CMOS Cameras and CCD as well a bit ;)

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Full Frame Camera from Sony, [dpreview.com]

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General Camera Build-Up

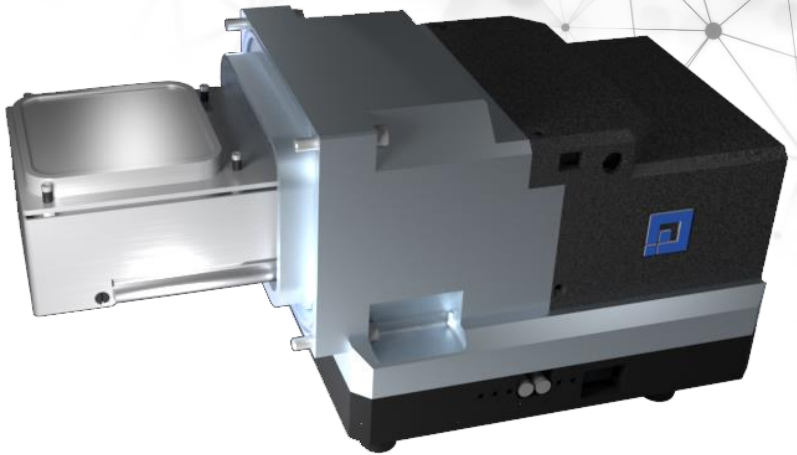
Light to charge conversion

Charge accumulation

(Charge transfer)

Charge voltage conversion

Amplification

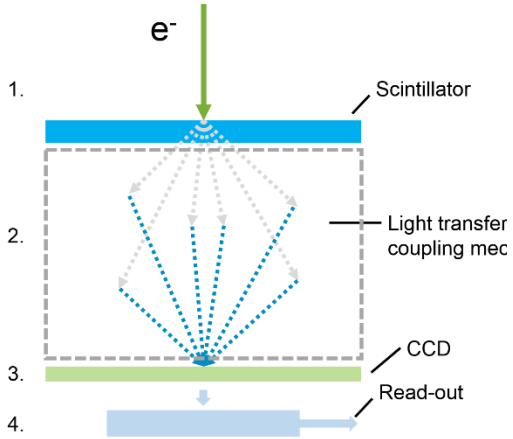


- Charge-coupled device (**CCD**)
- Complementary metal-oxide-semiconductor (**CMOS**)

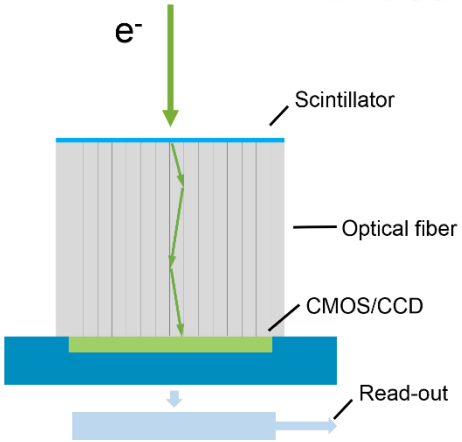
[TVIPS GmbH]

General Camera Build-Up

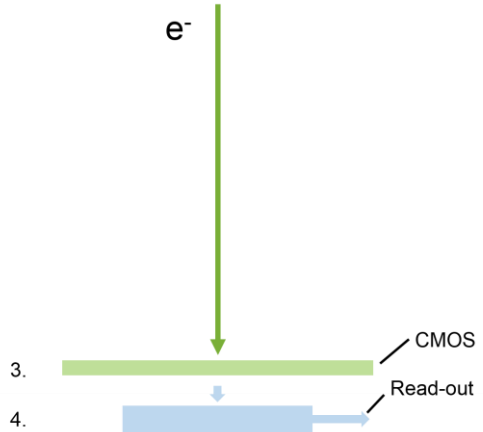
Conventional



Fiber-coupled



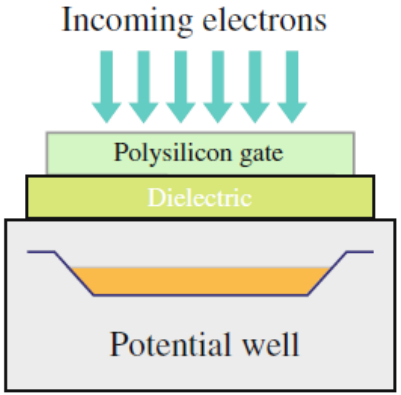
Direct

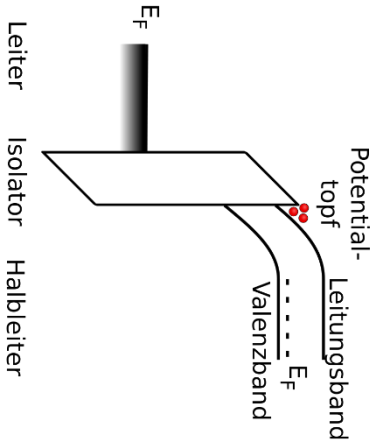


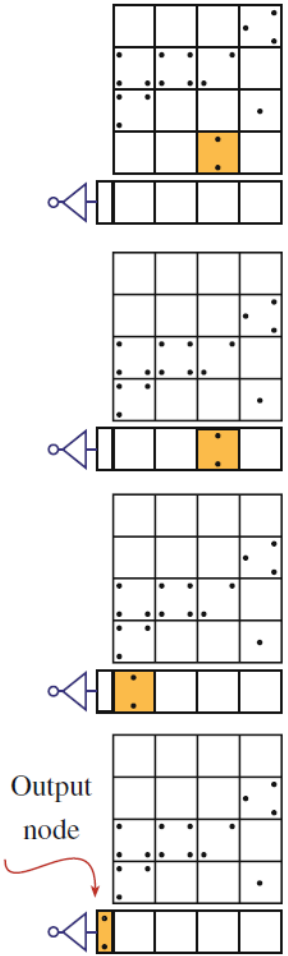
1. Convert electrons to signal
2. Transfer signal
3. Detect signal with sensor
4. Electronically transfer signal and read-out to form image

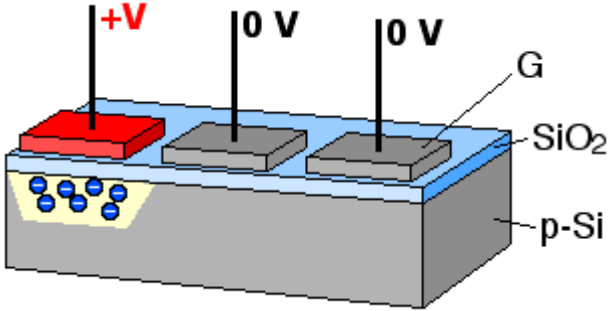
[Gatan Inc.]

CCD Sensor (Charge coupled device)









Working principle:

- By applying a voltage to the conductor a potential well is formed.
- The potential well can be filled with electrons.
- The accumulated charge is proportional to the incoming light.

Read-out:

- Line by line &
- Pixel per pixel

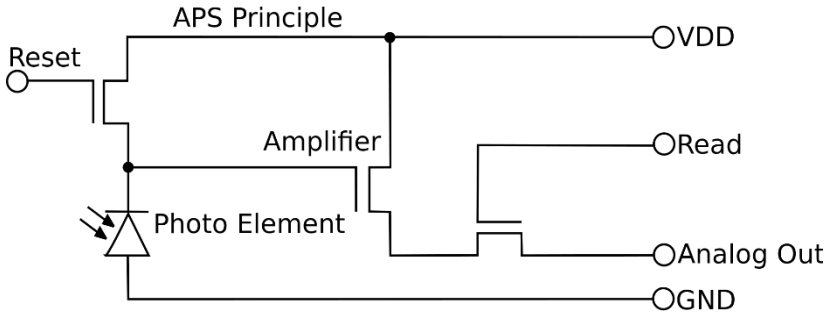
[Wikimedia, Carter & Williams]

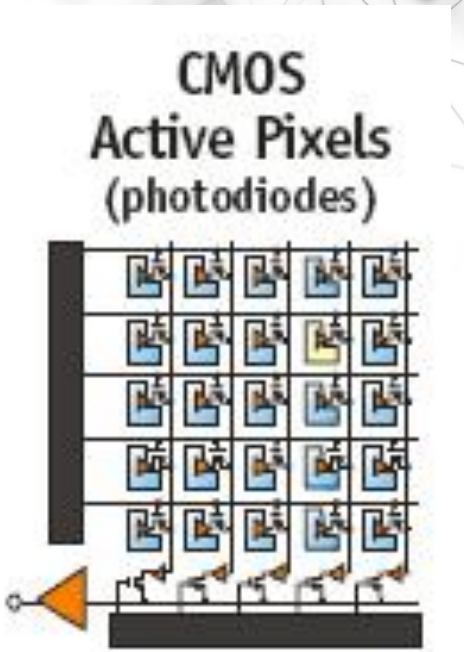
Active Pixel Sensor / CMOS Sensor

CMOS (Complementary metal-oxide-semiconductor)

Working principle:

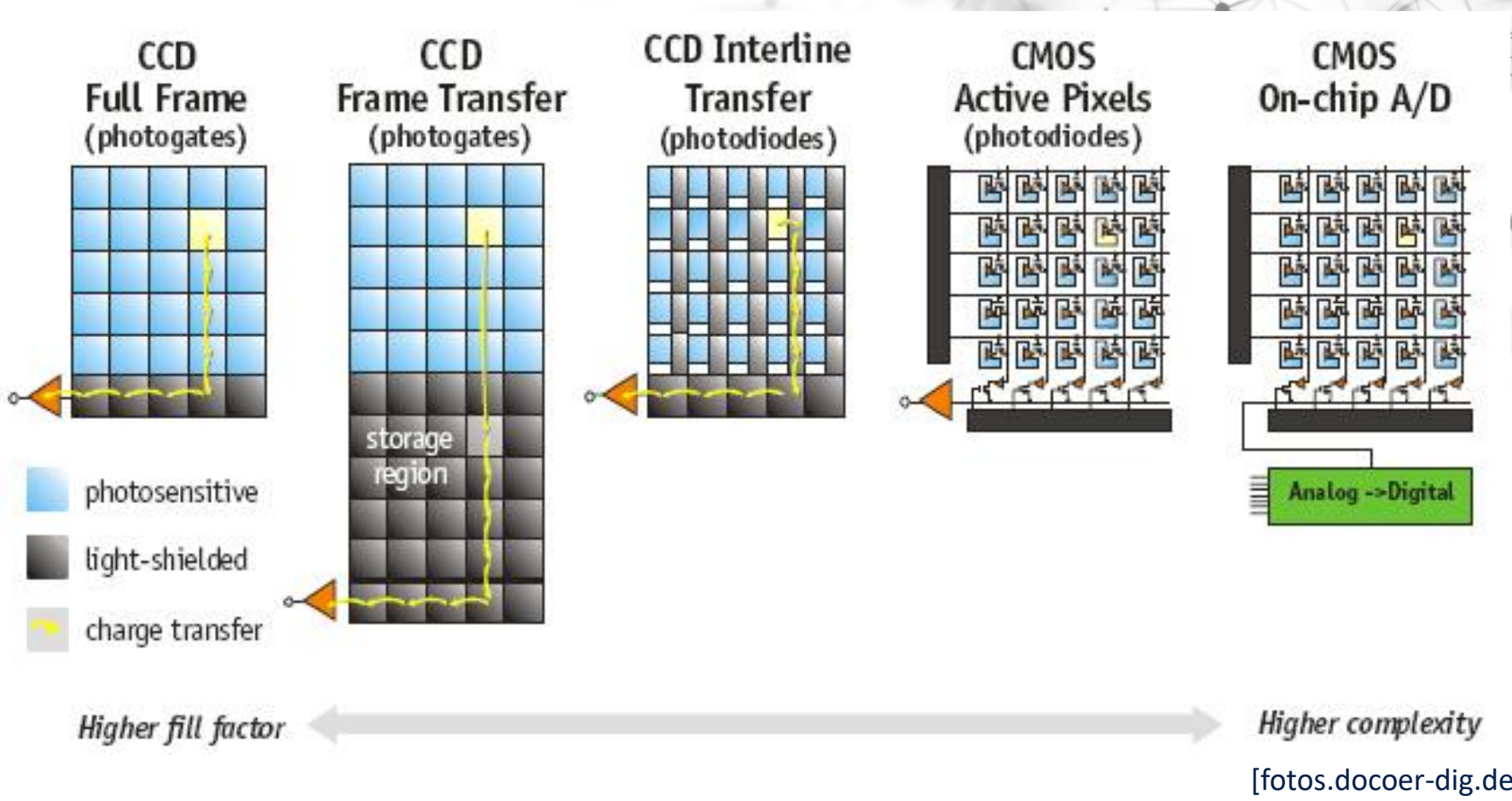
- Before illumination a defined voltage is set to each pixel.
- Incoming photos discharge the pixel.
- The discharge is proportional to amount of light.





[fotos.docoer-dig.de]

CCD and CMOS types



[fotos.docoer-dig.de]

Advantages and Disadvantages of CMOS (CCD)

- Significantly lower power consumption
- Smaller size of the camera, as the evaluation logic can be integrated on the same chip (system on a chip).
- Very high frame rates
- Flexible readout by direct addressing of the individual pixels enables more possibilities for binning & partial scan
- Greatly reduced blooming
- Higher sensitivity in the NIR range (near infra-red)

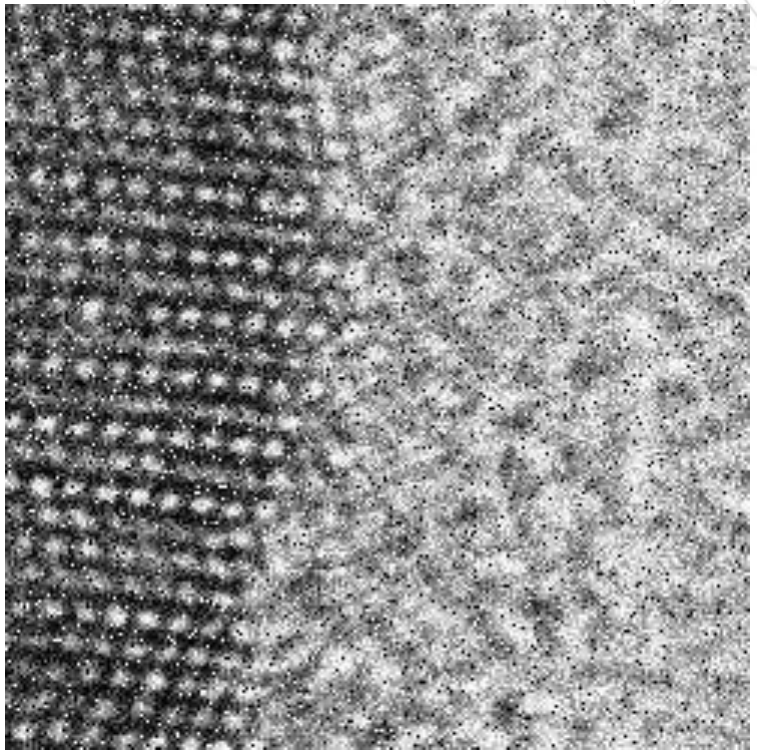
- Greater differences in sensitivity between the pixels due to manufacturing tolerances.
- Significantly lower fill factor (ratio of light-sensitive to total pixel area), resulting in an overall poorer light sensitivity.
- When images are recorded with lower brightness, an increased image noise quickly becomes apparent.

Noise

Noise is the deviation of brightness (or color) in an image. The sample can also causes noise (e.g. unwanted X-rays), but we are talking about digital noise.

Origin of noise:

- High temperature
- Temperature fluctuation
- **Inhomogeneous scintillator material**
- **Electronic fluctuations, e.g. no uniform amplification (CMOS!)**
- Blooming (CCD!), cross-talk



Noise intentionally added

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Noise is defined with the power of the signal P (meaningful input)

$$SNR = \frac{P_{signal}}{P_{noise}}$$

With only positive noise (e.g. images) →

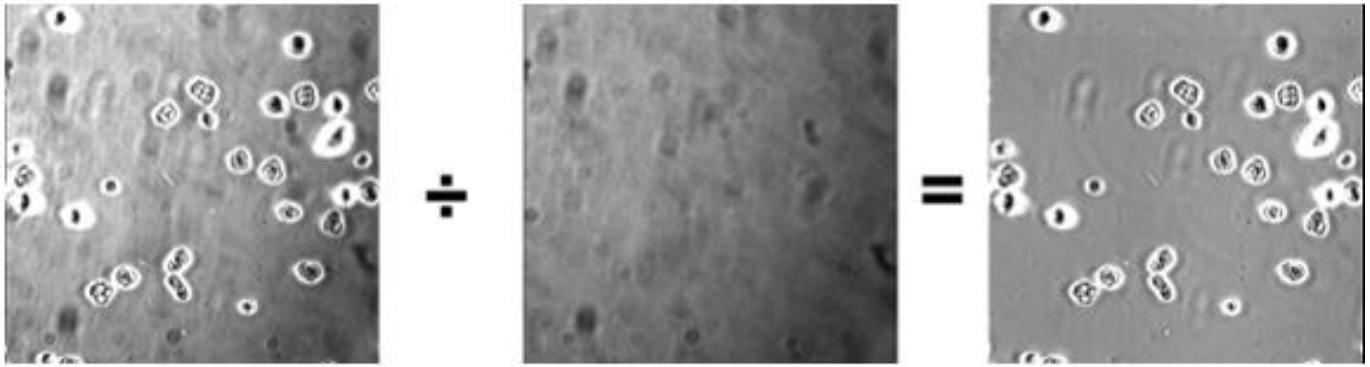
$$SNR = \frac{\mu}{\sigma}$$

μ: mean deviation

σ: standard deviation

Flat-Field-Correction

Flat-field correction is a technique used to improve quality in digital imaging. It cancels the effects of image artifacts caused by variations in the pixel-to-pixel sensitivity of the detector and by distortions in the optical path.

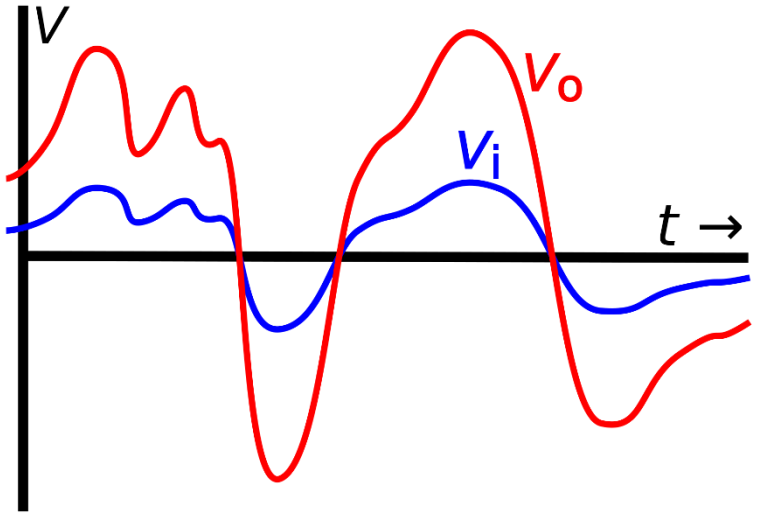


$$C = \frac{(R - D) * m}{(F - D)} = (R - D) * G$$

C = corrected image
R = raw image
F = flat field image
D = **dark field or dark frame**
m = image-averaged value of (F-D)
G = **gain**

[Imagej]

Gain

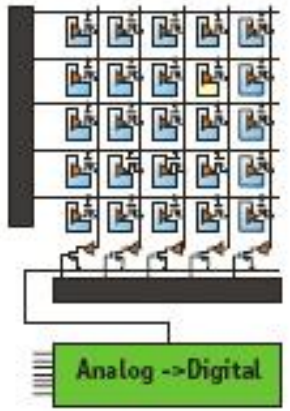


Graph of the input *(blue)* and output voltage *(red)* of an ideal linear **amplifier** with a voltage gain of 3 with an arbitrary input signal. At any instant the output voltage is three times the input voltage.

[wikipedia.com]

Origin of noise:

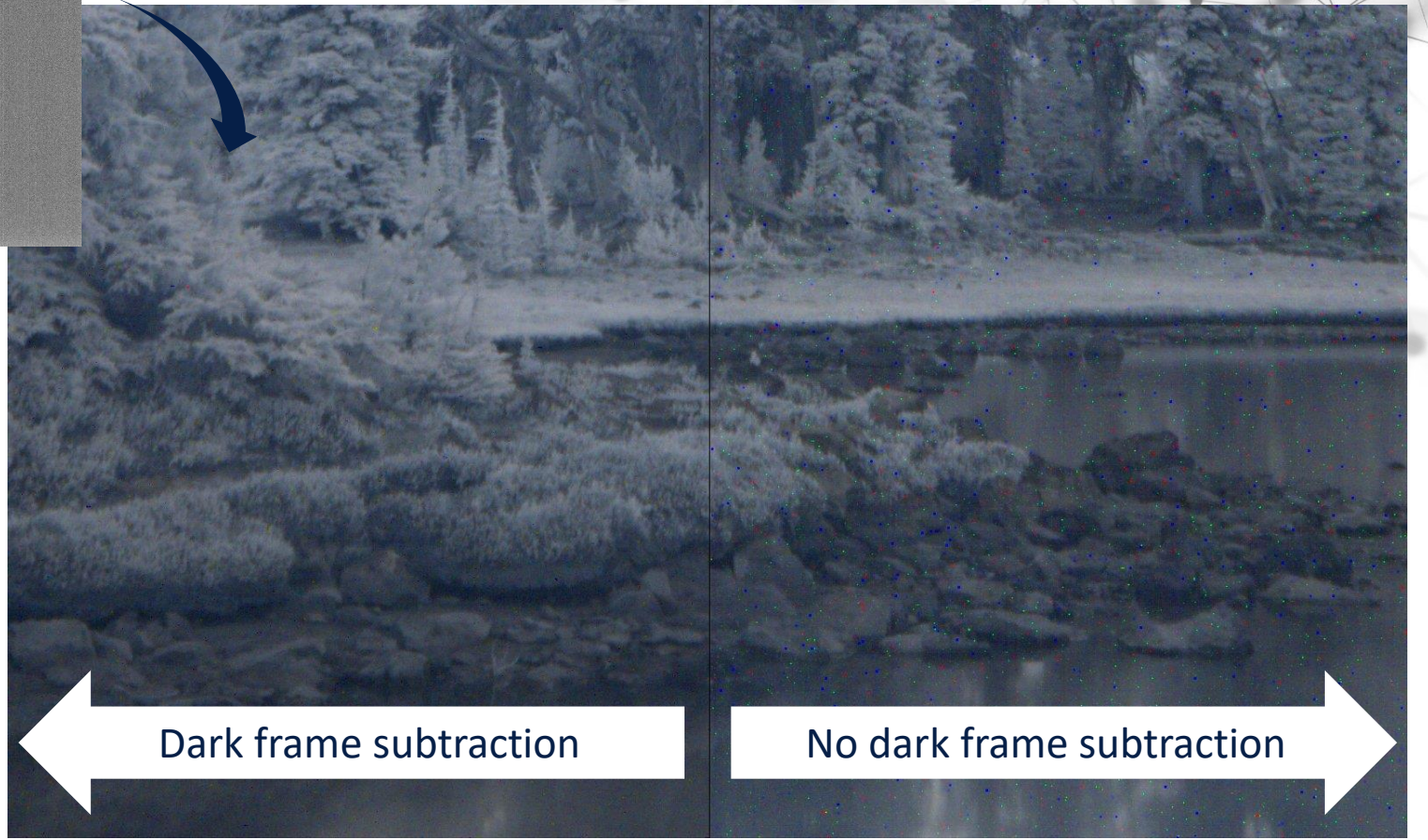
- Amplification is not uniform for all pixels
- Scintillator material is not uniform
- …



Dark-Current

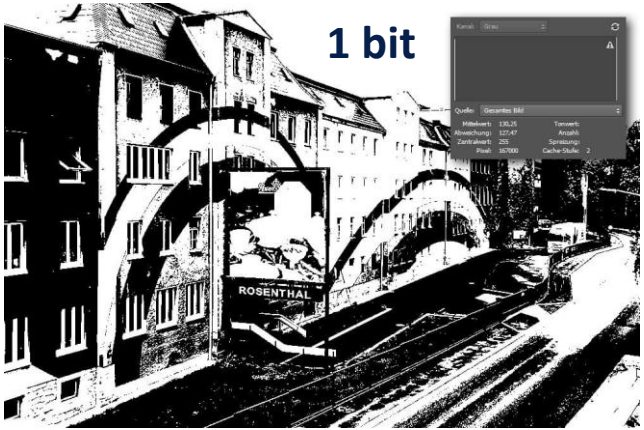
frame subtraction

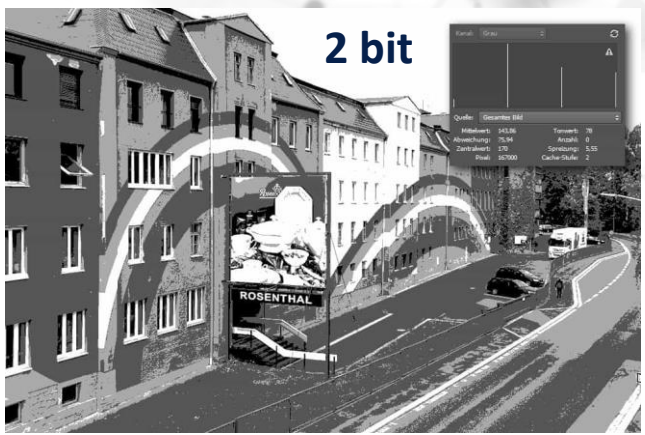
Origin of noise: Flow of a small current even without any light (electrons), i.e. the **dark-current**.

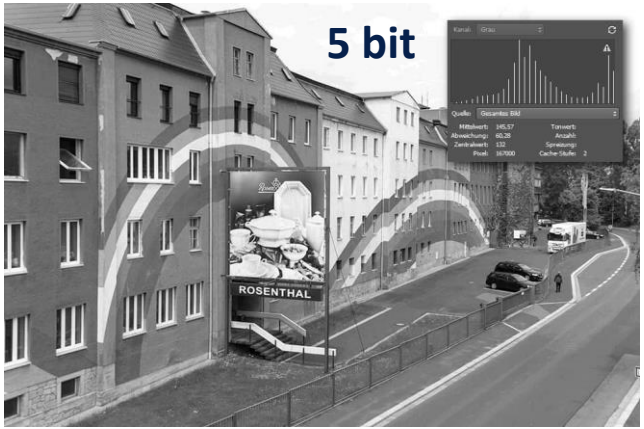


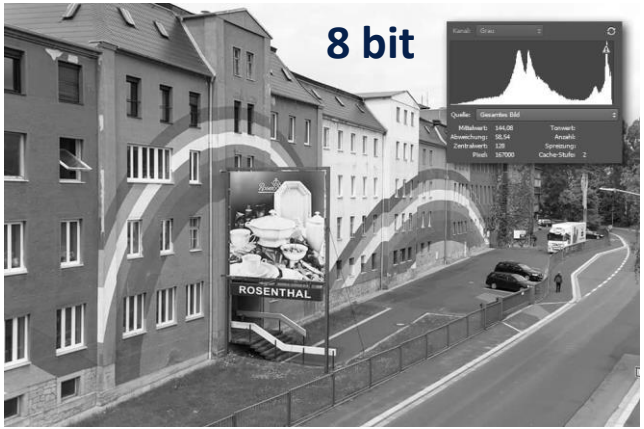
[wikipedia.com]

Image Size and bit depth





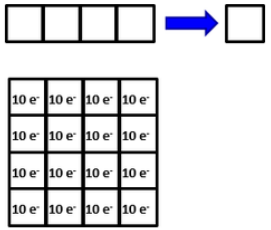
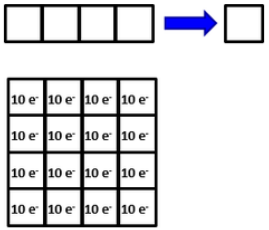
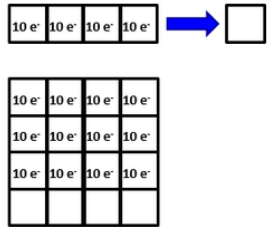
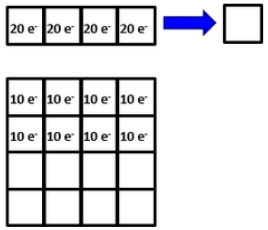
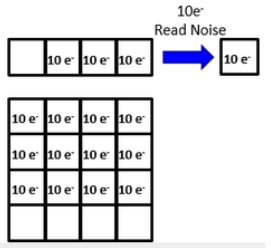
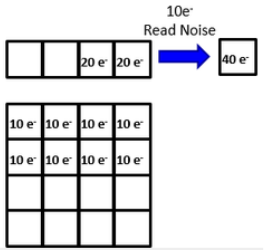




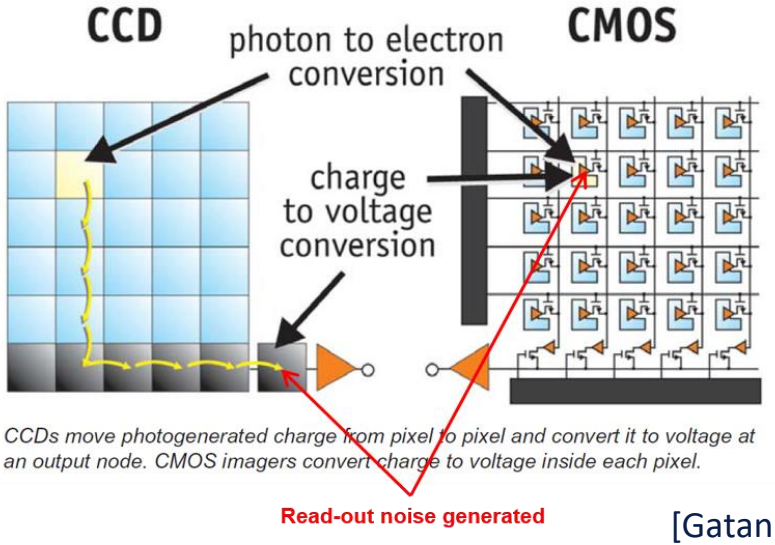
- The more bits, the larger the file.
- The larger the resolution, the larger the file.
- The CETA camera has 16 bit + 4k image: **32 MB** (actually even larger).
- JEPG has only 8 bit.
- TIFF has often 16 bit.

[nachbelichtet.com]

Binning CCD vs. Binning CMOS

	1x (no) Binning	2x Binning
Collect signal in each pixel		
Transfer charge to read-out register		
Convert to voltage, amplification, and read-out	 SNR = 10/10 = 1. Weak signals lost in read-out noise.	 SNR = 40/10 = 4. Weak signals detected above noise floor.

In the case of CMOS devices, the charge-to-voltage conversion is done in each pixel, therefore the read-out noise is applied per pixel: Instead of N-fold benefit it only becomes $N^{1/2}$.



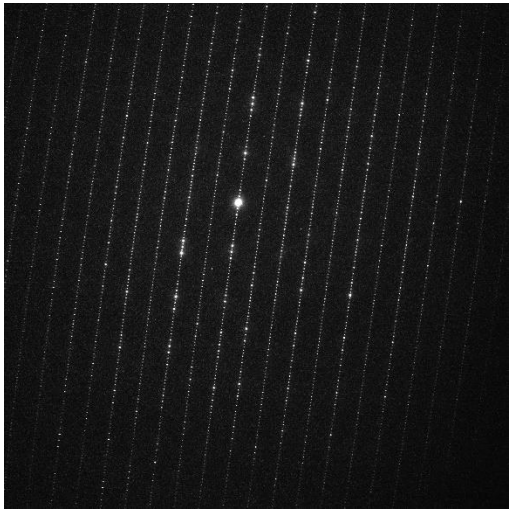
[Gatan Inc.]

Dynamic Range

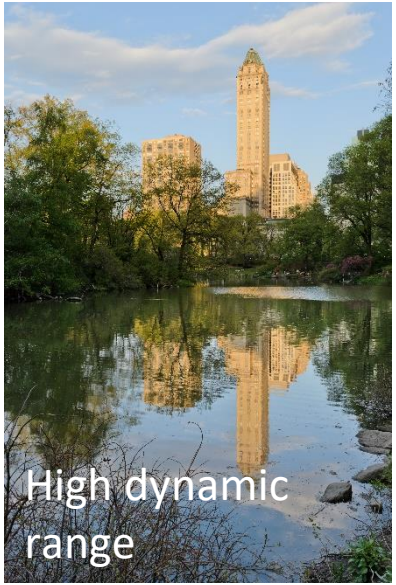
Dynamic ranges of common devices

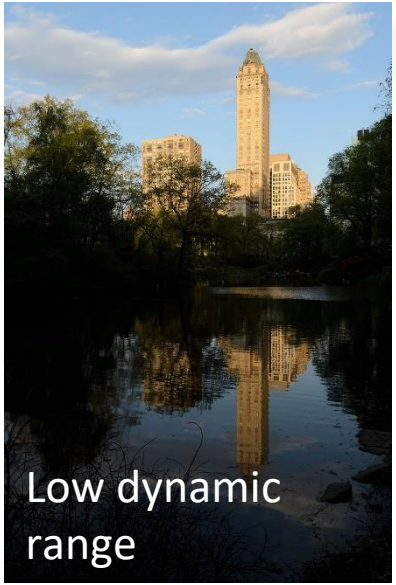
Device	Stops	Contrast ratio
Glossy photograph paper	7 (7 - 7 2/3) [58]	128:1
LCD	9.5 (8 – 10.8)[*citation needed*]	700:1 (250:1 – 1750:1)
Negative film (Kodak VISION3)	13[59]	8000:1
Human eye	10–14[54]	1000:1 – 16000:1
High-end DSLR camera (Nikon D850)	14.8[60]	28500:1
Digital Cinema Camera (Red Weapon 8k)	16.5+[61]	92000:1

A high dynamic range is important for diffraction



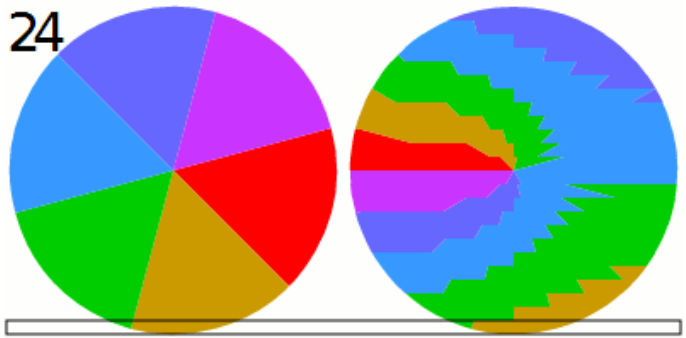
[Wikimedia, tvips.de]





Rolling Shutter

- For CMOS sensors with line read-out (cheaper design), rolling shutter artifacts can be a problem.
- No problem for single image acquisition in TEM.



[Wikimedia]