Trends in CMOS Image Sensors

532. WE-Heraeus Seminar, 23~25 May 2013

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Contents

- History of Imaging Technology
- Pixel Development and High Speed ADC
- New Differentiation
- Mirror-less DSLR
- Automotive, Gesture and Plenopitcs

Evolution of Image Technology

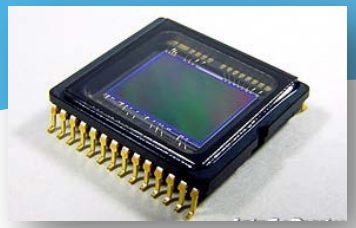
- Development of camera leads to mass proliferation of imaging technology

Pinhole Camera

Film Camera

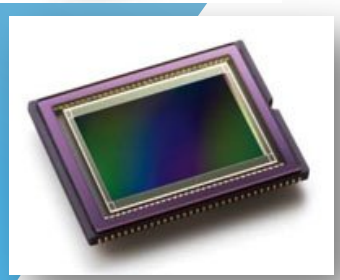
Eastman Kodak

CCD Camera



CCD Sensor

CMOS Camera



CMOS sensor

Digital Era through Mobile Phone

2005, before mobile device

The faithful gather in 2005 near St. Peter's to witness Pope John Paul II's body being carried into the Basilica for public viewing

Photo by Luca Bruno, AP

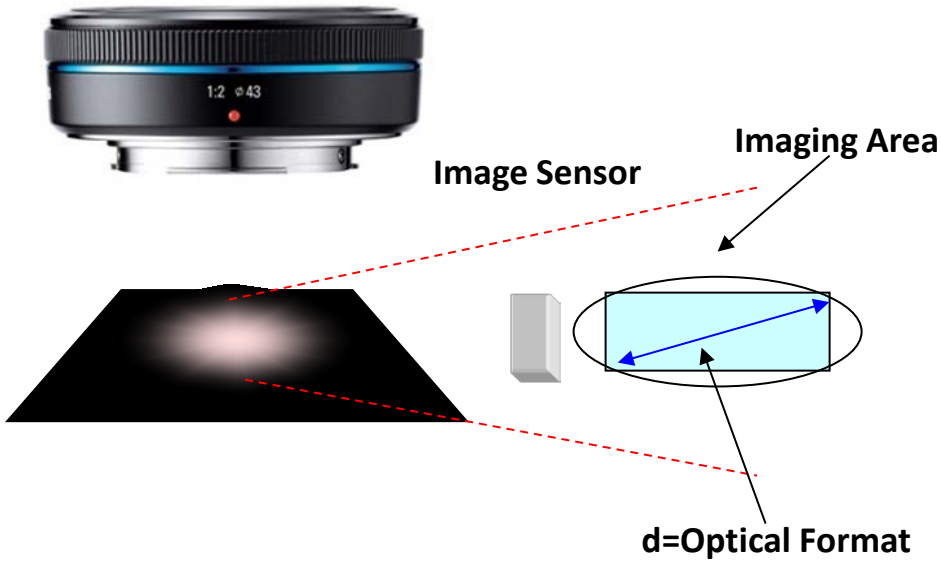
2013, after mobile device

St. Peter's Basilica at the Vatican, on March 13, 2013.

Photo by Michael Sohn, AP

Source : NBC news
http://photoblog.nbcnews.com/_news/2013/03/14/17312316-witnessing-papal-history-changes-with-digital-age?lite

- Imaging size of sensor depends on lens optical format



Optical Format	Imaging Size
1/7 inch (=3.63 mm)	~2.6 mm
1/6 inch (=4.23 mm)	~3.0 mm
1/5 inch (=5.08 mm)	~3.6 mm
1/4 inch (=6.35 mm)	~4.5 mm
1/3 inch (=8.47 mm)	~6.0 mm
1/2 inch (=12.7 mm)	~8 mm
2/3 inch (=16.9 mm)	~10.7 mm
1 inch (=25.4 mm)	~16 mm

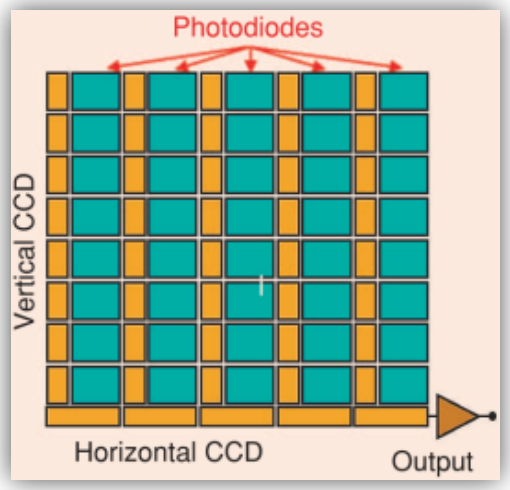
Resolution Standards

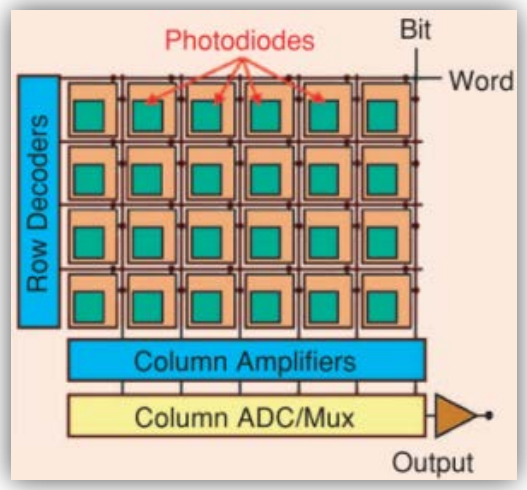
- Resolution has continuously increased

Standard	Description	Resolution	Dot Number	Aspect Ratio
QCIF	Quarter CIF	176x144	25,344	11:9
QVGA	Quarter VGA	320x240	76,800	4:3
CIF	Common Intermediate Format	352x288	101,376	11:9
VGA	Video Graphics Adaptor	640x480	307,200	4:3
HD	High Definition	1280x720	384,000	16:09
SXGA	Super XGA	1280x1024	1,310,720	5:4
UXGA	Ultra XGA	1600x1200	1,920,000	4:3
FHD	Full HD	1920x1080	2,073,600	16:9
QXGA	Quadruple XGA	2048x1536	3,145,728	4:3
QUXGA	Quadruple UXGA	3200x2400	7,680,000	4:3
UHD	Ultra High Definition	3840x2160	8,294,400	16:9

Comparison between CCD and CIS

	CCD	CIS
Advantage	High quality image	CMOS integration Random access Low power, High speed
Disadvantage	High power Low speed	Medium quality image





E.R. Fossum, "Active pixel sensors: are CCDs dinosaurs?", *Proc. SPIE, Charge-Coupled Devices Solid State Optical Sensors III*, 1900, p. 2, 1993.

Transition from CCD to CIS

Camcorder

CCD

CMOS

UHD 60fps

FHD 60fps

Speed

skype

YouTube
Broadcast Yourself

Compact DSC

CCD

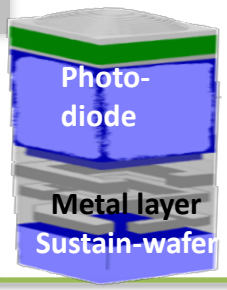
CMOS

Smaller Pixel

FHD 60fps

Image Quality

BSI



BSI 1.75um BSI

1.4um BSI

FSI 1.75um

30% UP Sensitivity

1.4um

Mobile Phone

CMOS

High Resolution
1.4um BSI

VGA

3MP

5MP

8MP

13MP

Low Resolution
1.75um/ 1.4um FSI

History of CMOS Image Sensor in S.LSI

- Total solutions from Mobile to Automotive
- Potential application might be mobile healthcare

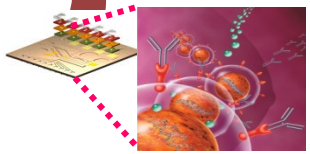
DSC/DSLR

- 3H(High Speed, Sensitivity and Resolution)
- Superior Image Quality

Automotive

- WDR
- High Sensitivity
- NIR vision

Mobile healthcare



Mobile MS No.1 ('09)

Game

- Gesture Understanding
- Low power, Depth Accuracy

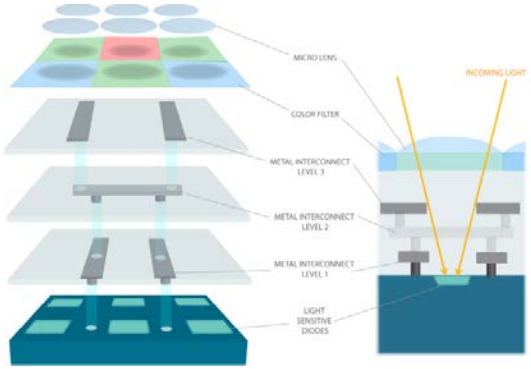
Web-Cam

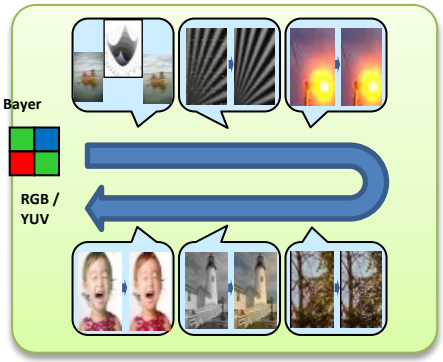
- Low light performance
- HD
- Low power

Image Sensor Structure

Pixel → **ADC** → **ISP**

Pixel	ADC	ISP
APS Color Filter Micro Lens	ADC Timing Generator	ISP Pipeline AF/AE/AWB





Contents

Resolution of Human Eye

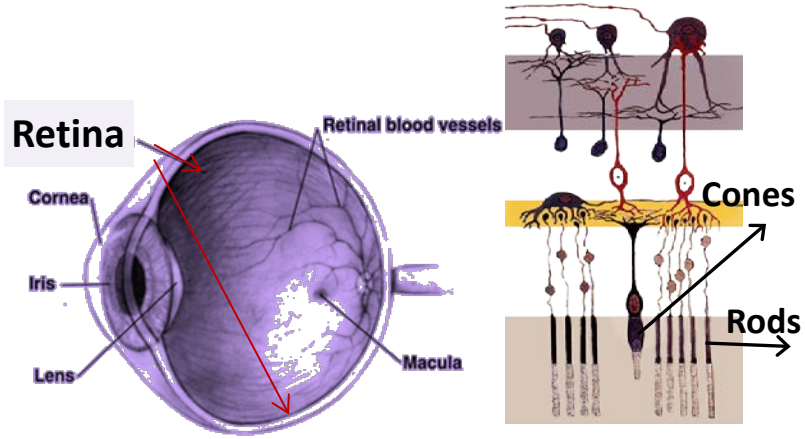
- Effectively, 5 MP for moving objects & 576 MP for still objects

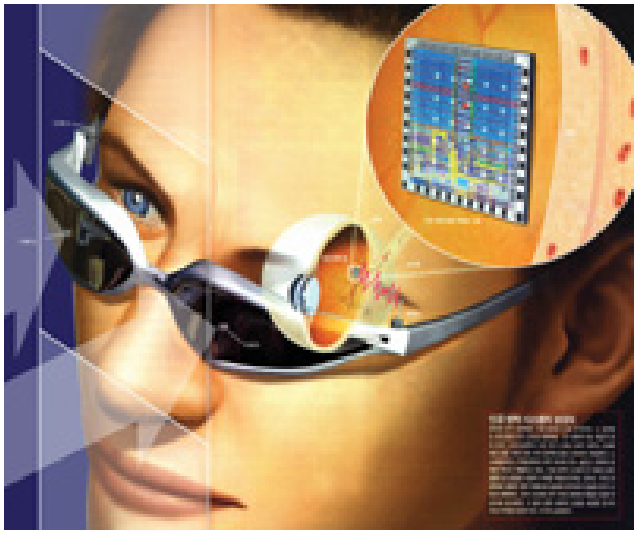
Angular resolution of human eye for still objects: 0.3 arc-minute = 0.005 deg.

FOV (Field of view): approximate 120 degrees

Resolution $(120 / 0.005)^2 = 576$ M pixels

Sourced by R. N. Clark (@www.clarkvision.com)



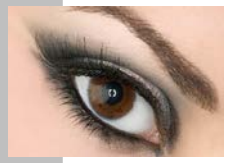


Mobile Sensor Resolution Trend

Can we predict the maximum resolution of mobile sensor ?

576Mp=Human Eye

Sourced by R. N. Clark

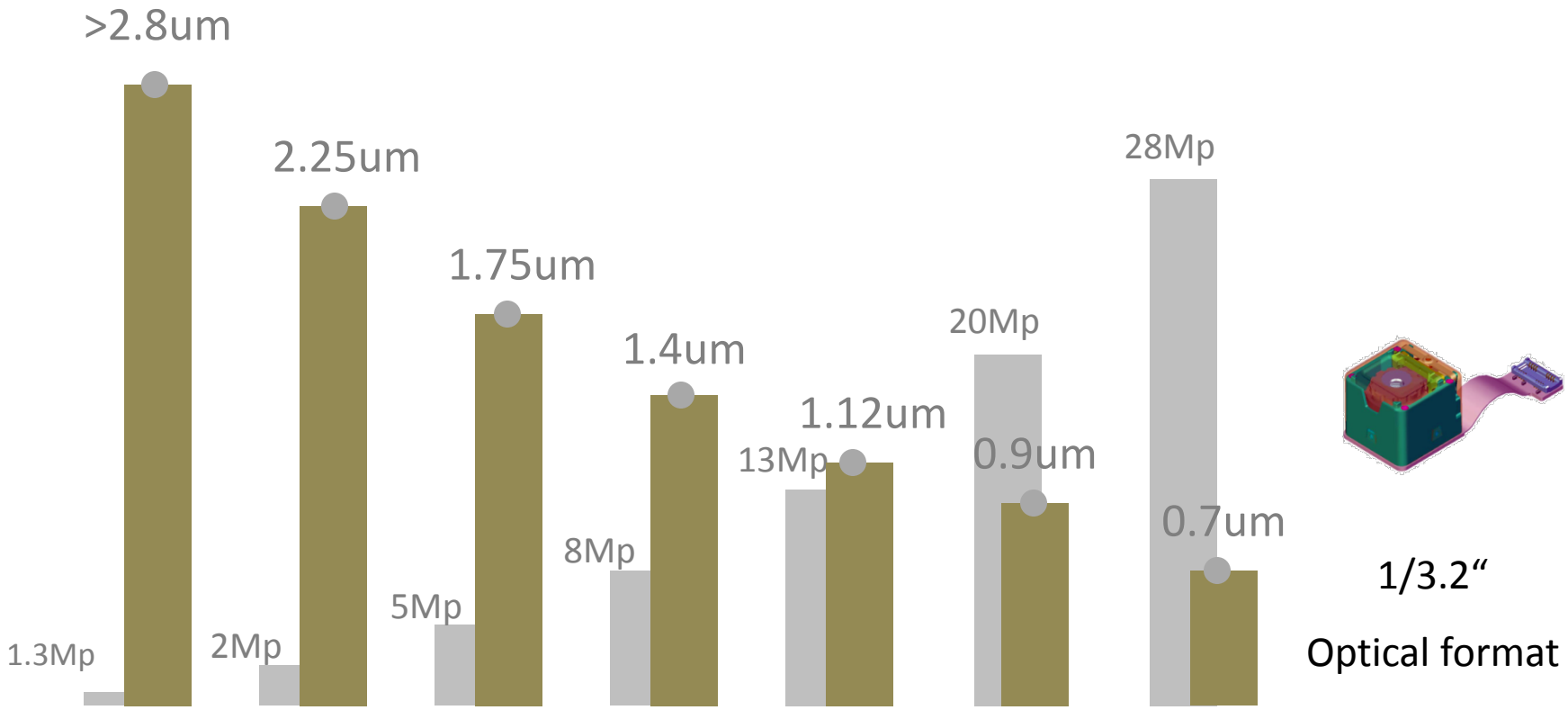


67Mp=35mm film

Sourced by Eric R. Fossum

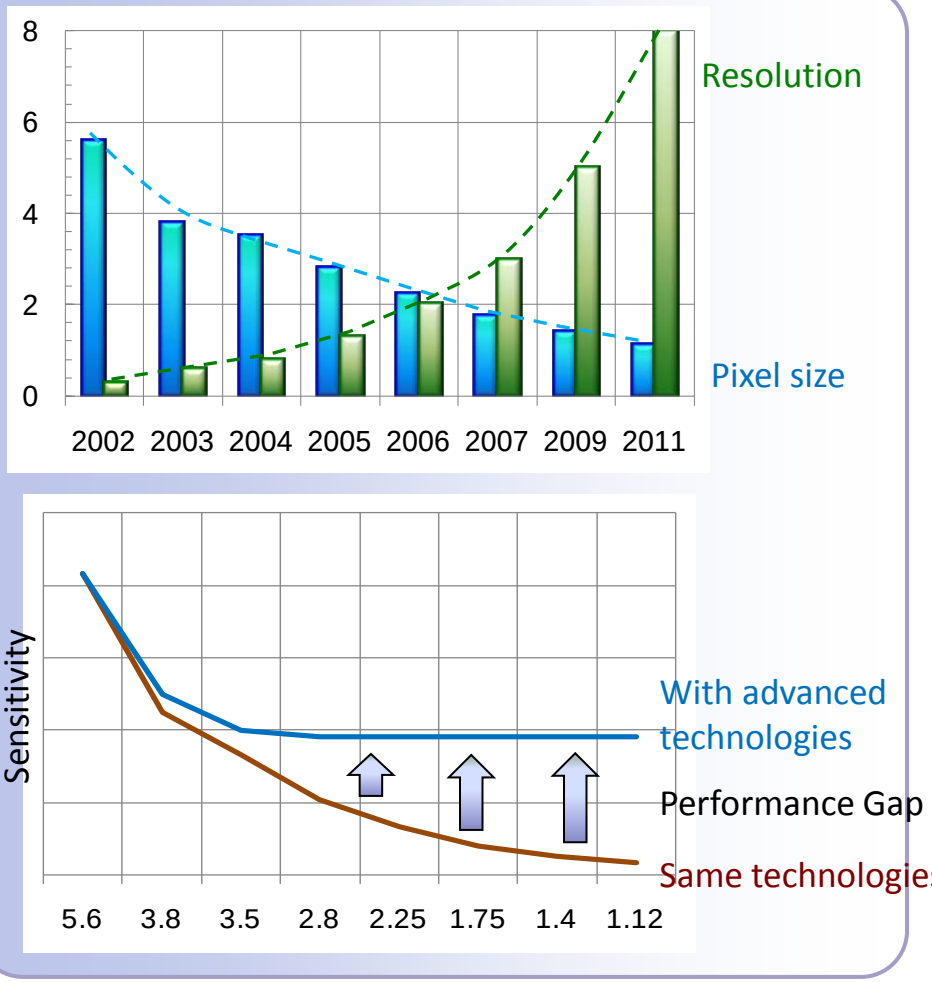
Resolution vs. Pixel Size

Rule: If we want better resolution, make it smaller!

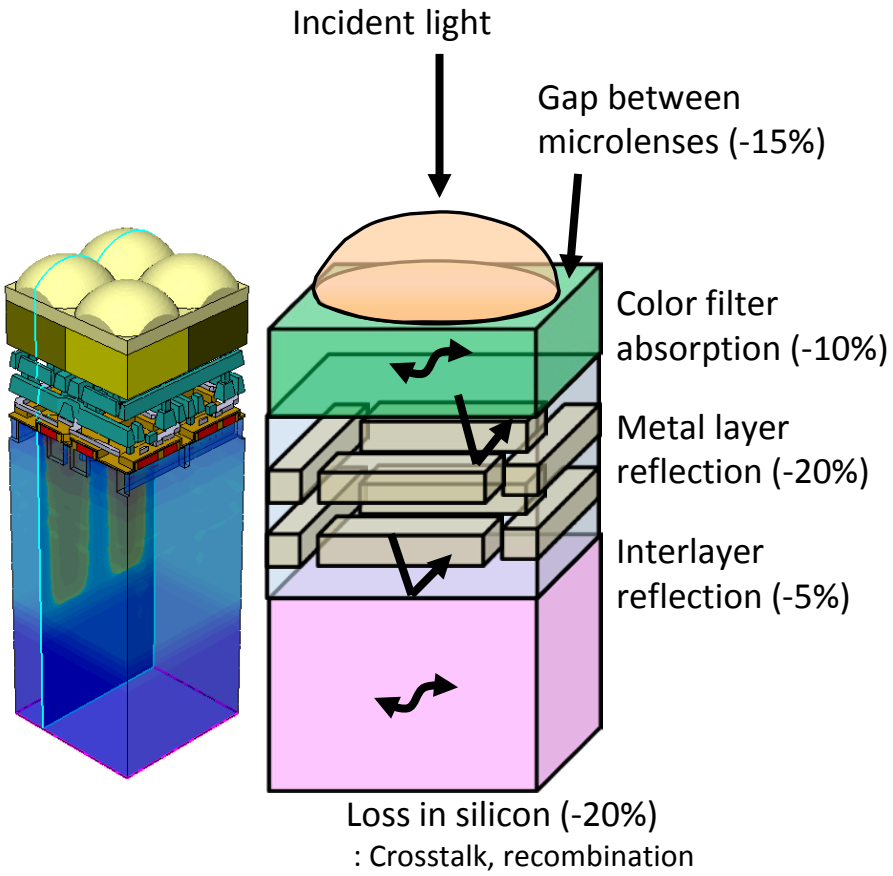


Challenge of Continuous Pixel Migration

- New pixel are developed to maintain SNR of previous generation



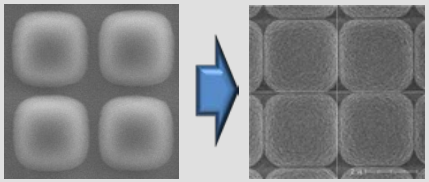
Loss factors in Pixel structure



Evolution of Pixel Technology

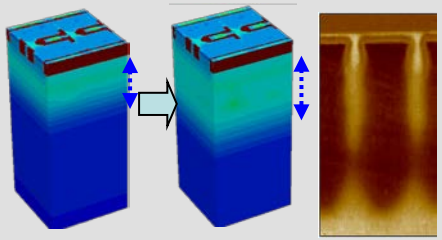
Gap-less microlens

Increase sensitivity



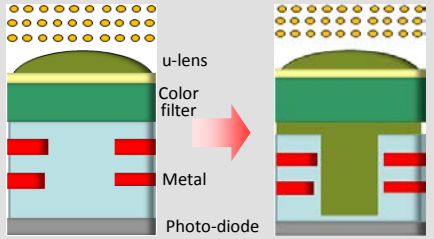
Deep PD

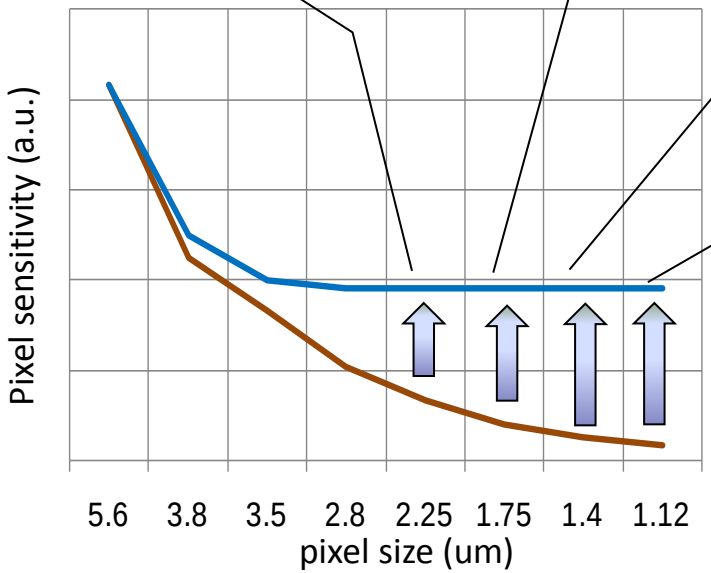
Rreduce loss in Si



Light-guide

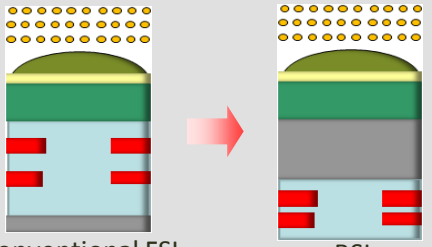
Reduce metal layer reflection





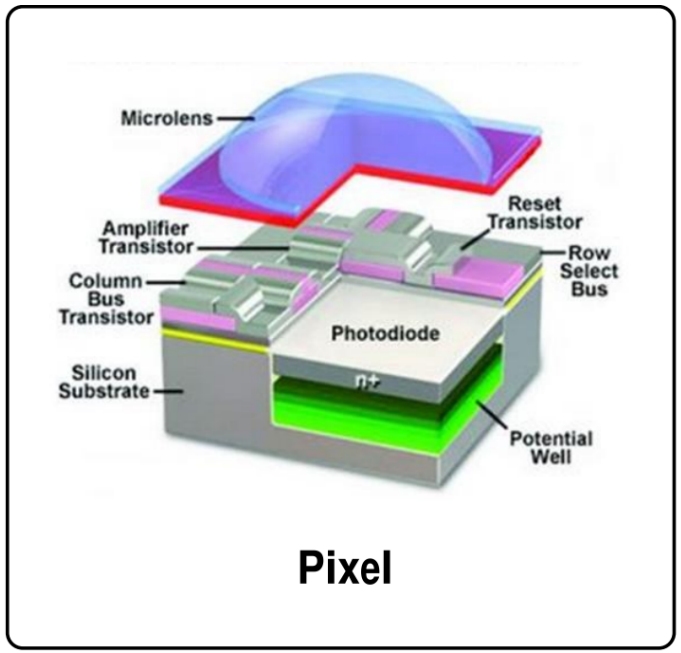
Back-side illumination

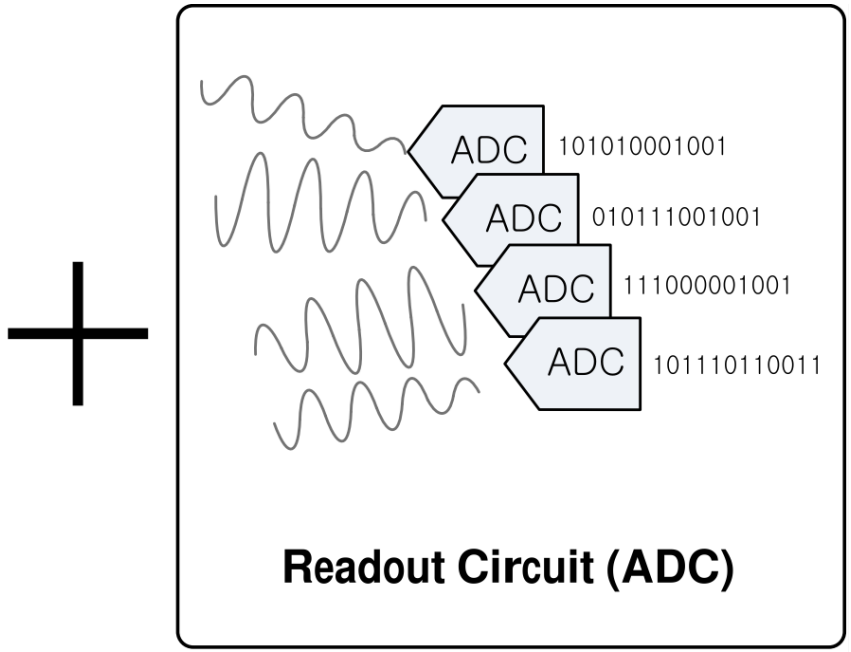
Remove metal layer reflection



Why ADC and what kinds of ADC?

- Special ADC is needed for the performance and power consumption



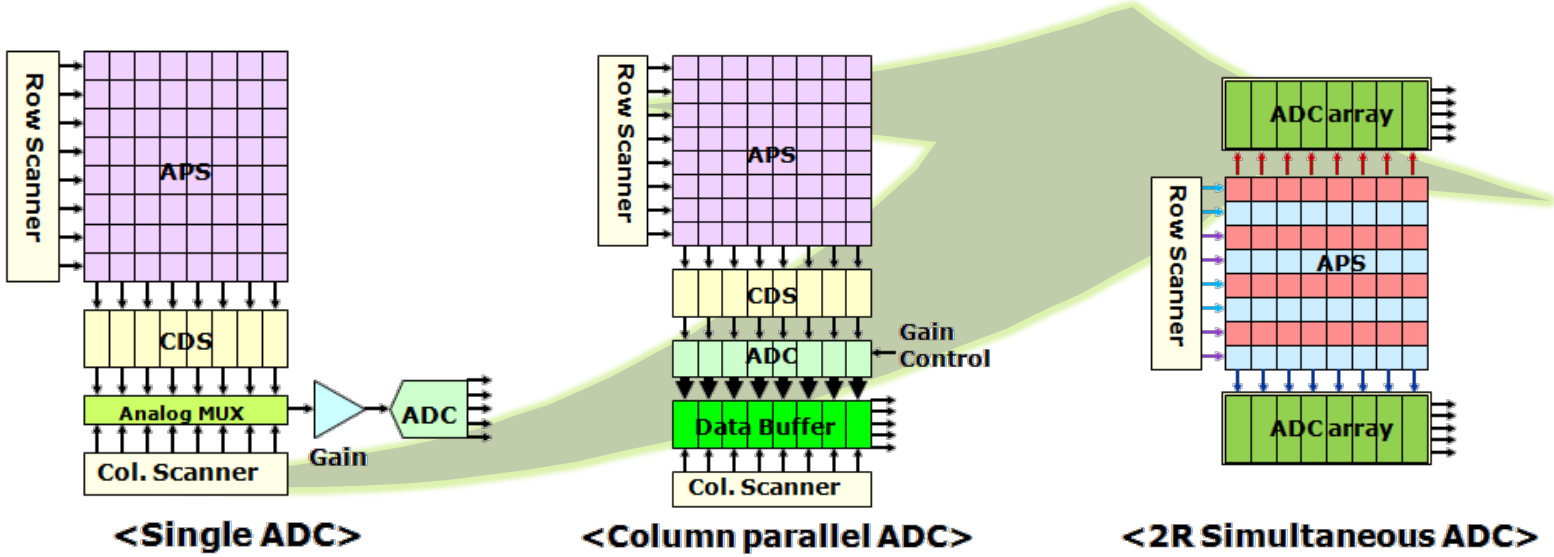


- Optical Performance
- Pixel Performance

- ADC Performance
- Power Consumption

Which is Better?

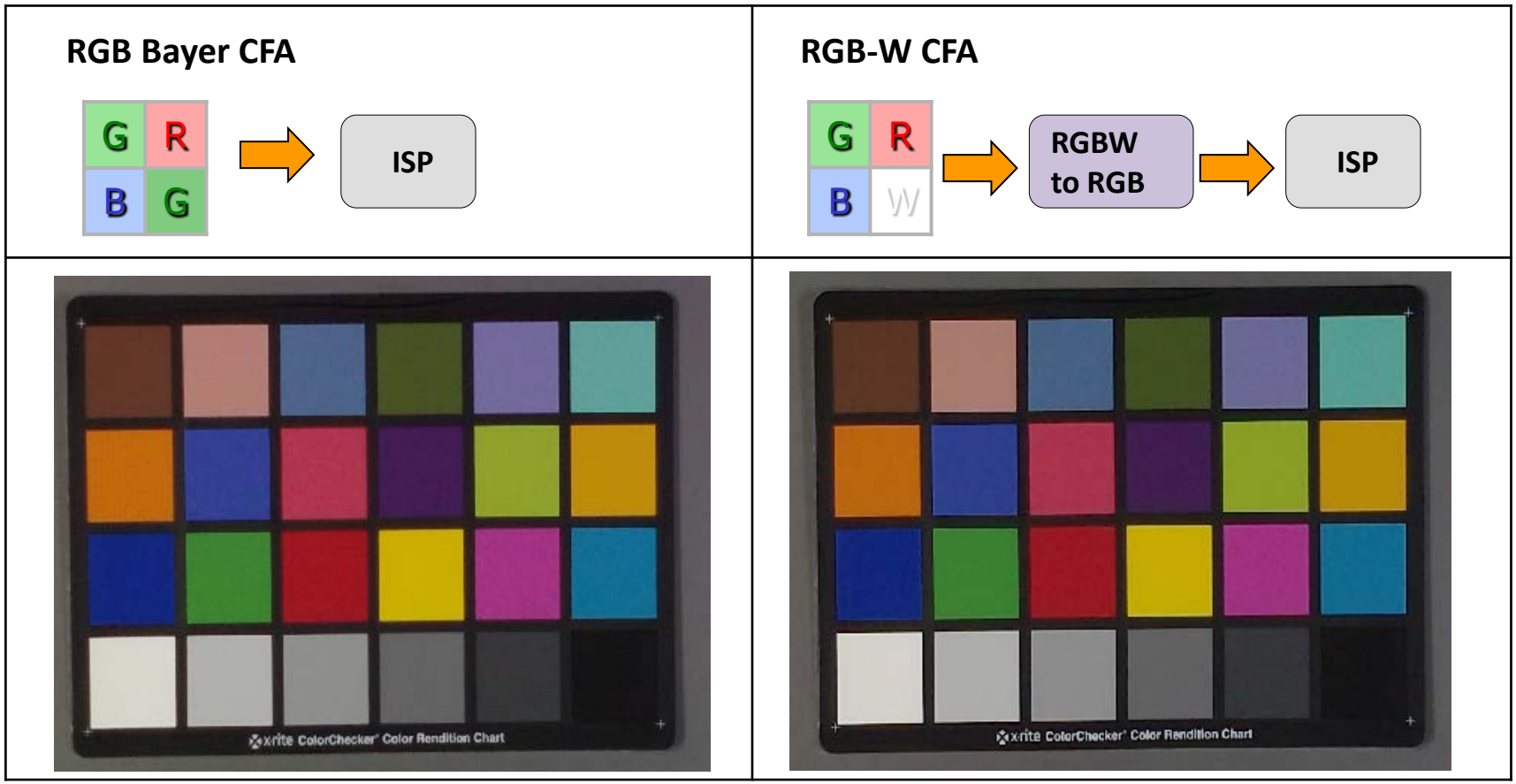
- Each ADC structure has its own Pros & Cons



Structure	FPS @High Resolution	AREA	Power	Random Noise	ADC Type
Single	☹	☺	☹	☹	▪ Pipeline ADC
Column parallel	☺	☹	☺	☺	▪ Single slope ▪ SAR ▪ Cyclic ▪ Sigma-delta
2Row Simultaneous	☺☺	☹☹	☺	☺	

Contents

- White pixel helps SNR improvement in low light

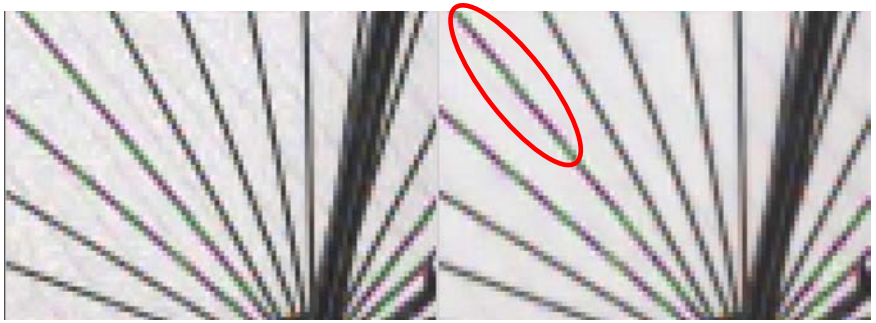


SNR = 34.1

SNR = 36.8

Image Quality Issues of RGBW

- High crosstalk due to white pixel
  - ➢Lack of color information → weak color fidelity
  - ➢False color near edge
  - ➢High Color Correction Matrix (CCM) gain
- Test results



Bayer RGBW (25% white)

RGBW (25% white)

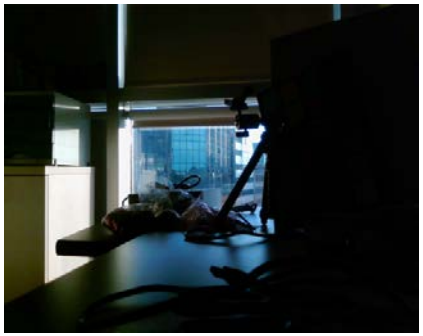
False color near edge

Bayer RGBW (25% white) RGBW (50% white)

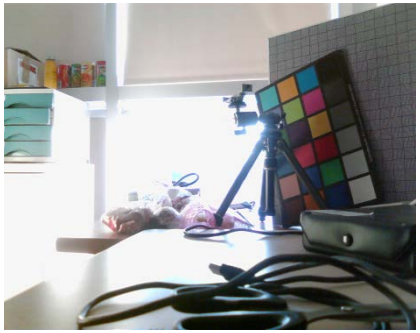
Higher white pixel portion, more false color

- Combine Long Exposure & Short Exposure
  - Each Row is exposed 2 times with different exposure times.
    - Long exposure image was captured at the lower illumination condition.
    - Short exposure image was captured at the higher illumination condition.

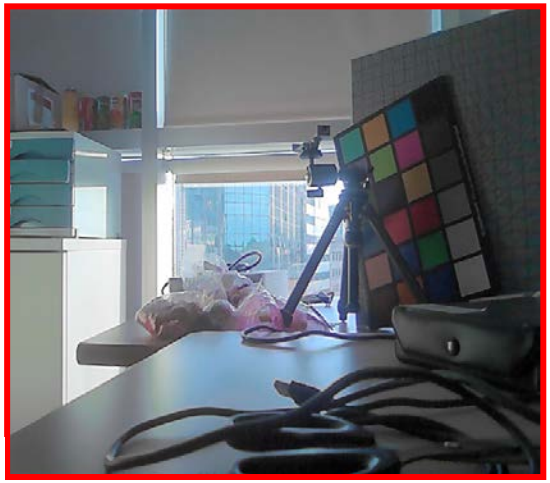
Short Exp.

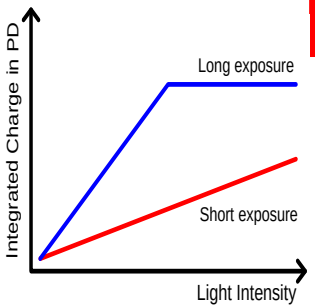


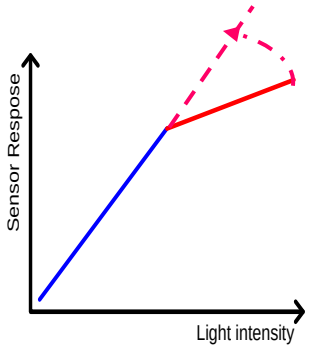
Long Exp.



Merging







Contents

Camera Market

12MP 24fps@720p

24~32MP 60fps@1080p

High End

Larger Imager and Interchangeable Lens for Professional Image

DSLR

Heavy and High Price	High Image Quality
Insufficient Image Quality	Light and Small Low Price

Compact DSC

Mid End with APS-C

CSC

And High end DSC

10MP 30fps@720p

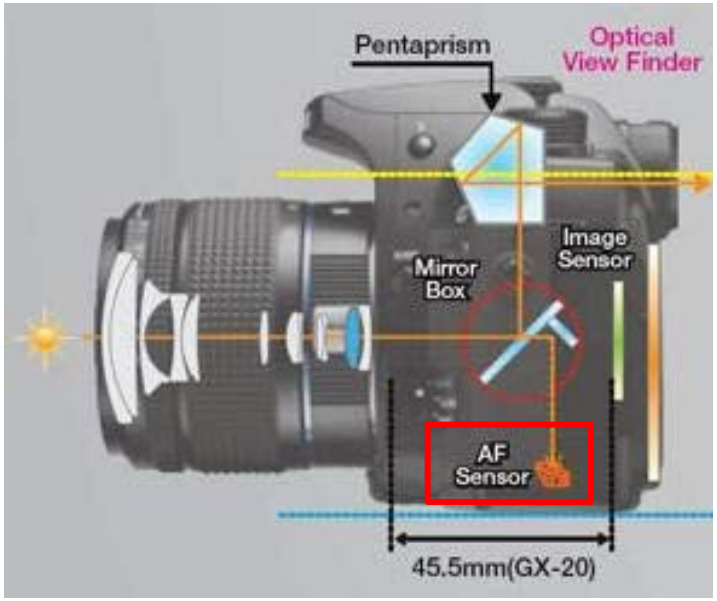
16~20MP 60fps@1080p

Low End

Higher Resolution, Higher Speed and Easy to Buy

Mirror-less and Auto Focus

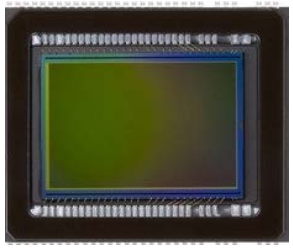
- **Its Origin is DSLR**

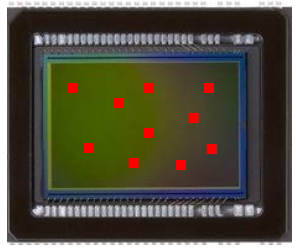


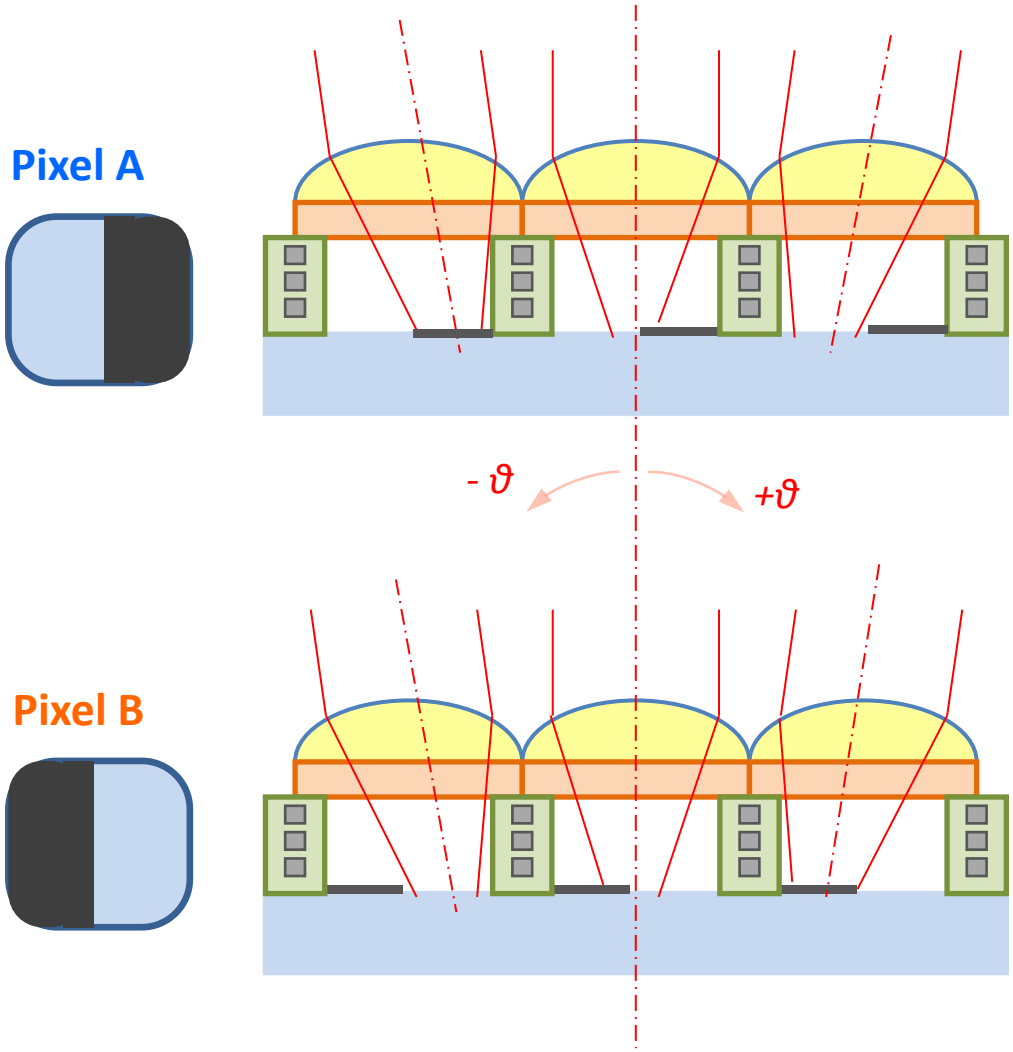
DSLR
Dedicated Phase Detection AF sensor
Fast AF

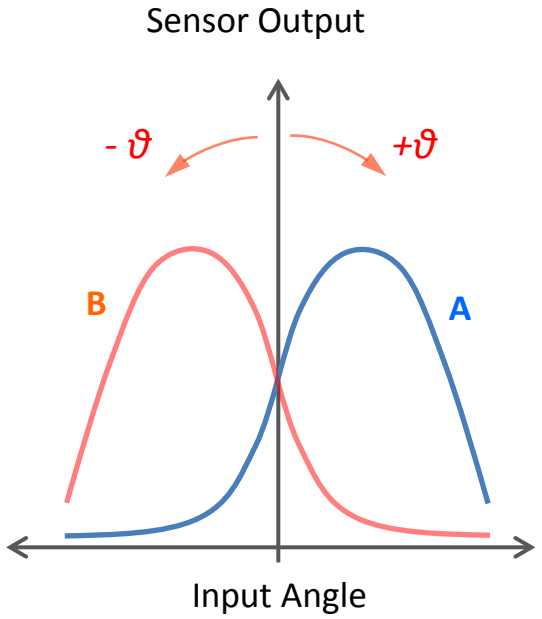
Mirror-less
Contrast AF
with Image sensor
Slow AF

Image Sensor with
Phase Detection AF pixel
for Fast AF in Mirror-less



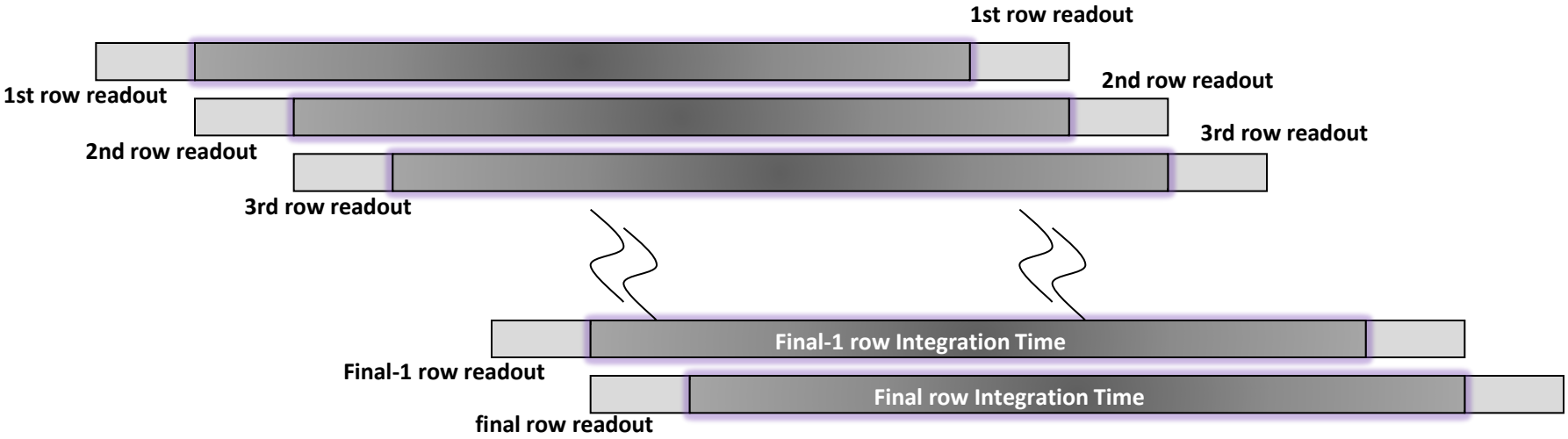


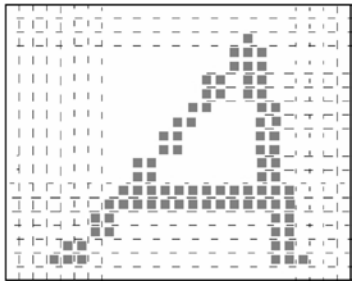




AF Pixel Output will be changed according to input angle shift

Rolling Shutter Operation



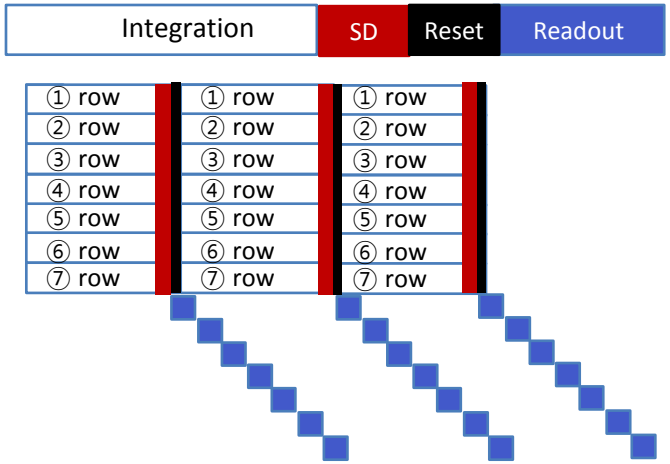


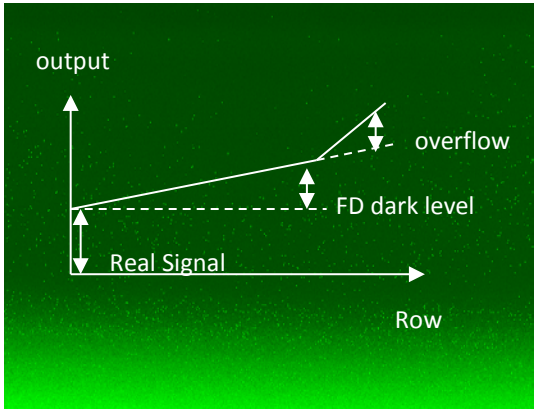
Jello effect due to rolling shutter !

Global shutter can avoid Jello effect from rolling shutter

Global Shutter :

Operation : All pixel rows are reset and then exposed and moved to another storage simultaneously.
The pixels are then read out row by row.





Pros:
- can avoid Jello effect

Cons:
- Size increase due to another storage node
- kTC noise
- Overflow from PD to FD

Contents

• Vehicle Camera by Legislation → Sensing for driver safety system

Front (13.3%)
• Night Vision

Side (9.1%)
• Blind Spot Detection

(CAGR)

Interior (16.9%)
•Driver Monitoring
• Occupant Detection

Rear (60.7%)
• Rear View

• Automotive Customer Requirement

Specification

Automotive	Mobile
▪ 5~6um Big Pixel	▪ <1.4um Pixel
▪ AEC-Q100 G2 (-40C ~ 105C)	▪ AEC-Q100 G4 (-30C ~ 70C)
▪ 120dB WDR	▪ 60dB WDR
▪ VGA/ 1.3MP	▪ ~ 8M/ 12MP
▪ PKG	▪ Module
▪ One Digit PPM	

Characteristics

- High Secure Reliability
- Long Design Cycles (2-5 years)
- Long term Supply

(Expect 7-10 year life span)

- Extremely difficult to have PCN*

* PCN : Process Change Notice

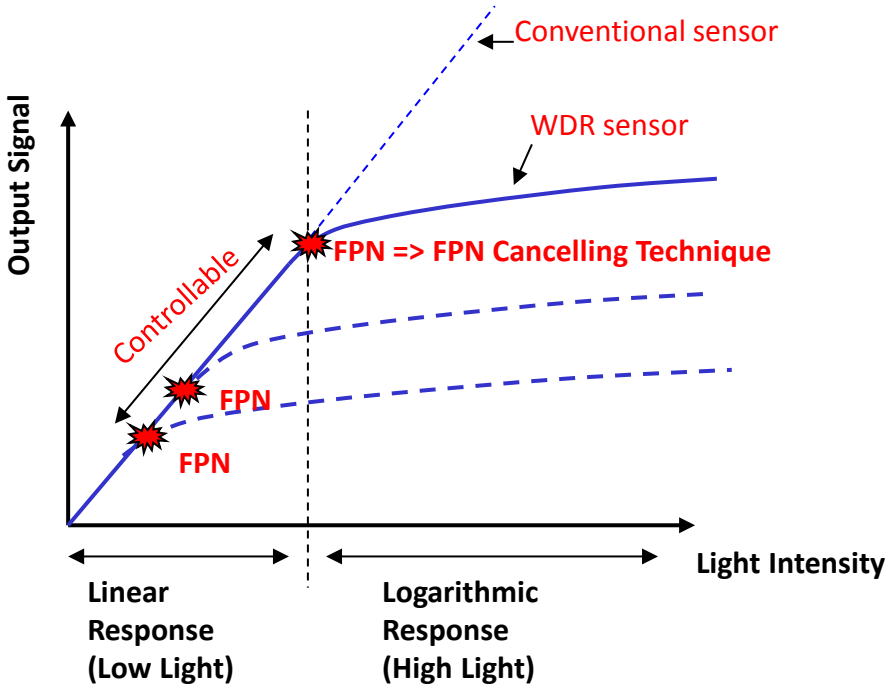
Requirement of Automotive CIS

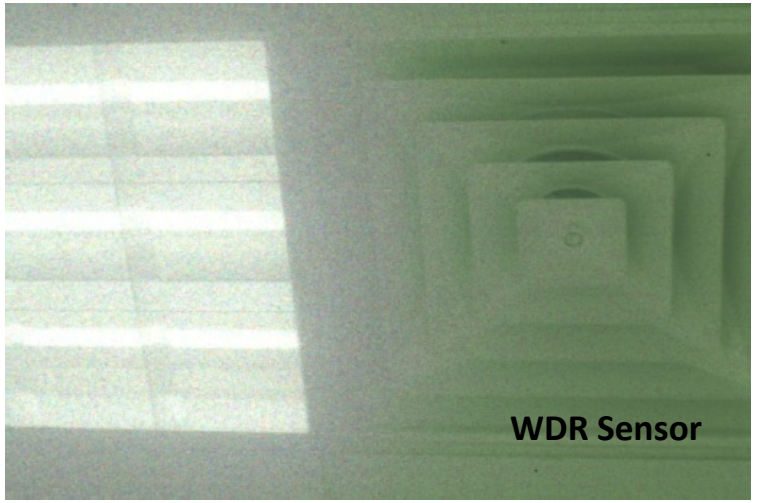
●Technologies : Higher Dynamic Range and Digital Interface.

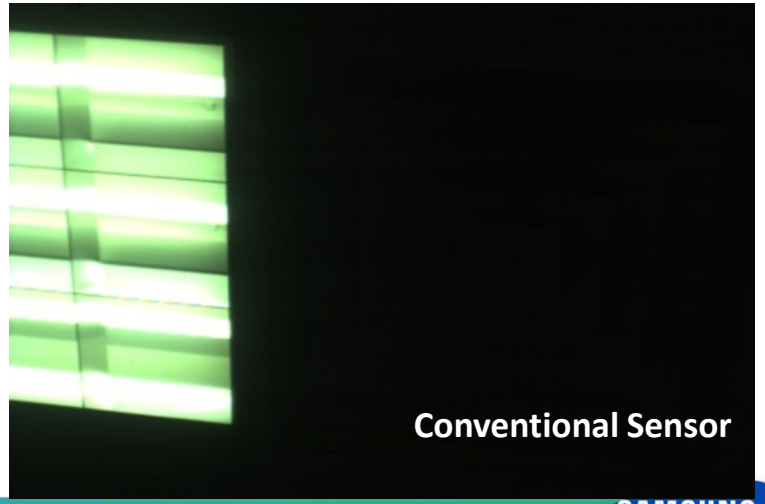
	Mega Trends	2010	2015	2020
Wide Dynamic Range	• 80dB~100dB for Rear View • over 120dB for NV/LDWS/Sensing • No Memory & Algorithm Preferred	80~100dB	80~120dB	> 120dB
Color Filter	• Currently RGB Bayer for Viewing • NV with IR color Filter • Complementary or White C/F Trend for Better Low Light performance	RGB for Viewing	IR Color Filter for NV	
Interface	• Analog Video with NTSC/PAL • Mega pixel needs Digital Interface • Advent of Automotive Ethernet	NTSC/PAL	Digital (Ethernet)	

** NV: Night Vision*

- Combine Linear Response & Logarithmic Response
  - Linear Response is for low light and Logarithm Response is for high light







Gesture Sensor Market

- Game Interface

Kinect™
with Microsoft
XBOX360

EBOX™
by EEDOO

- PC and TV Interface

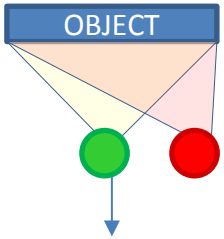
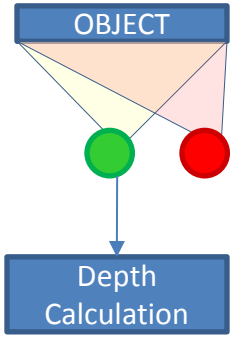
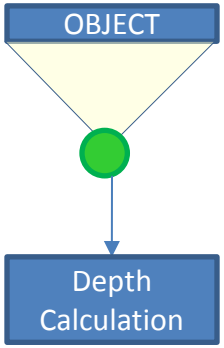
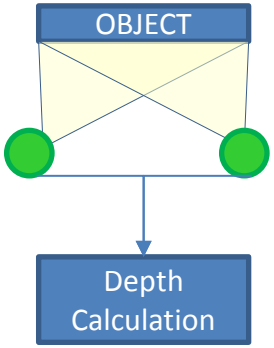
Smart TV

- Mobile Device/ Automotive Interface

Gesture Sensor Technologies

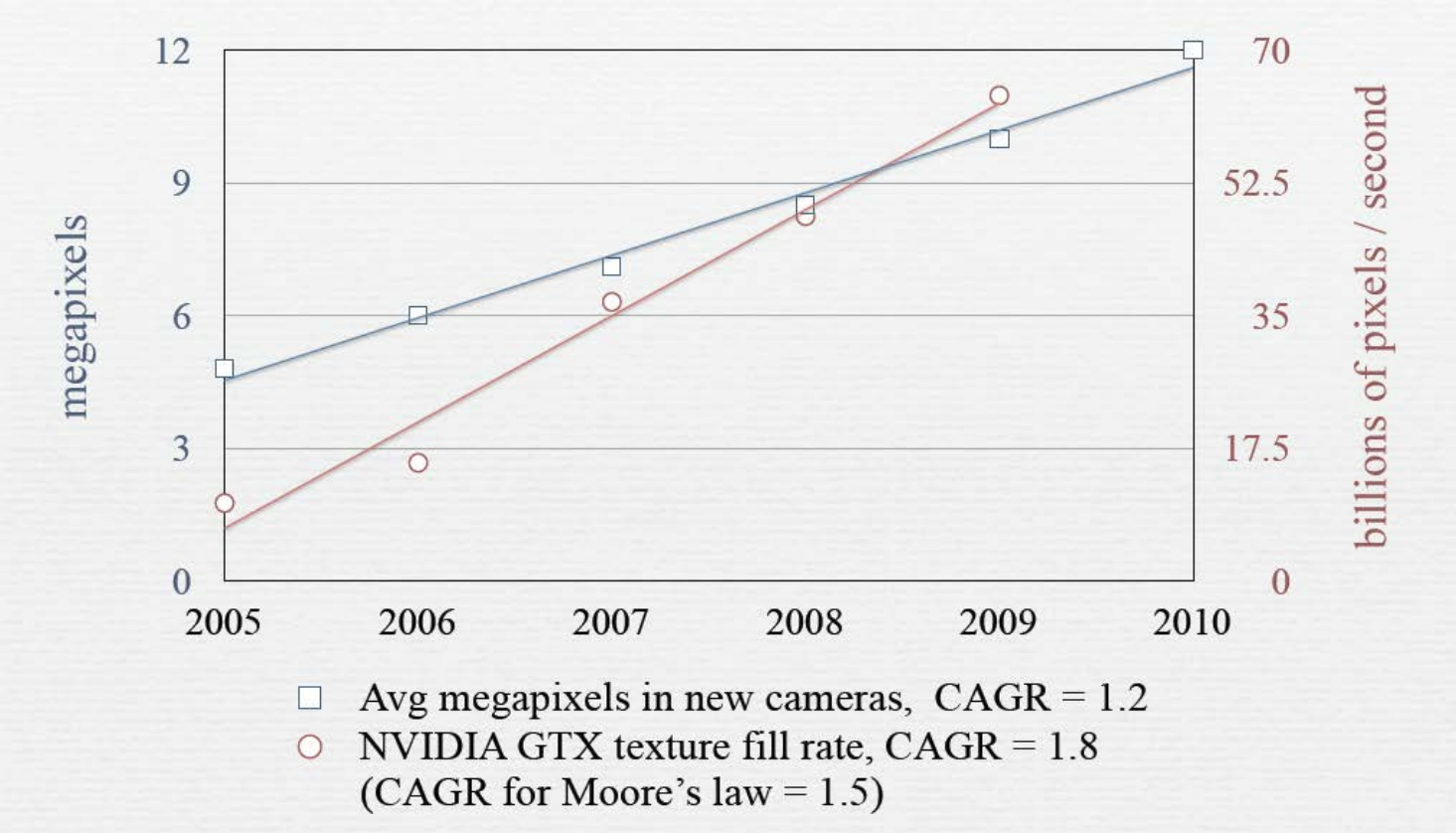
Samsung Confidential

Sensor
IR Emitter

Type	Time Of Flight	Structured Light	Single Image sensor	Stereo Vision
Maker	Samsung, Softkinetic, PMDtec, MESA	PrimeSense (MS Kinect)	Eyesight	TYZX
System	 Output itself is depth			
Merit	Not much processing High Depth Accuracy	General Sensor can be Used		
Demerit	•IR emitter should be accompanied •Limitation of outdoor usage	Much of processing	Low Depth Accuracy	

Camera Evolution

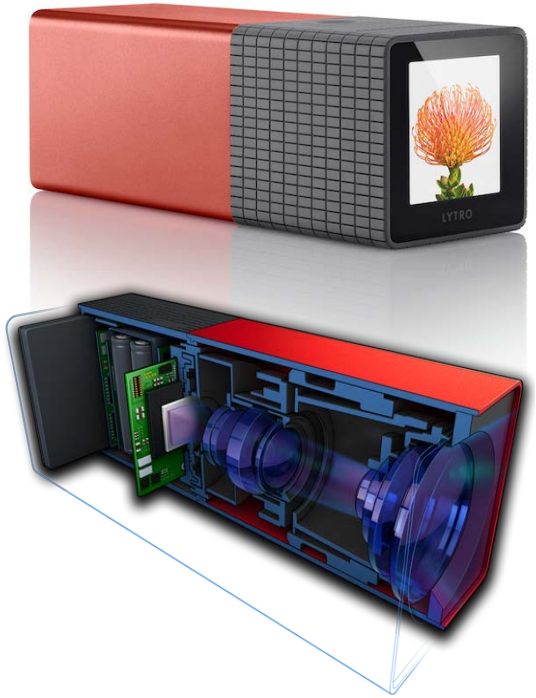
- Available computing power in camera is rising faster than megapixels
- This “headroom” permits more computation per pixel or more frames per second, or less custom hardware



Sourced by Professor Marc Levoy (Computer Science Department, Stanford University)

Plenoptic Camera

- Lytro
  www.lytro.com



  - Refocusing
  - x8 optical zoom

- Pelican Imaging
  www.pelicanimaging.com

  - Thin thickness
  - 3D depth
  - Gesture control
  - Refocusing
  - Smartphones and tablets

- Raytrix, Germany
  www.raytrix.de

  - 3D reconstruction
  - Refocusing
  - Industrial applications

Summary

- Mobile camera leads the innovation of imaging technology
- Advanced technologies will be developed for high resolution race
- Remained serious problem at CIS is “Global Shutter”, which should be solved
- CIS market is expanding to Automotive, Gesture and Computational Photography

Thank you

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