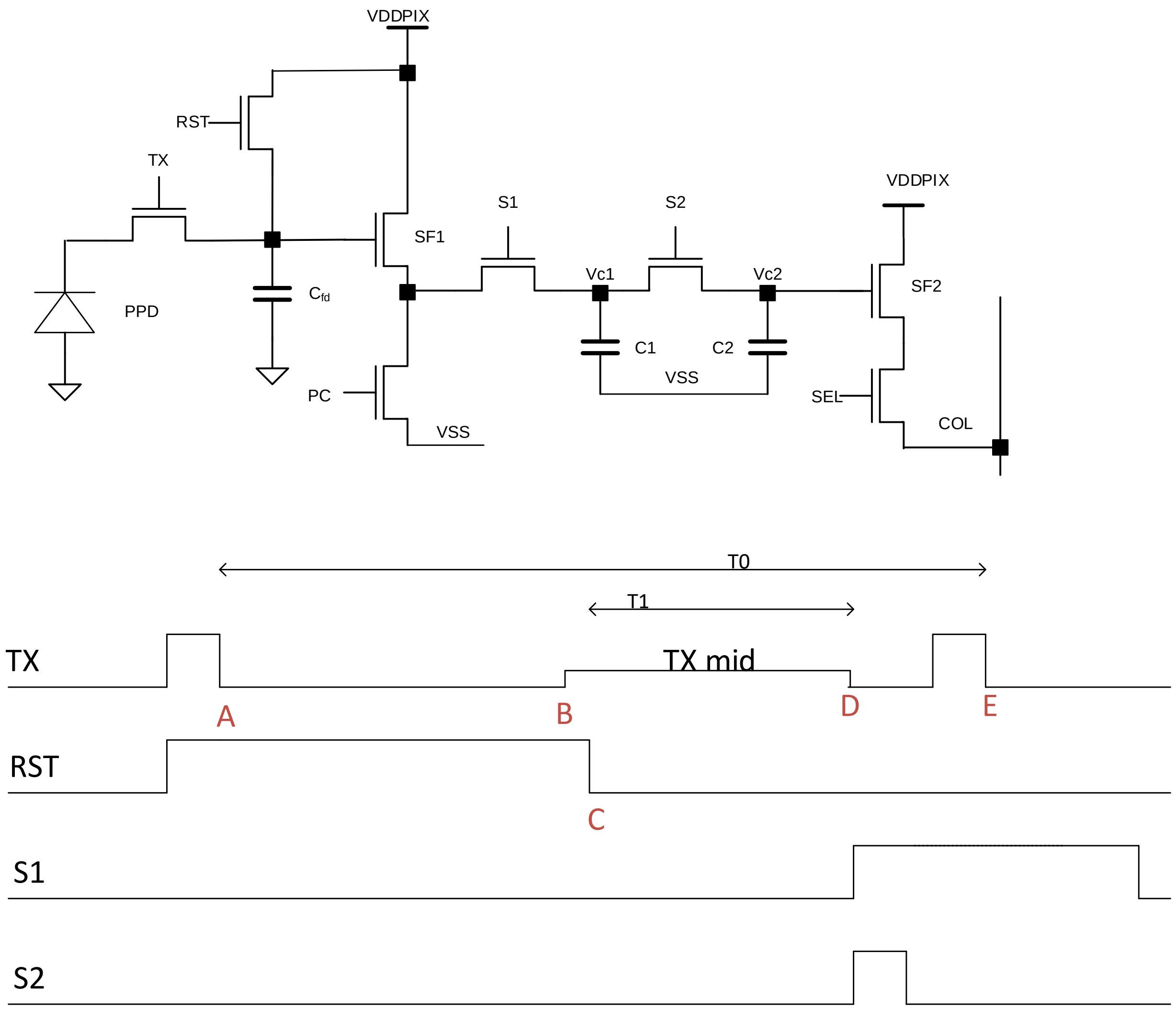
>= 4x HD MIM caps / pixel



Xu, ISSCC'19

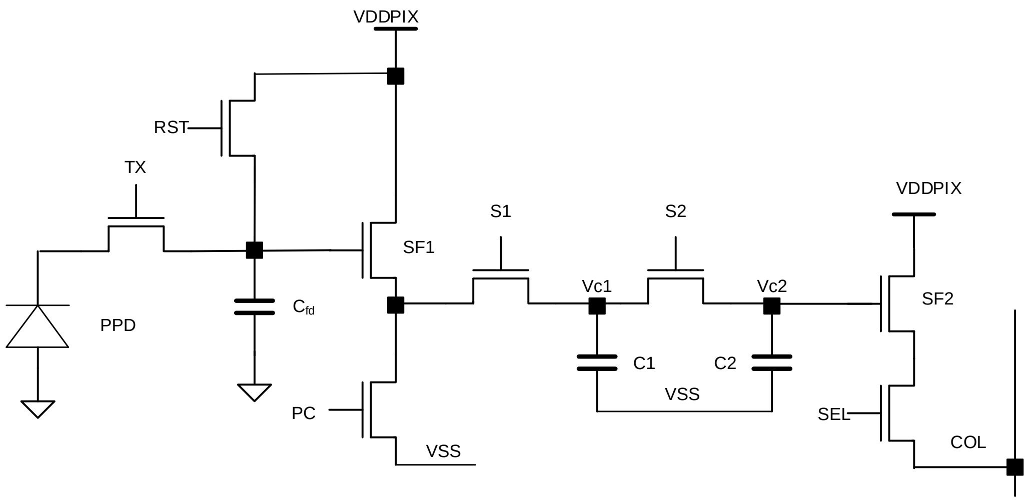
- Complex FPN calibration
- Limited DR extension
- No pipeline operation

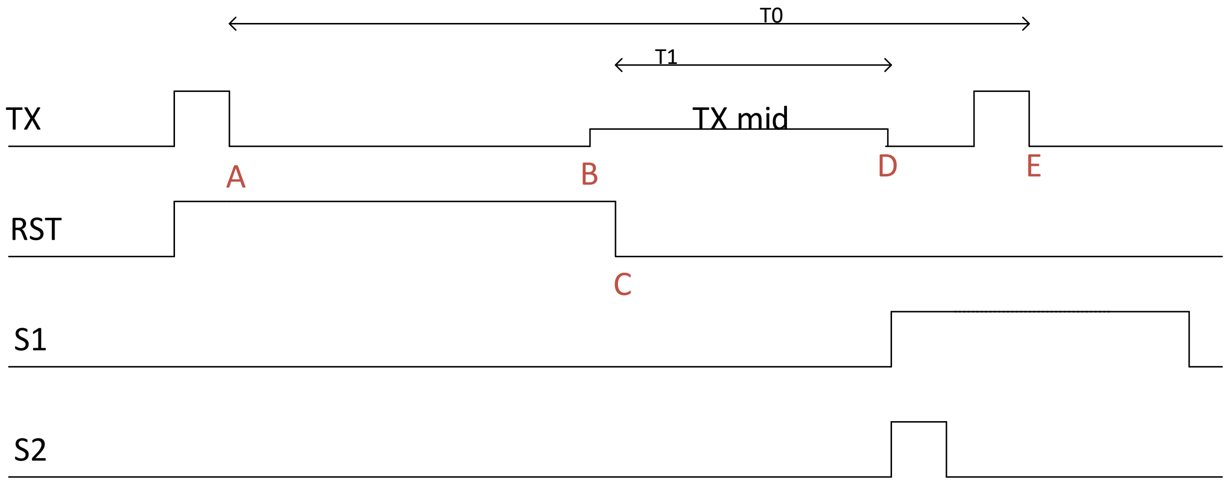
Proposed HDR technique: Short overflow



- Highlight exposure during T1: Overflow operation
  - No large LOFIC cap needed
  - Similar performance as conventional LOFIC with cap T0/T1 larger
- Lowlight exposure T0: normal readout
- Similar HDR operation as odd/even row exposure approach without loosing row information

Proposed HDR technique: operation

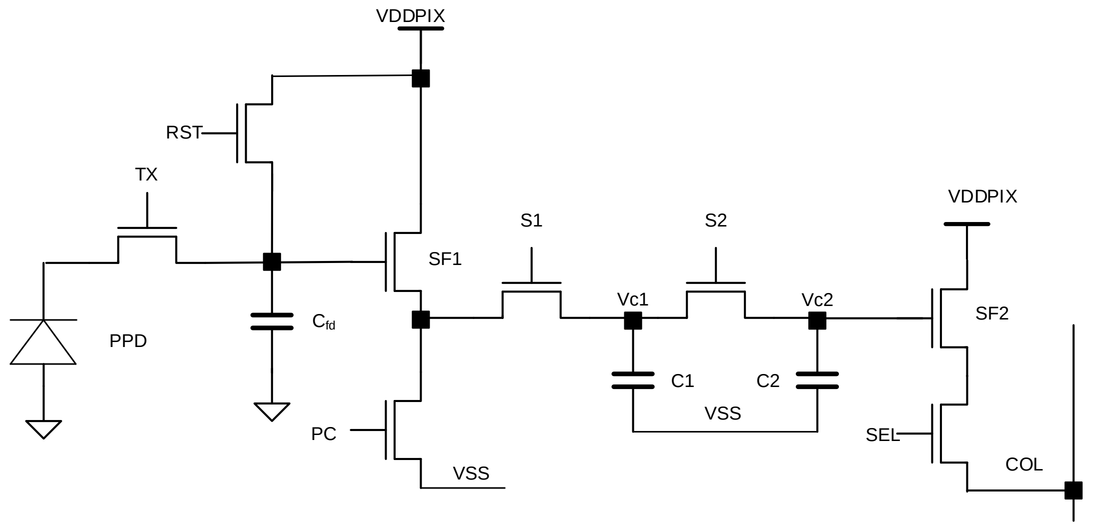




Global operation

A) start of T0 exposure
B) TX mid level pulse: flushes away from PD changes above certain barrier
C) Start of exposure T1
D) Stop exposure T1 and storage of T1 sig on C2 (Vc2)
E) Stop exposure T0 and store of T0 sig on C1 (Vc1)

Proposed HDR technique: operation

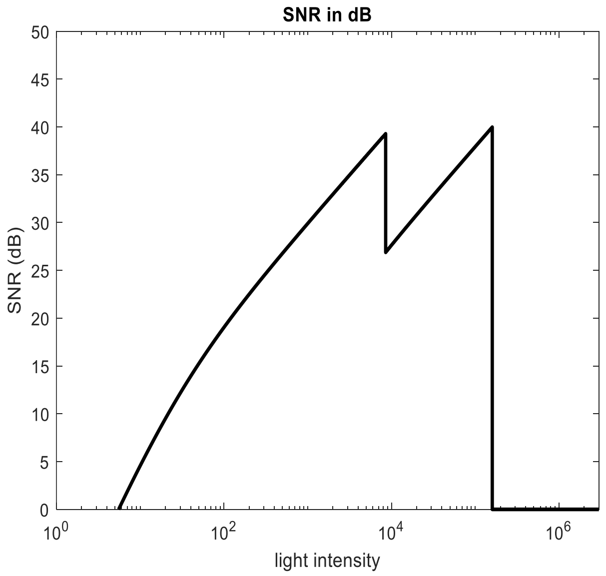


Row-by-row operation

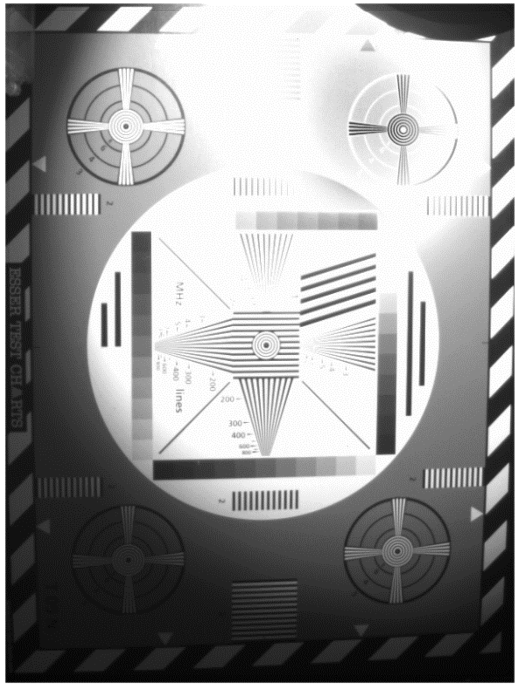
1) Read Vc2: if highlight, VC2 contains overflow charges of T1. If lowlight, no overflow hence VC2 is used as reset level for low light CDS operation
2) Read Vc1 merged to Vc2: perform convectional digital CDS of 8T pixel
3) Re-access reset level of FD
4) Perform DDS highlight by subtracting Vc2 – REST FD

CDS lowlight + DDS highlight available with only 2 capacitors

Proposed HDR technique: preliminary performance eval



12bit, 1x gain



12bit, HDR mode

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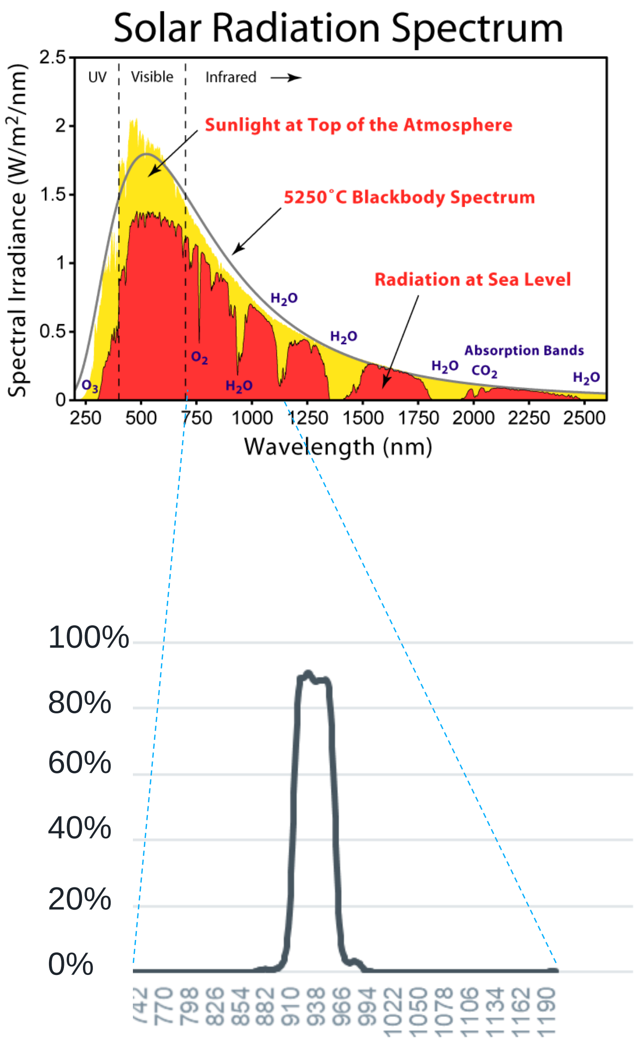
Background Light Cancellation

Problem Description



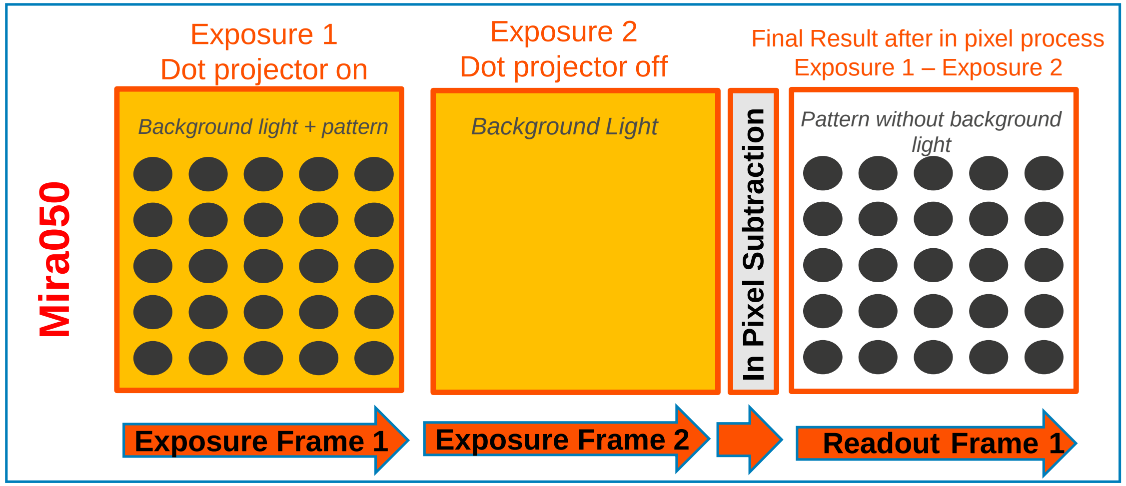
NIR band-pass filter

NIR 940nm band-pass filters have a bandwidth of about 40 to 50 nm, which causes undesired exposure of the sensor by residual sunlight in outdoor conditions

→ the NIR dot pattern gets covered by residual NIR light which reduces the accuracy of 3D reconstruction algorithms

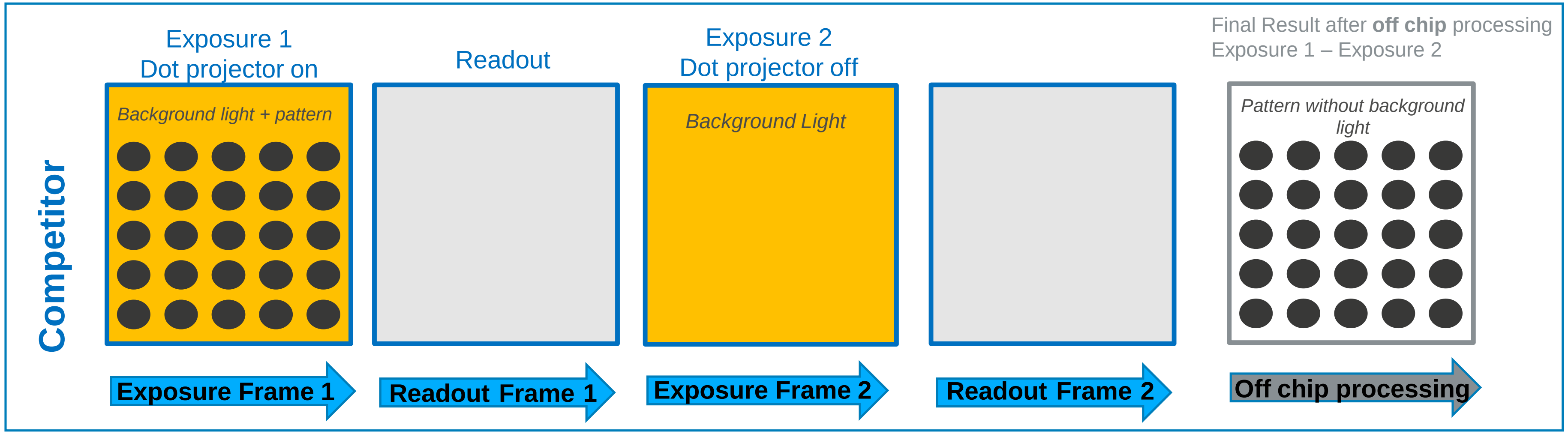
In-Pixel background subtraction on Mira050

Unique ams Mira050 solution which cancels background light with in the pixel to save power and time



✓ **Fast** - Provides dot pattern in a single frame.

✓ **Power savings** at 50% lower readout (single ADC and MIPI output readout needed as opposed to two for competitors which contributes to large power savings)



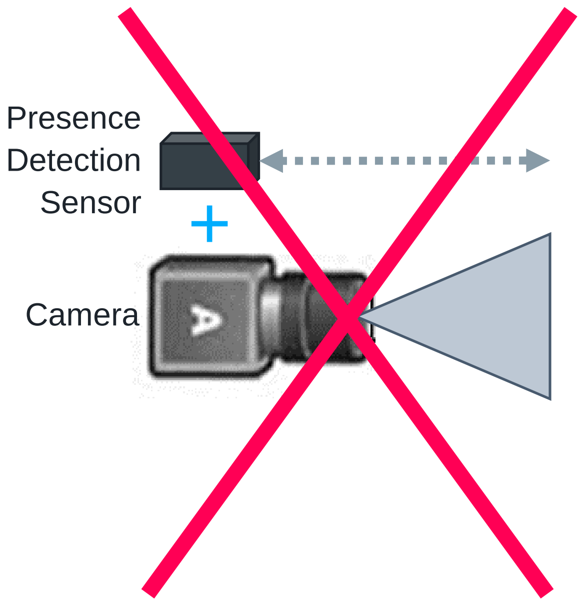
✗ **Requires 2 frames** to be read out to provide a dot pattern which means two readouts needed (ADC and MIPI) = higher power

✗ **Requires off chip processing** which further increases system power requirements

Event detection for camera wake-up from 3mW event detection state

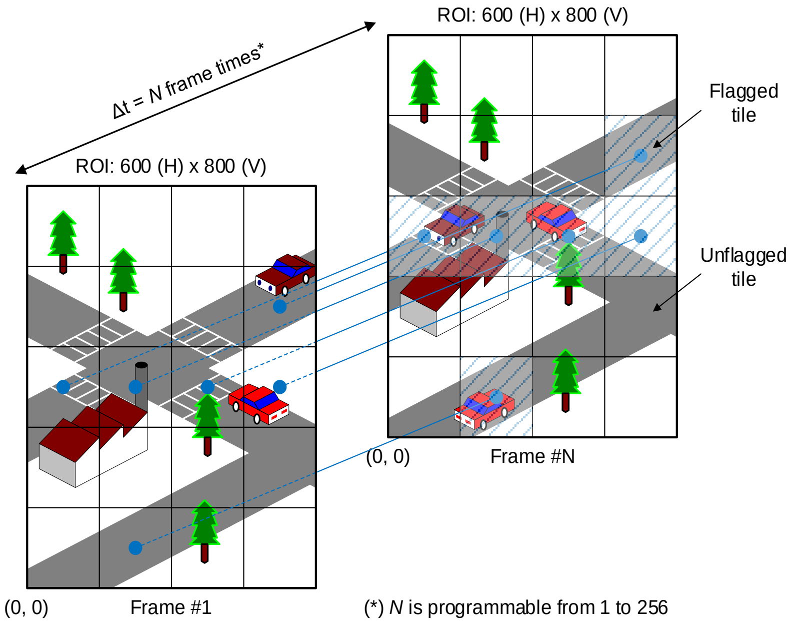
Mira050 provides user-configurable tile-based event detection functionality on chip

Conventional event detection setup



Requires a more expensive BoM and more complex system design to provide a similar wake-up function

Camera wake-up / on chip event detection by Mira050



(*) *N* is programmable from 1 to 256

Parameter	Event Detect. Example	Normal Mode
Frame Rate	1 fps	120 fps
Power	3 mW	48 mW
Resolution	Programmable	600x800

Simple system design for low-power modes on battery operated or event triggered cameras:

- Reduced BoM as no additional sensor needed
- Simpler system design both for hardware and software

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Characterization results summary

Parameters	Units	Value	Comments
Linear Full-Well	*ke-*	9	At unity gain
Non-linearity	*%*	0.26	-
Temporal dark Noise	*e-*	5	@ 12b or 10b 4x gain mode
Fixed Pattern noise (FPN)	*e-*	3	
Linear Dynamic Range	*dB*	63.4	-
SNR Max	*dB*	39.5	-
PRNU	*%*	0.7	-
Peak QE (peak, 850, 940nm)	***%***	**94** **55.4** **36**	
Dark Current @ 60C	*e-/sec*	27	-
PLS @ 940nm	***dB***	**-91**	
PLS @ vis	***dB***	**-120**	
Power Consumption 0.5MP @ 30fps 10bit	***mW***	**18.5**	10 bit mode
Power Consumption 0.5MP @ 120fps	***mW***	**53**	10 bit mode

Characterization results comparison

Parameter	Park et al., IEDM'19 on OG0VA	Miyauchi et al., IISW'21	This work
technology	stacked 45nm-65nm	stacked 45nm-65nm	stacked 45nm + 40nm
Pixel pitch (um)	**2.2**	4	2.79
Resolution	640 x 480	1024 x 832	600 x 800
Shutter	Global VD	Global VD	Global VD
DR (dB)	61	**90**	**90 (HDR mode)**
Noise (e-)	**2.3** (HCG mode)	4	5 (LCG mode)
Power (mW)	139	-	<20mW@10b,30fps, <60mW@10b,120fps
Footprint (mm x mm)	2.6 x 2.95	8 x 8	**2.3 x 2.8**
Footprint efficiency ratio (%)*	19.2	21.3	**58**
QE 940nm (%)	38	40	36 @20C, >40%@60C

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Summary

- 0.5MP 3D stacked GS image sensor with 0.5MP and 2.3mm x 2.8mm package size
- Low power and small footprint achieved via mostly digital readout IC combined with scaled tech node and bias current optimization
- System power reduction achieved via GS with high QE at visible + 940nm and by stretching active area
- Despite small area sensor includes all modern consumer sensor needs such as mipi interface, I2C communication, smart power down modes, event detection, etc.