Excursion to dSPACE

- Excursion to dSPACE planned for June, 2nd
  - Further details to be announced

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33102 Paderborn

TECHNISCHE HOCHSCHULE
OSTWESTFALEN-LIPPE
UNIVERSITY OF
APPLIED SCIENCES
AND ARTS

Autonomous Vehicles

Camera

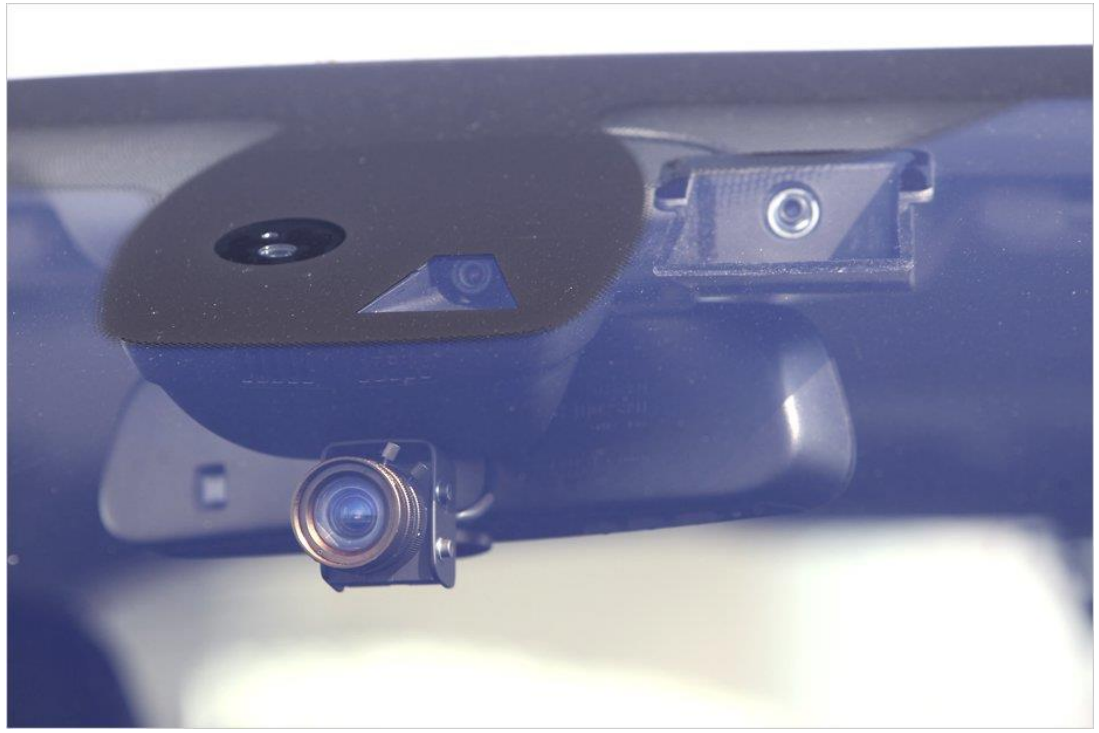
Prof. Dr.-Ing. habil. Ulrich Büker

Agenda

1. Motivation
2. Building Blocks
    1. Lens
    2. Sensor technologies
        1. CCD vs. CMOS
        2. Color
        3. KPIs: Resolution, Noise, Dynamic range
    3. Vision Processors
3. Applications

Motivation camera in vehicle

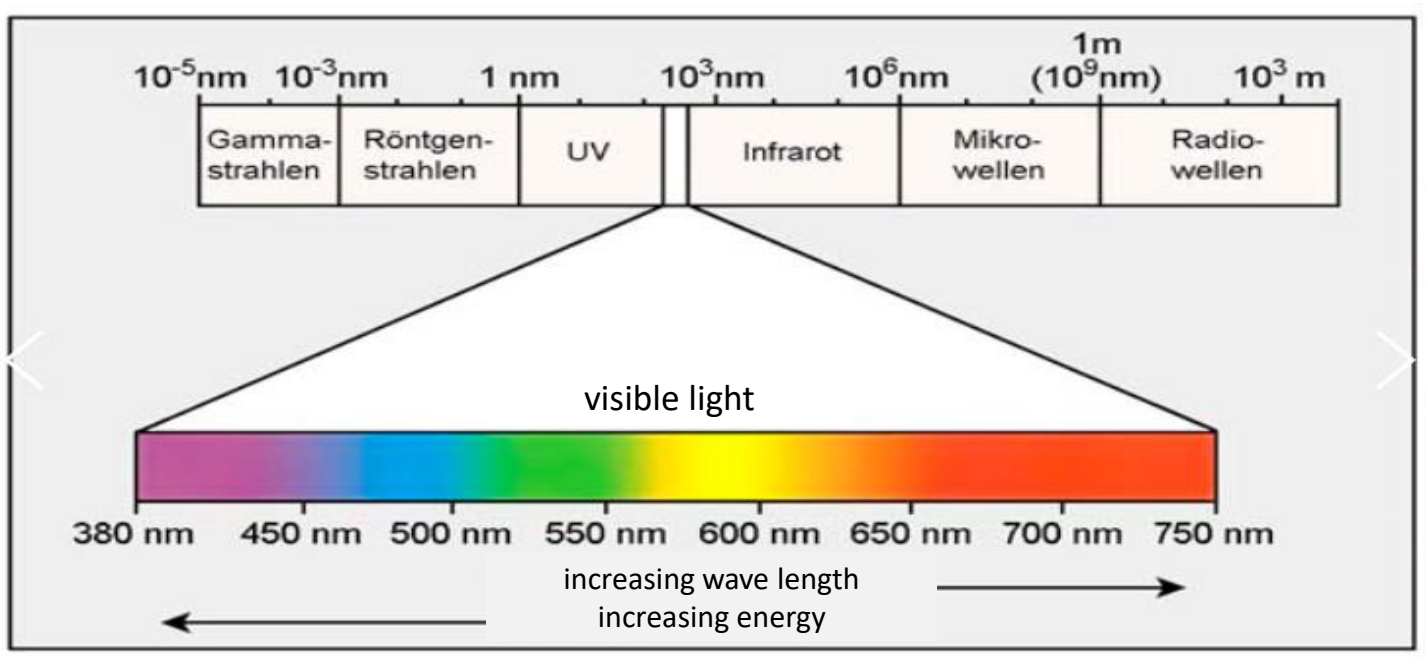
- Comfort systems
- Support systems
- Accident prevention
- Autonomous Driving



Visible Light

- Visible range of the electromagnetic spectrum of light :
- 380nm - 780nm

- UV < 380nm
- IR > 780nnm



Building blocks

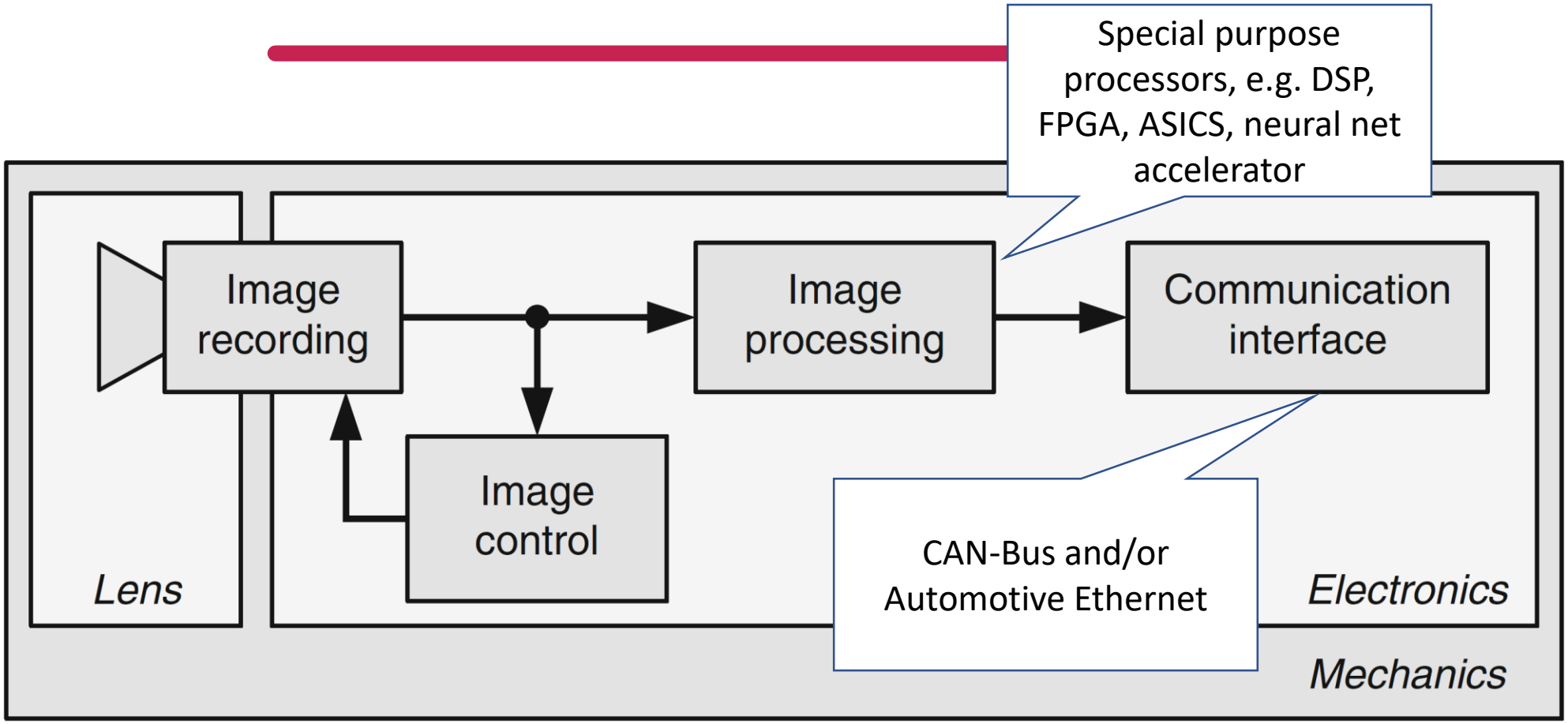
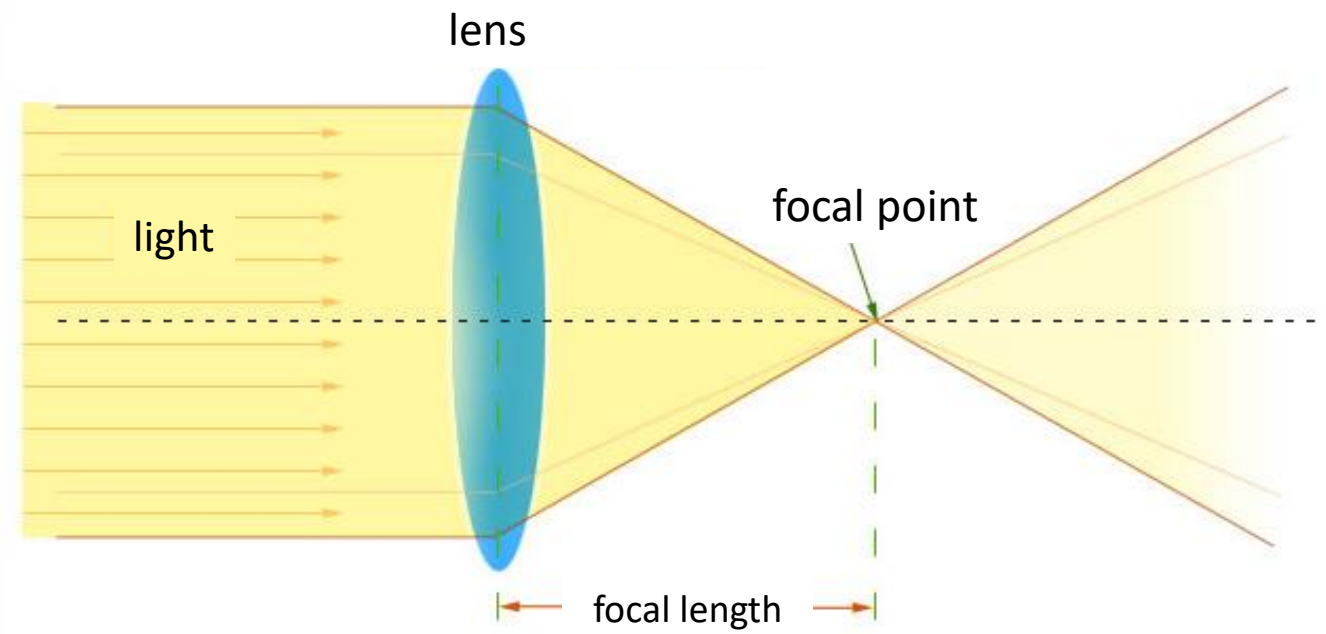


Image: Winner, et.al.: Handbook of Driver Assistance Systems

Lenses

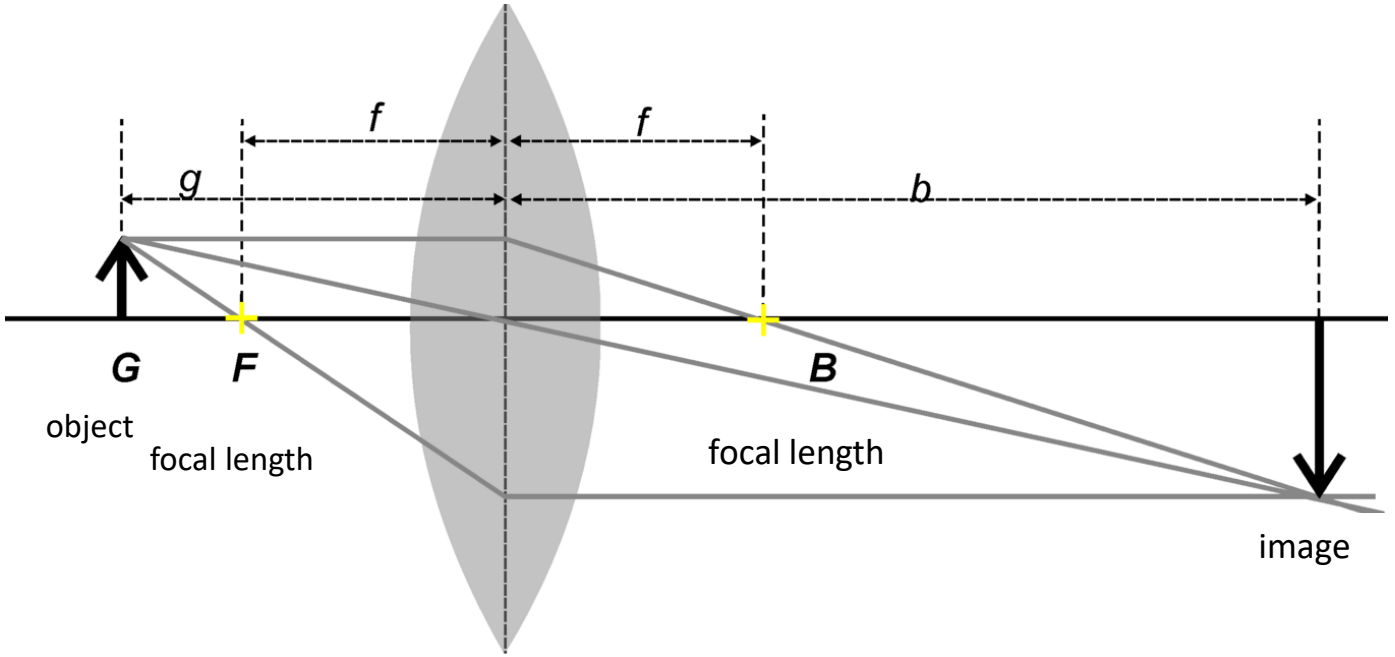
- Lens materials:
  - Flint (SiO_2)
  - Crown lenses
  - Plastics



- Focal point:
  - The meeting point of the converging rays and the optical axis.
- Focal length:
  - The distance between the principal plane of a lens and the focal point.

Lenses

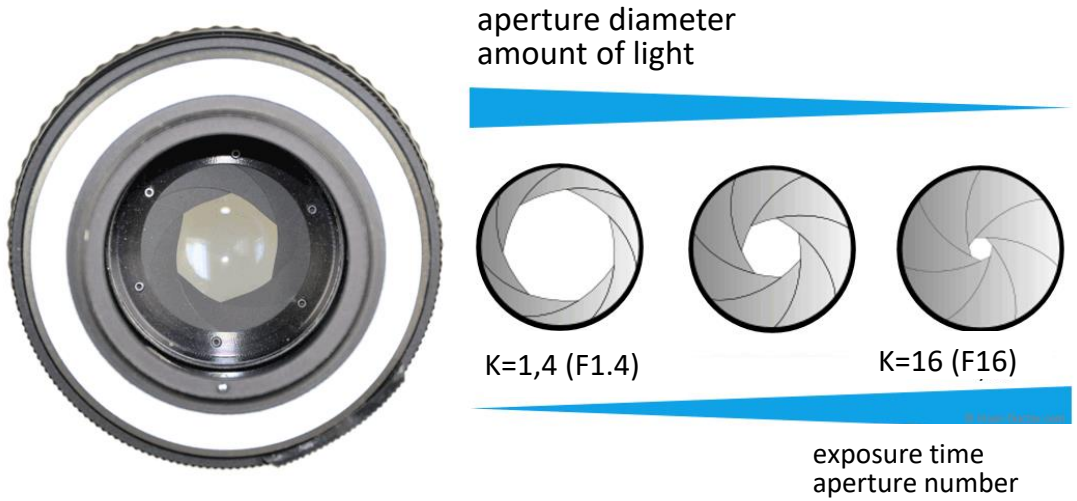
- Lens can only focus on objects of a certain distance
- Focusing by moving the lenses in the lens tube



$$\frac{1}{f} = \frac{1}{g} + \frac{1}{b}$$

Aperture and Exposure time

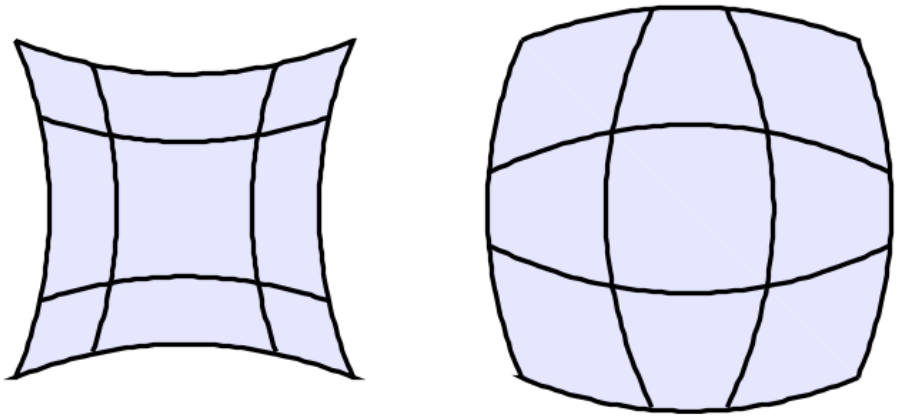
- Aperture and Exposure time influence the amount of light reaching the sensor
- Aperture Number : $K = \frac{F}{D}$
  - F : focal length
  - D : Aperture diameter



- Aperture also influences the depth of field of the image
  - Large diameter ≙ small aperture number
    ➔ small depth of field
    ➔ large amount of light onto the sensor
  - Small diameter ≙ large aperture number
    ➔ large depth of field
    ➔ small amount of light
  - Extremly small diameter
    ➔ Diffraction blur

- Caution: doubling the diameter quadrublicates the amount of light

Aberrations



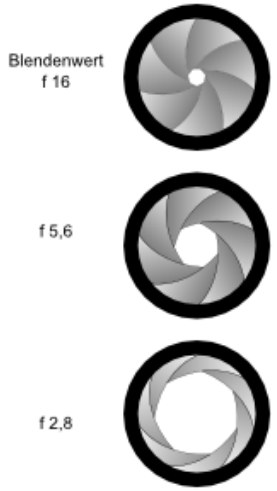
- Spherical aberration
- Blur can be minimized by stopping down (using larger aperture numbers)

- Chromatic aberration due to varying refraction of light waves
- Lenses with different materials can minimize the error

Depth of field

The depth of field depends on

- Lens aperture
- Focal length of the lens
- Pixel size of the camera
- Distance to the test object



Depth of field: depending on the aperture

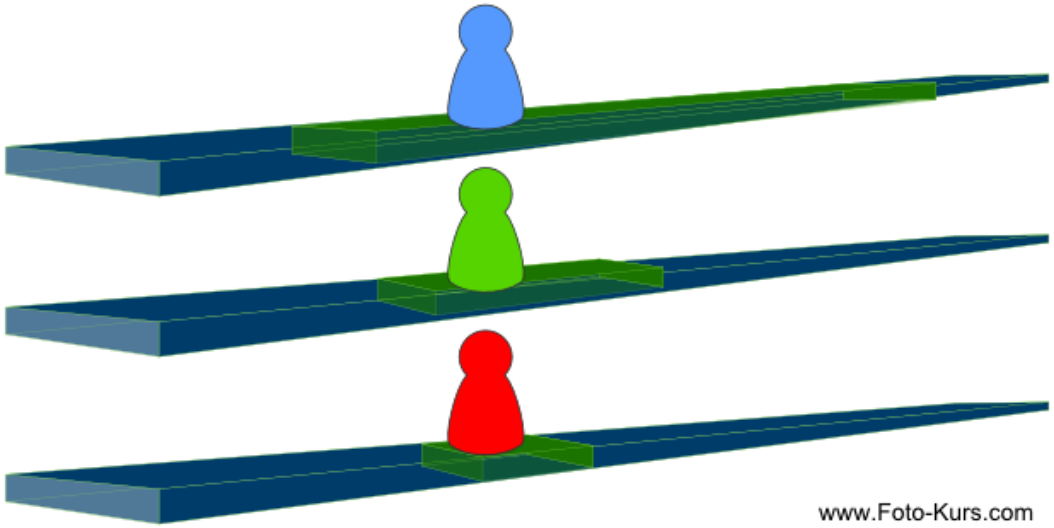
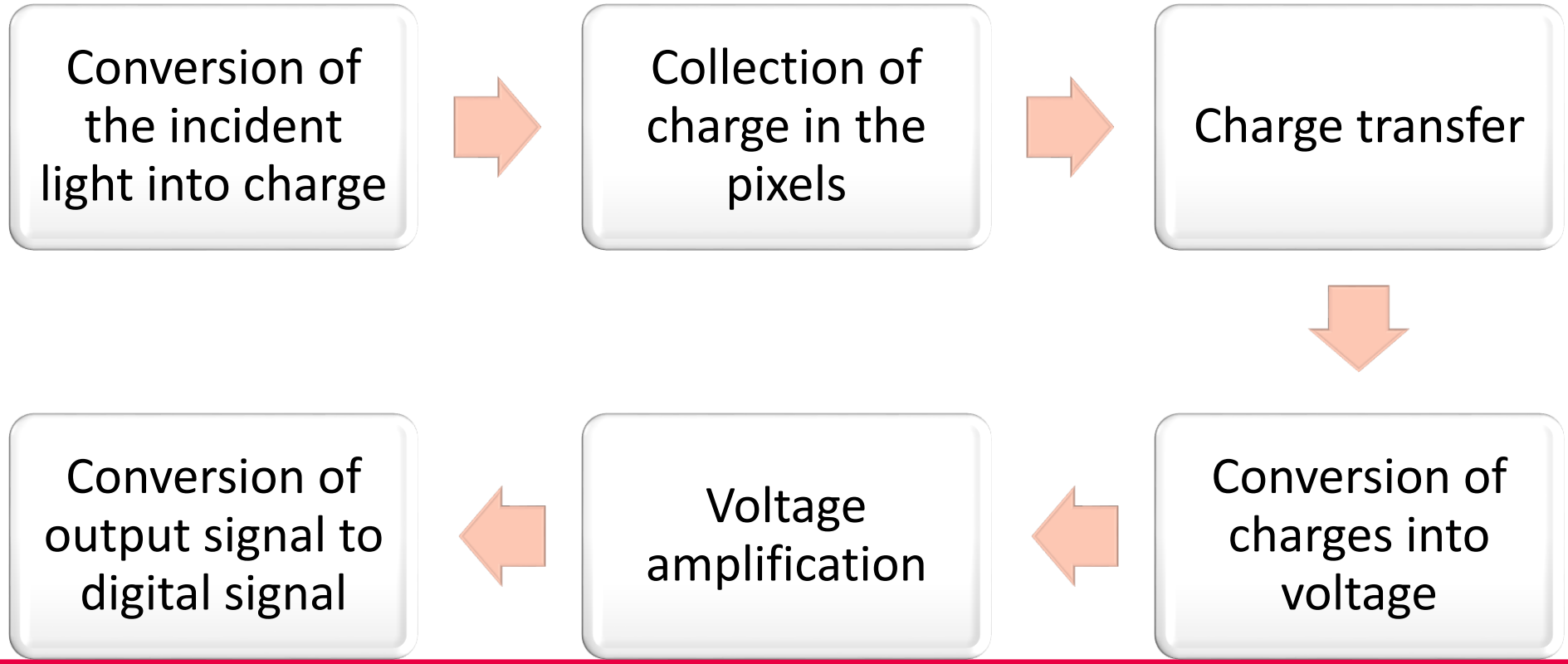


Image Sensors : Processing steps



CCD-Sensor I

- Matrix of photodiodes
- Based on the internal photoelectric effect

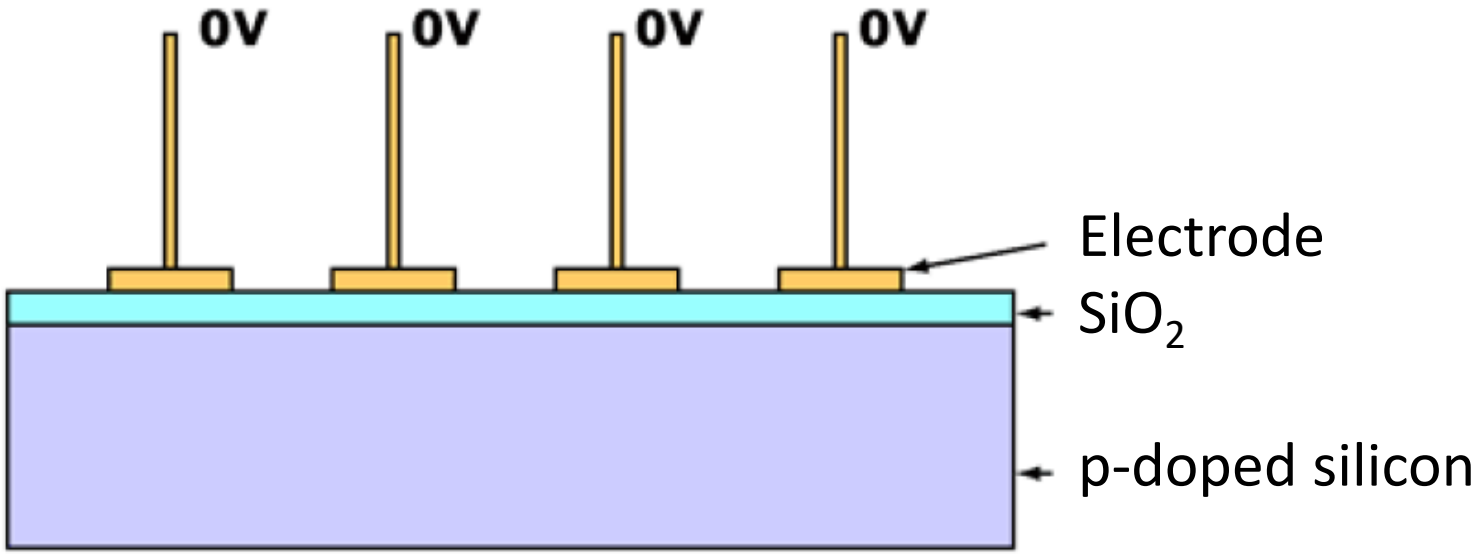
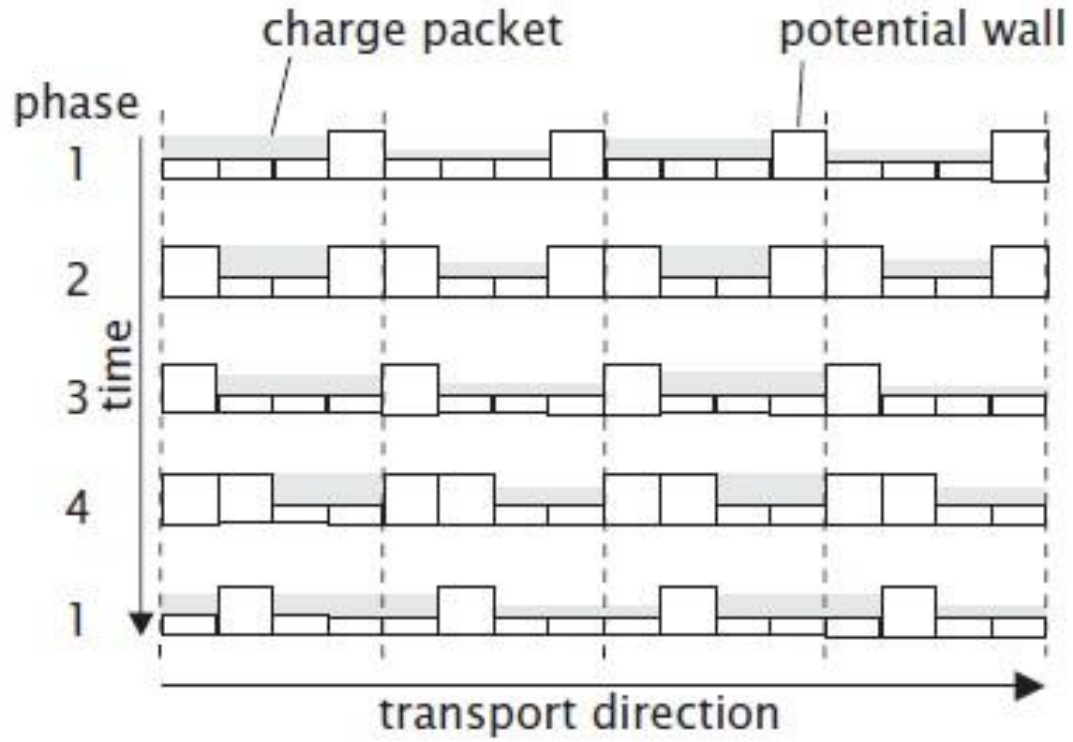


Image: https://kompendium.info-tip.de/bildsensoren.html (19.11.2017)

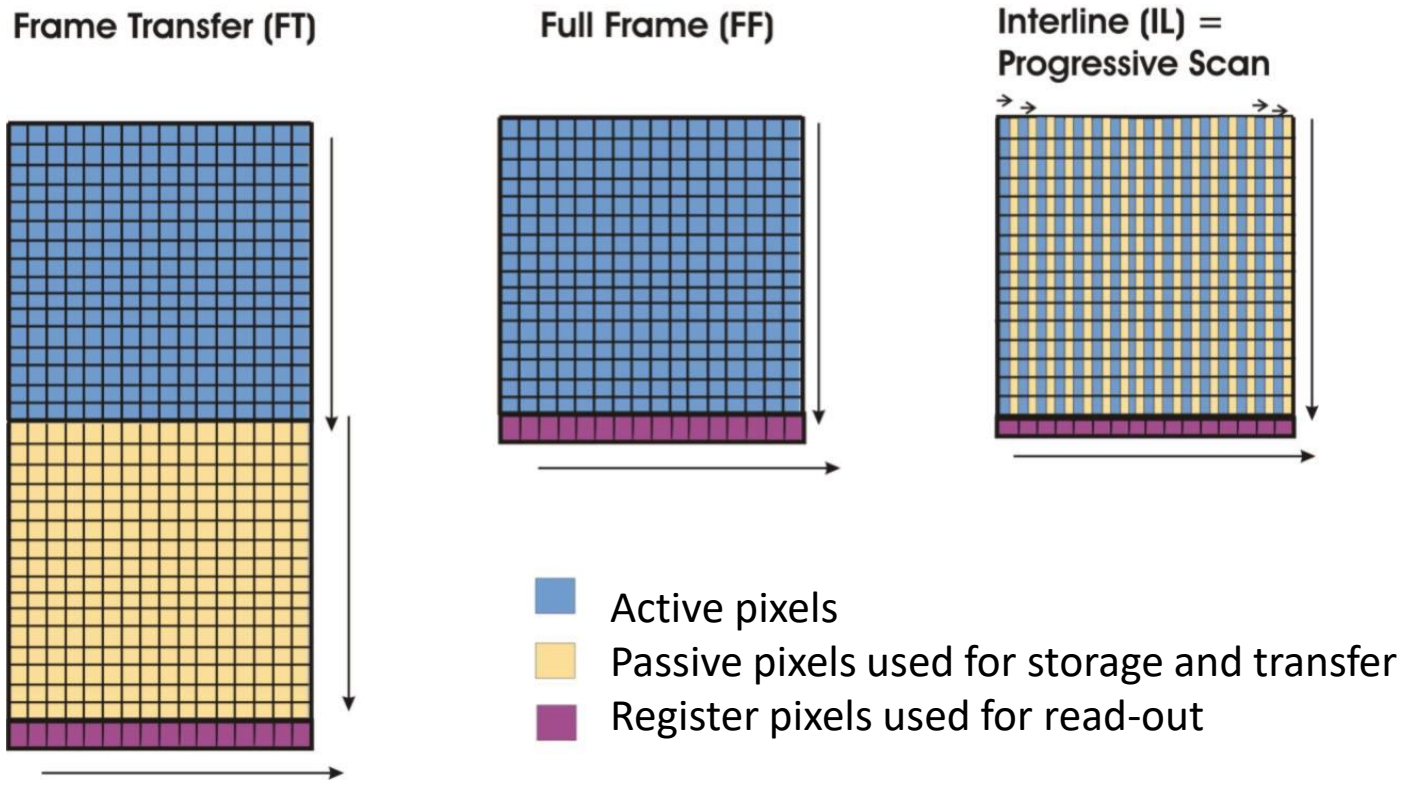
CCD-Sensor II

- Pixel not individually readable
- Charge transport via bucket brigade principle
- Fill factor of 100%
- Blooming



CCD-Sensor III

- Various CCD architectures
  - Frame transfer
  - Full-Frame
  - Interline transfer

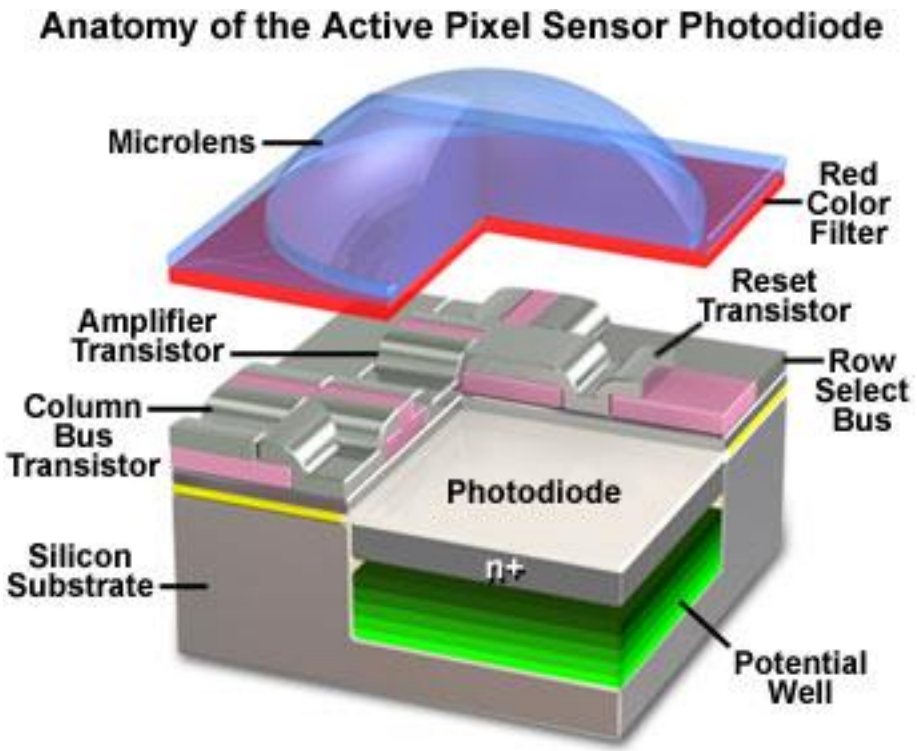


http://www.spectra-magic.de/Vorlagen/Detektion/D-Version/94_CCD-Architektur_D_MR.jpg (Abrufdatum 28.12.2016)

CMOS-Sensor I

- **C**omplementary **M**etal-**O**xid **S**emiconductor (or APS – Active Pixel Sensor)
- Active sensor
- Current technology

CMOS-Sensor II



- Microlens
- Photodiode
- Readout electronics

https://micro.magnet.fsu.edu/primer/digitalimaging/cmosimagesensors.html

Comparison

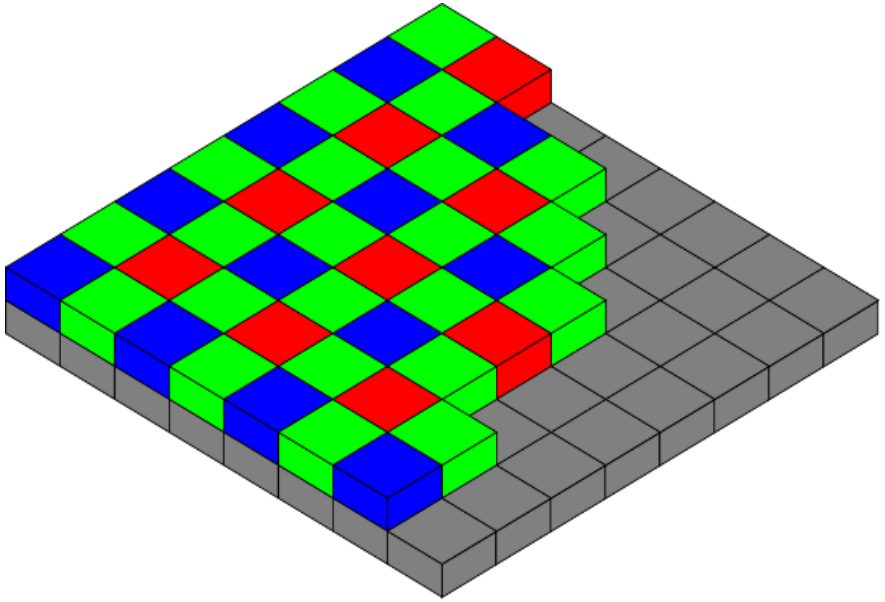
CCD	
+ high light sensitivity (fill factor 100%) - low dynamic range (60dB)	
CMOS	
+ high dynamic range (up to 120dB) - Orignially lower light sensitivity (fill factor up to 70%) In the last years solved by new technologies like backside illuminated sensors or stacked sensors	

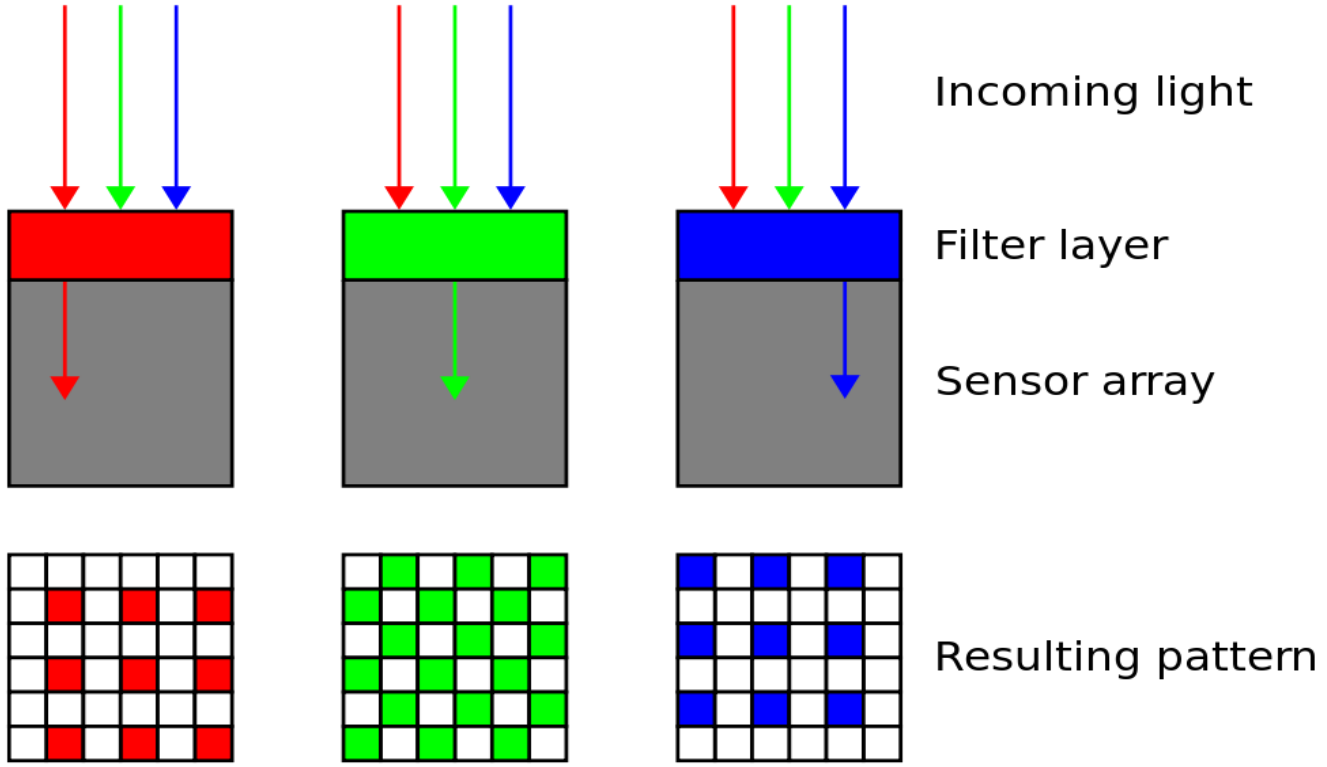
Colour sensors

- Image sensor are sensitive to photons reaching the pixels
- Measuring brightness (grey values)
- How do we get colour images?

Colour sensor

- Acquisition of colour information





- Most commonly used colour filter array: Bayer filter

https://en.ids-ima-ging.com/techtipps-detail/en_techtip-18mp-color-sensor-as-mono.html

Resolution

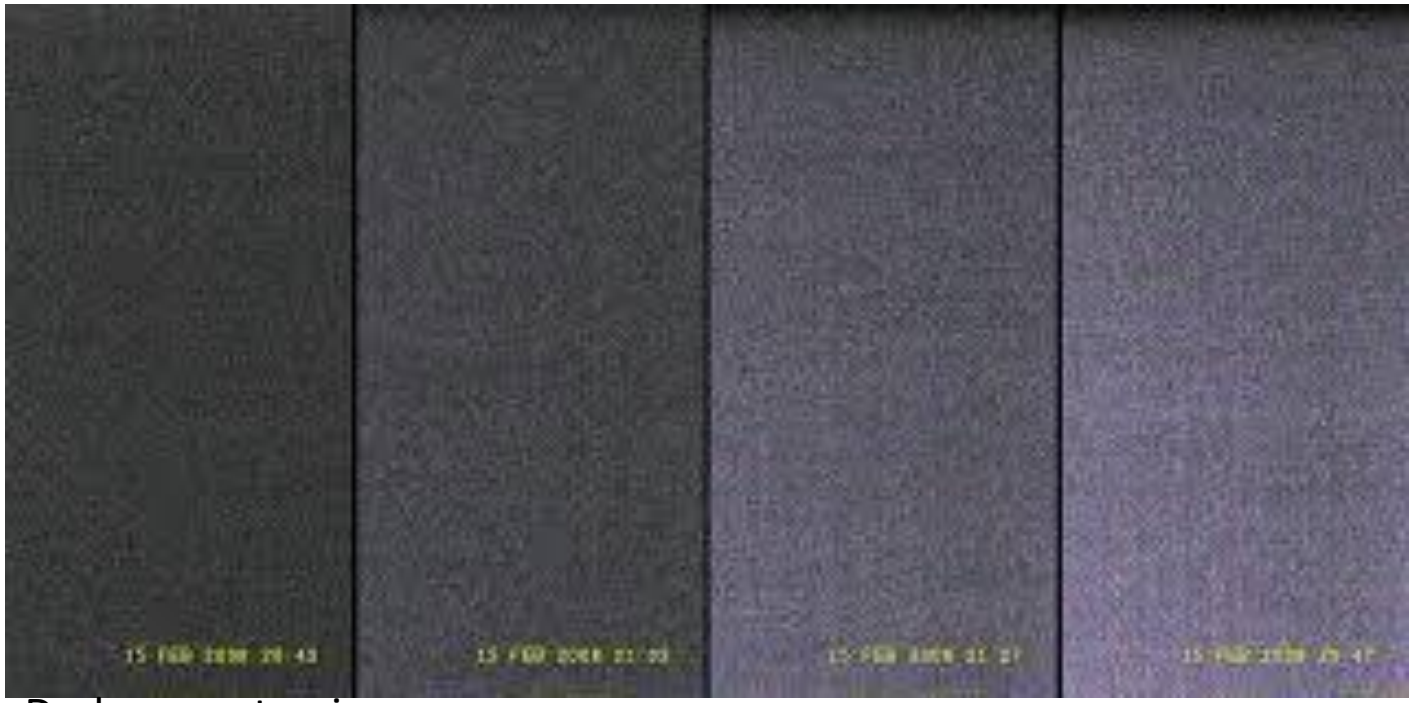
- Spatial resolution
- Temporal resolution
- Contrast resolution

Decreasing spatial resolution

Image: Winner, et.al.: Handbook of Driver Assistance Systems

Noise

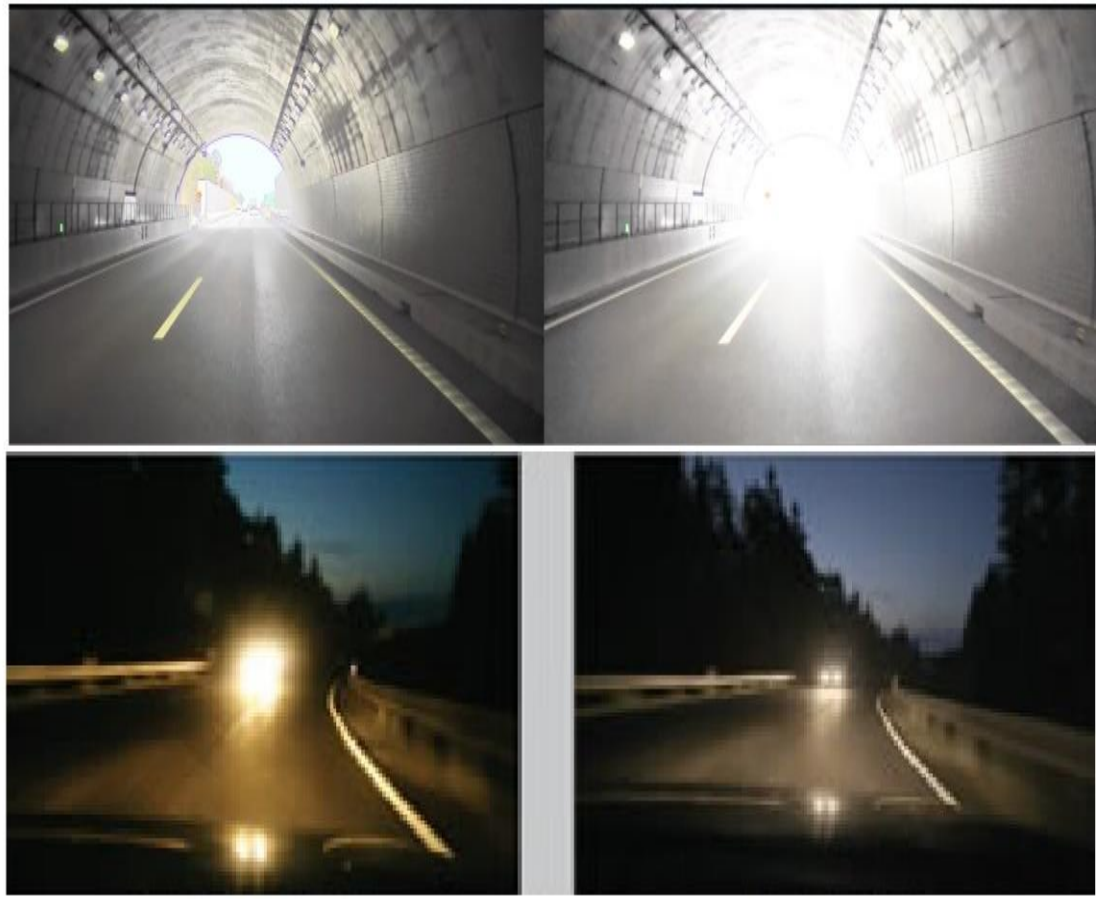
- Dark current noise
- Photon noise
- Fixed Pattern Noise
- Quantization noise



Dark current noise

Dynamic range

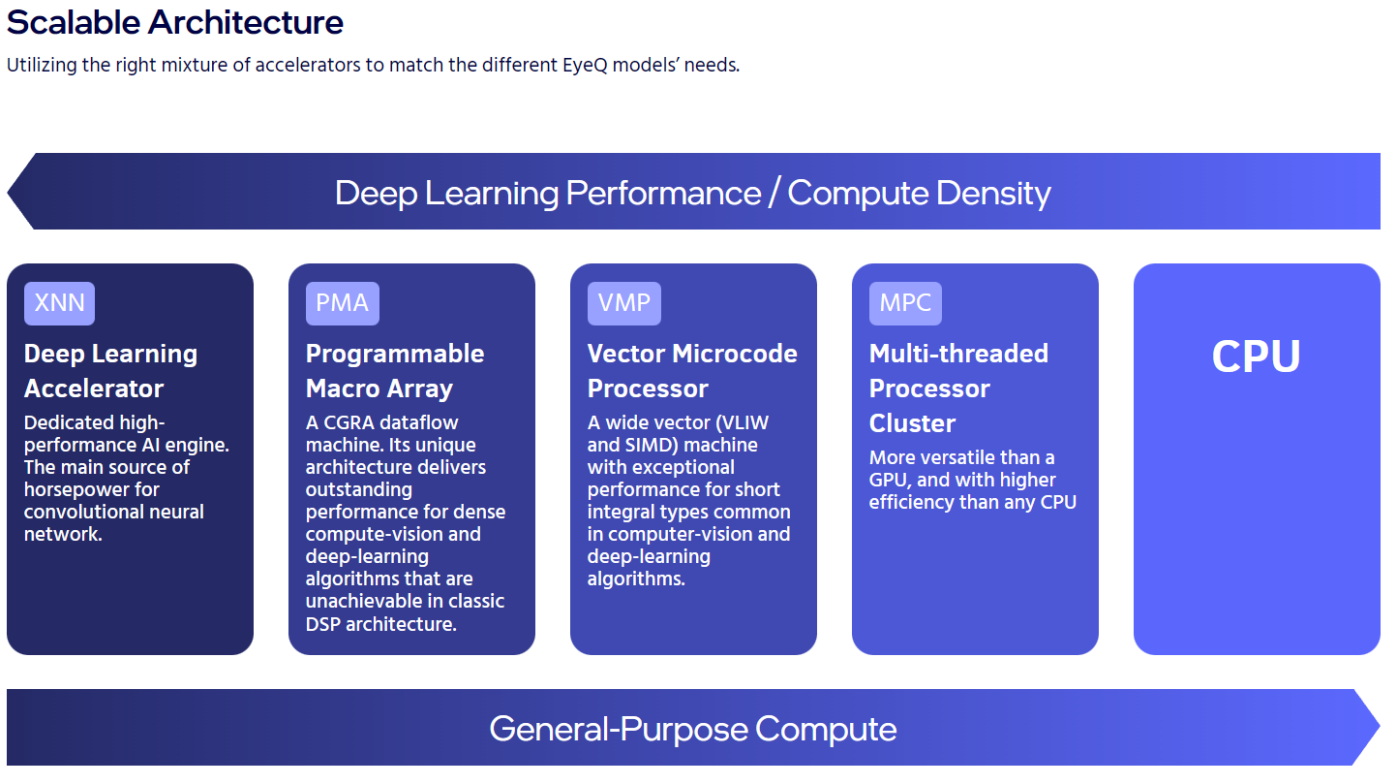
- Tunnel exit or headlights switched on
- Guarantee of clear images in high contrasts scenarios
- Imaging of clear images in high dynamic range



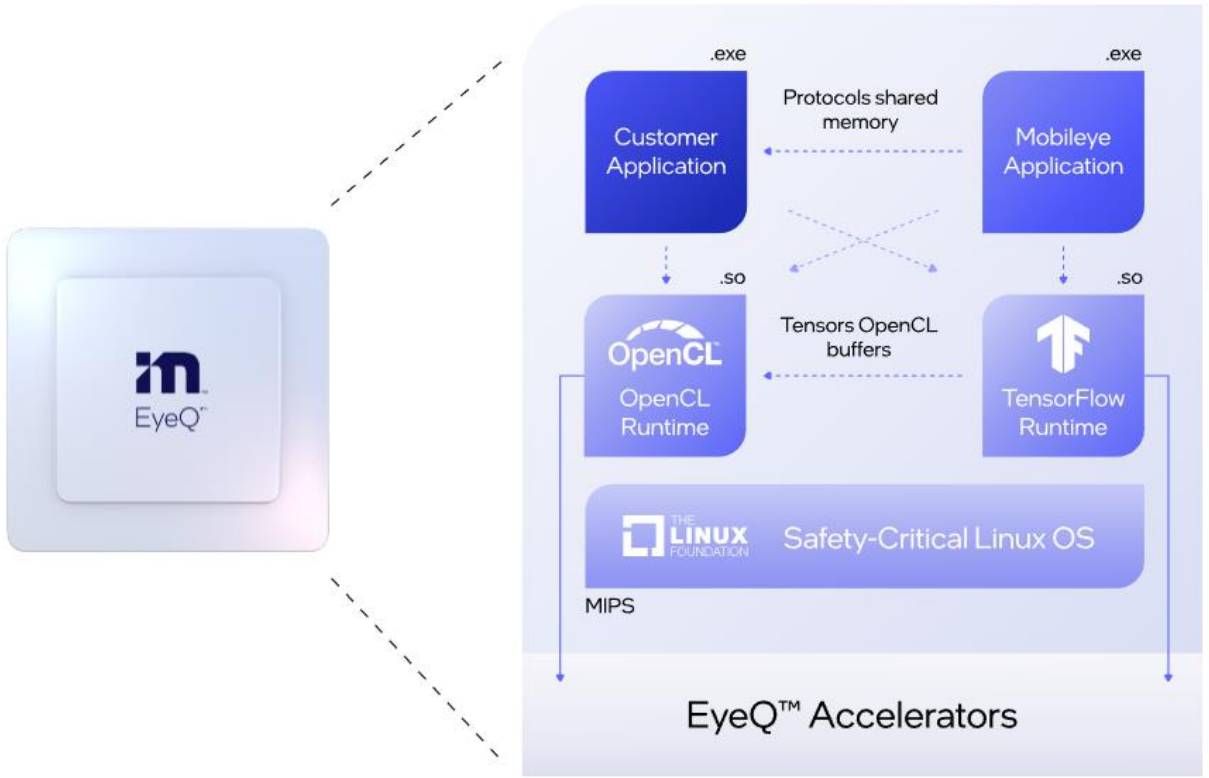
- **HDR Sensors Dynamic 120dB**
- **CCD sensors dynamic range 60dB**

MobilEye

- Israel based company Mobileye
- Supplier of EyeQ computer vision chips with integrated SW for automotive front cameras
  - EyeQ chips used by most of the manufacturers of automotive front cameras

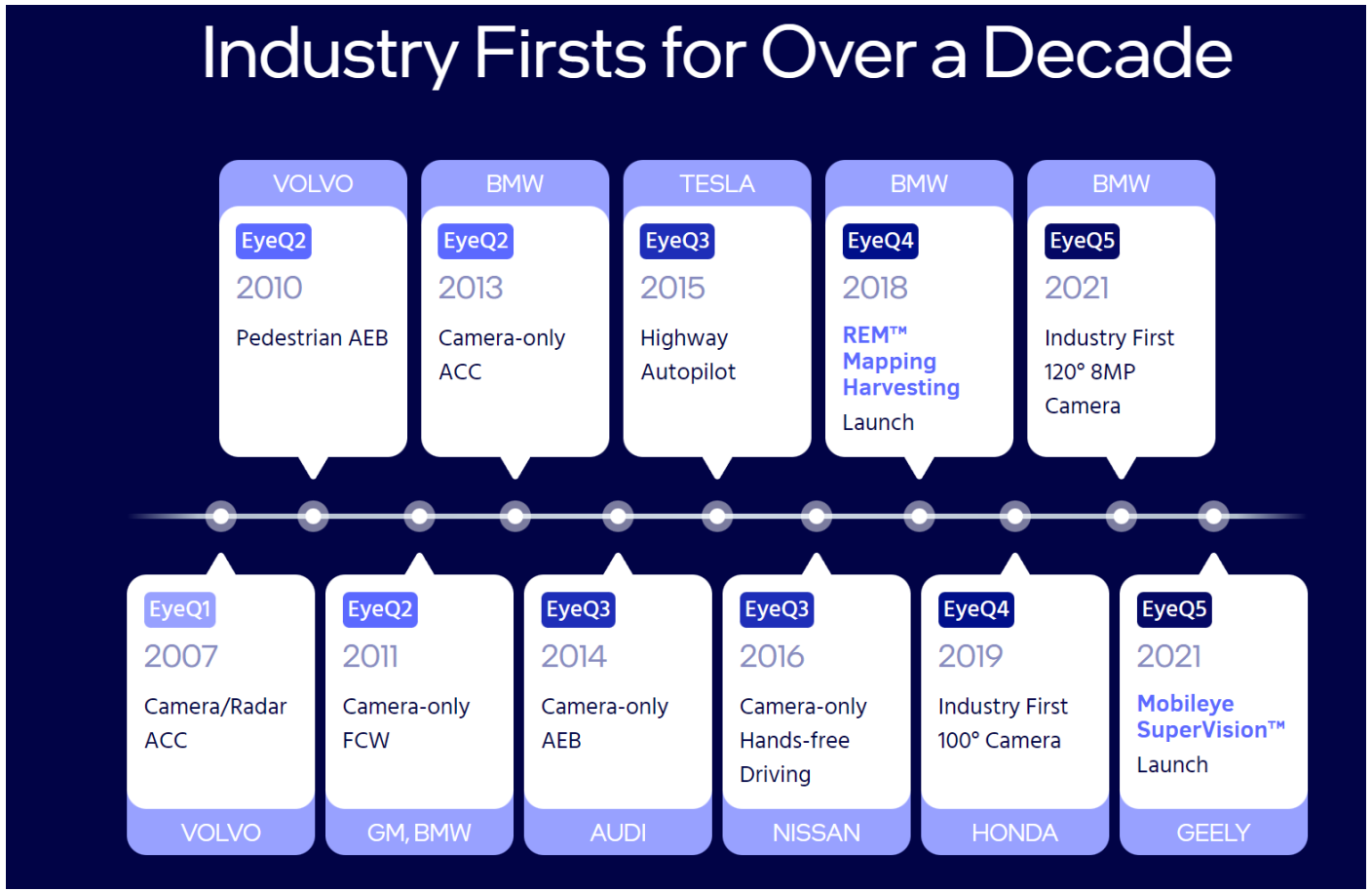


Develop applications using industry-standard tools



- OpenCL runtime environment
- TensorFlow support
- Standard Linux, enabling 3rd-party middleware and libraries
- X86-based development platform
- Supports the full development cycle: from functional bring-up to deployment and performance tuning

MobilEye


Industry Firsts for Over a Decade
VOLVO
EyeQ2
2010
Pedestrian AEB
BMW
EyeQ2
2013
Camera-only ACC
TESLA
EyeQ3
2015
Highway Autopilot
BMW
EyeQ4
2018
REM™ Mapping Harvesting
Launch
BMW
EyeQ5
2021
Industry First 120° 8MP Camera
EyeQ1
2007
Camera/Radar ACC
VOLVO
EyeQ2
2011
Camera-only FCW
GM, BMW
EyeQ3
2014
Camera-only AEB
AUDI
EyeQ3
2016
Camera-only Hands-free Driving
NISSAN
EyeQ4
2019
Industry First 100° Camera
HONDA
EyeQ5
2021
Mobileye SuperVision™
Launch
GEELY

MobilEye converting from vision chip supplier to an Autonomous Driving supplier

- https://youtu.be/A1qNdHPyHu4 (56 min)

Automotive Cameras

Technical Specifications

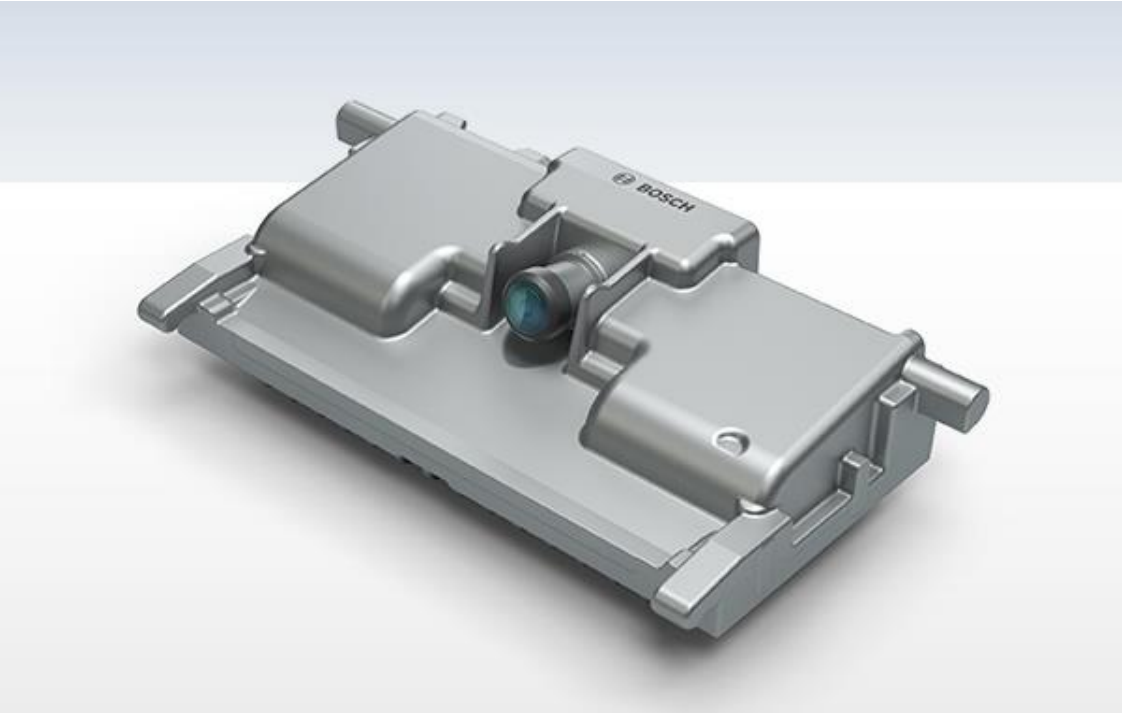
- Dimensions: 88 x 70 x 38mm
- Mass: < 200g
- Field of View: hor. up to 125° (effective) / vert. up to 60° (effective)
- Temperature Range: -40° up to +95° (full operational)
- Power Dissip.: <7 W
- Supply Voltage: 12V

Image+Spec: Continental

Automotive Cameras

TECHNICAL CHARACTERISTICS

Optics	Horizontal field of view	± 50°
	Vertical field of view	27° up, 21° down
	Aperture	F1.8
Imager	Resolution	2.6 MP HDR (2,048 x 1,280 pixels)
	Color pattern	RCCG
	Frame rate	45 frames per second, with flicker mitigation
System on chip	Technology	16 nm FFC
	Processing system	4 x ARM quad core (~ 9000 DMIPS) + 1 x ARM dual lockstep
	Hardware accelerator	DNN, classifier, optical flow, flexible CV engines
Safety level		Up to ASIL-B
Mechanics	Box size	120 x 61 x 36 mm



Image+Spec: Bosch

Front Camera

Front camera with split view technology to support the driver

Stereo front camera for lane detection

Images: Ford, Mercedes

Mirror View Camera

Fuel saving, Noise reduction

Image: Continental

Rear View Camera

Accidents avoidance when reversing

Image: Continental

Surround View Camera

Recognition of objects in the vicinity of the vehicle (mainly for parking)

Image: Continental

Interior Camera

- Driver identification
  - Car theft
- Driver attention
  - Warnings in case of inattention
- Driver fatigue
  - Warnings in case of sleepiness
- Driver Monitoring
  - Hand over requests for autonomous driving

Image: Continental