Visit Mid-Sweden University - November 2006

CCD- and CMOS-Imaging

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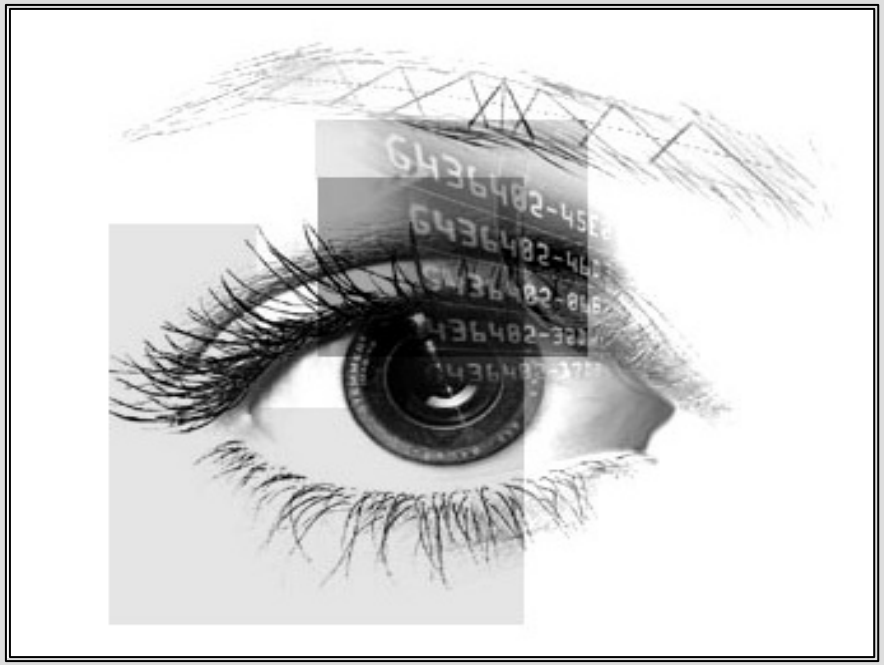
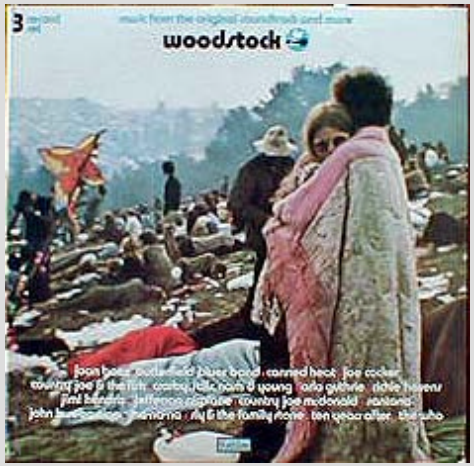
Imaging



If a picture tells more than 1000 words,

imaging is the language of the future !

1969



Woodstock

Moon landing

Invention of the CCD

Overview

CCD Principles

Device Architectures: Frame Transfer and Interline

Special Aspects

CMOS Principles

Overview

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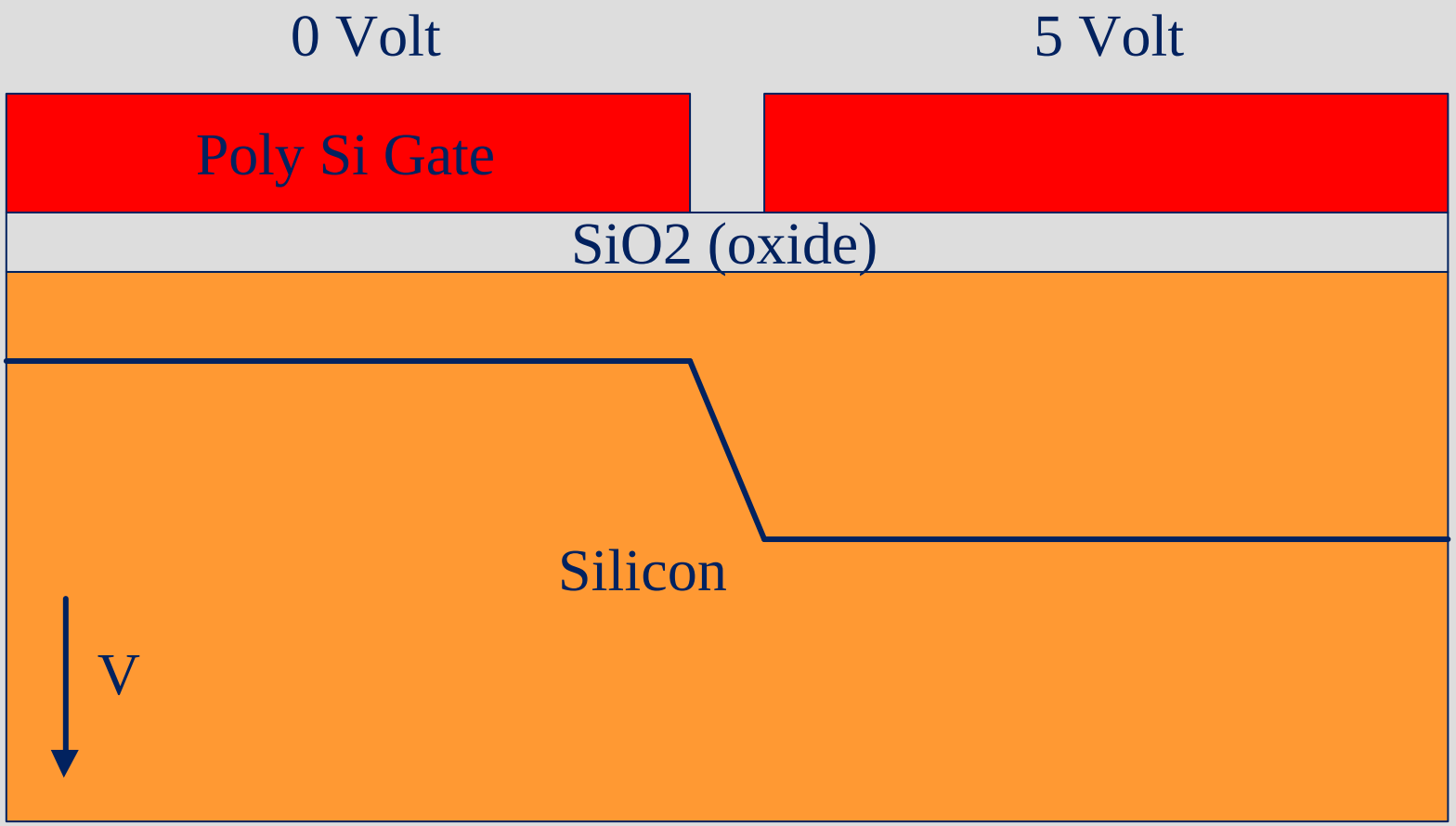
CMOS Principles

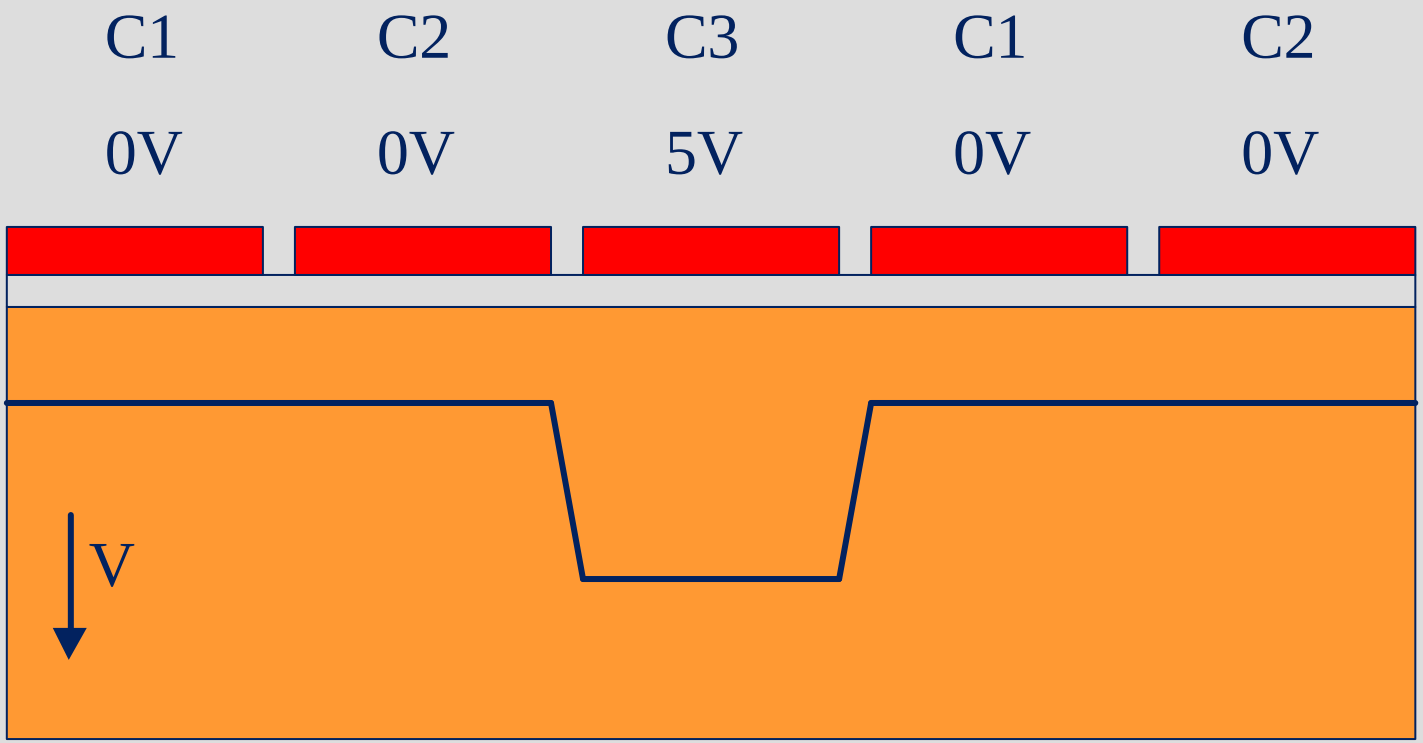
The Human Eye and the CCD Imager

Human Eye	CCD Imager
120 Mpixels	80 Mpixels
2-3 micron pixels	2-12 micron pixels
< 1 mW	1 W
perfect quality	good quality
color: perfect	color: good
parallel read-out	serial read-out
15 images/sec	up to 1.000.000 images/sec
500 Myears	25 years

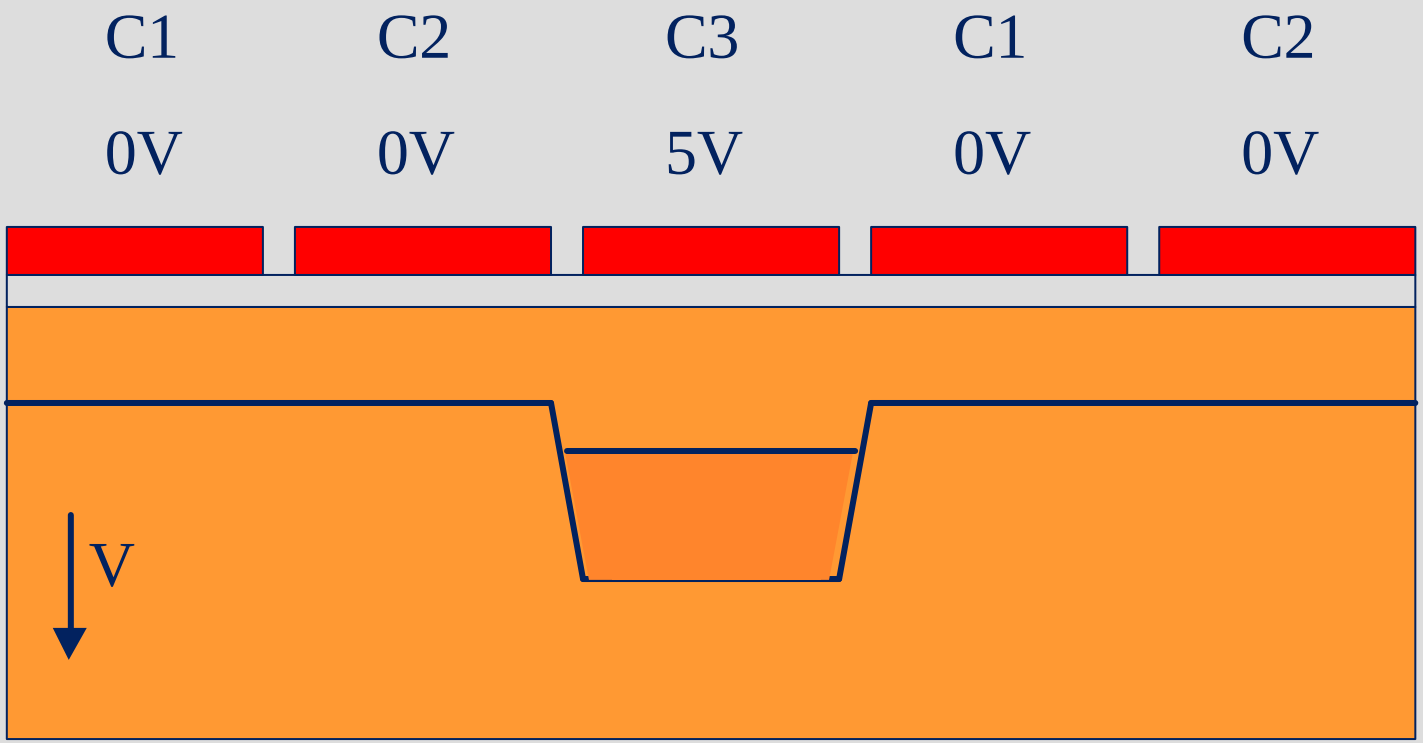
MOS structure



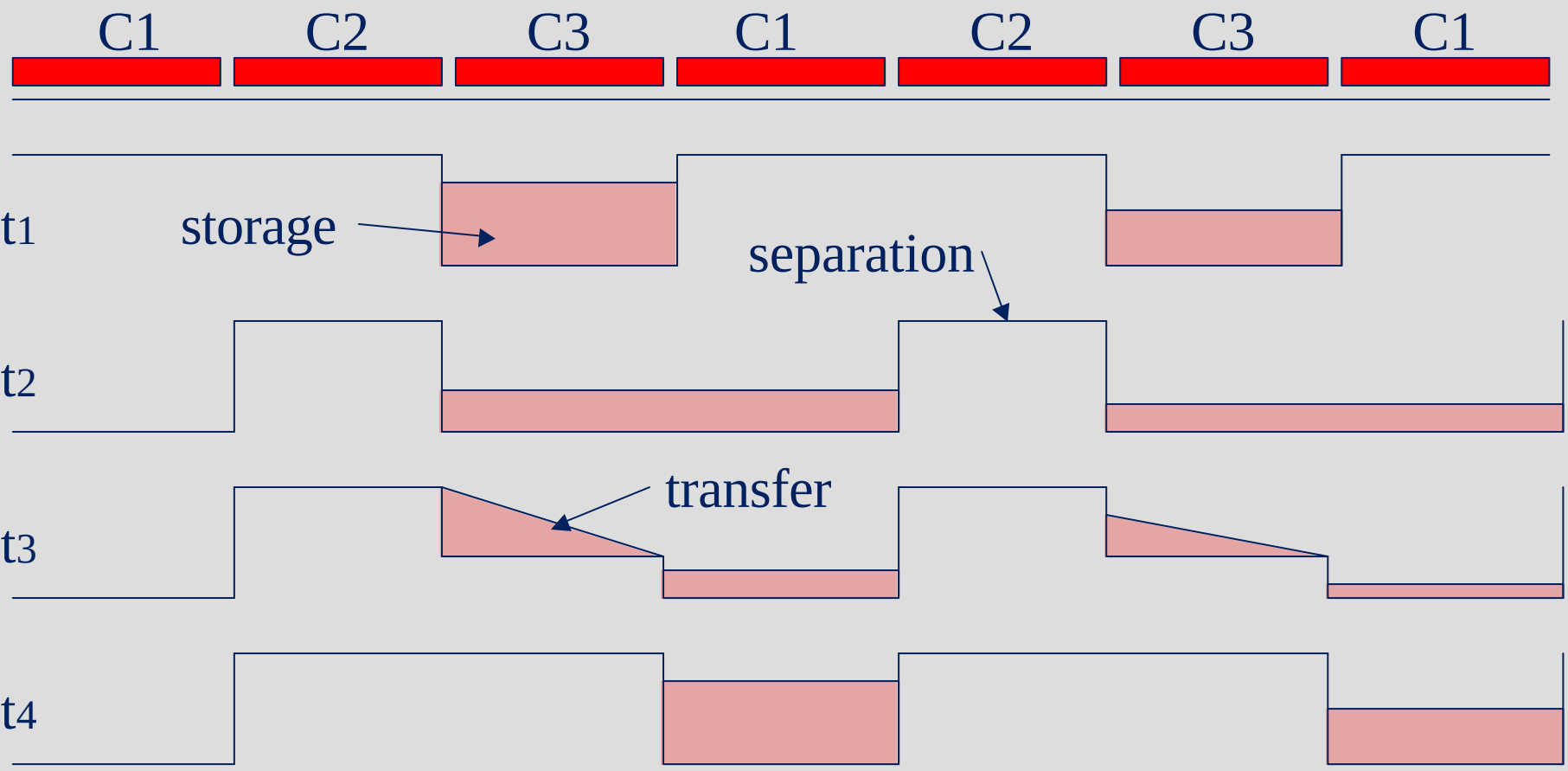
CCD



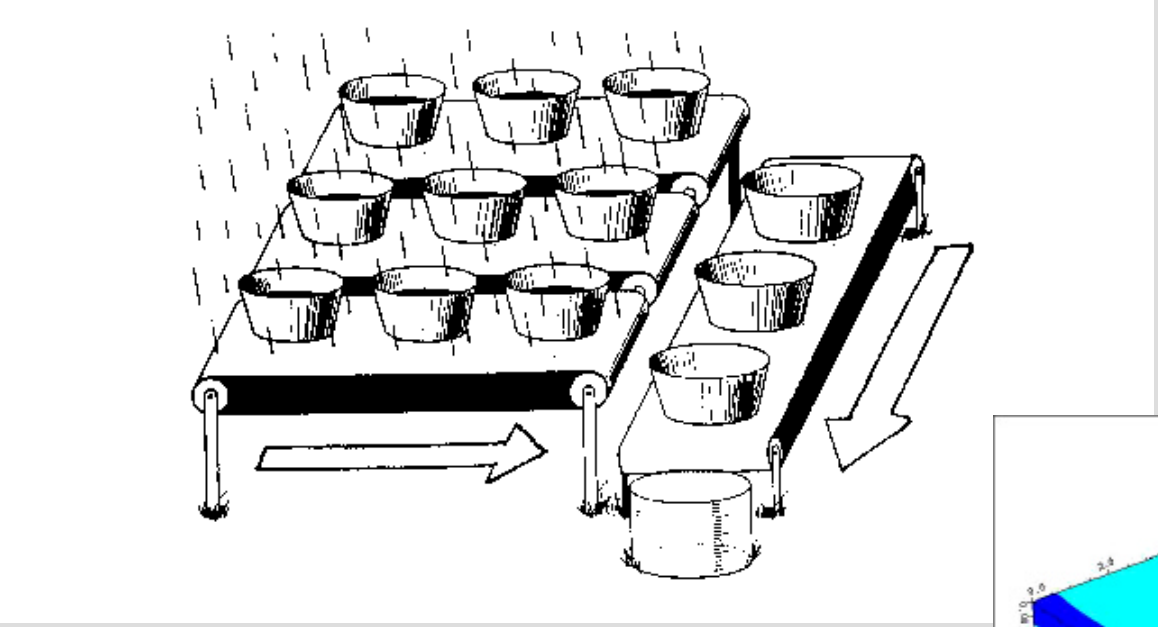
CCD

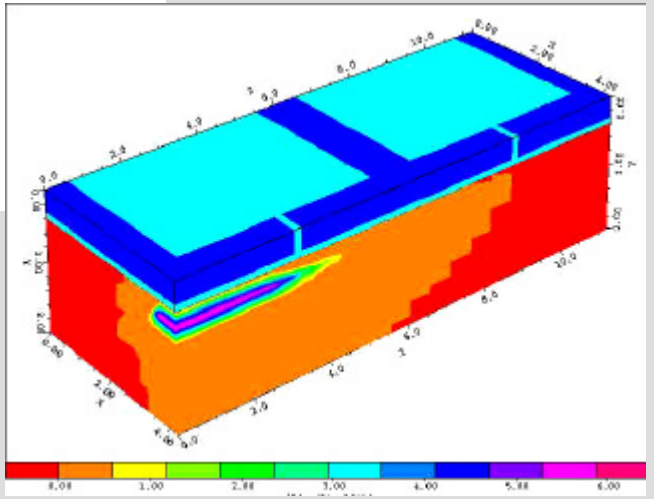


Transport

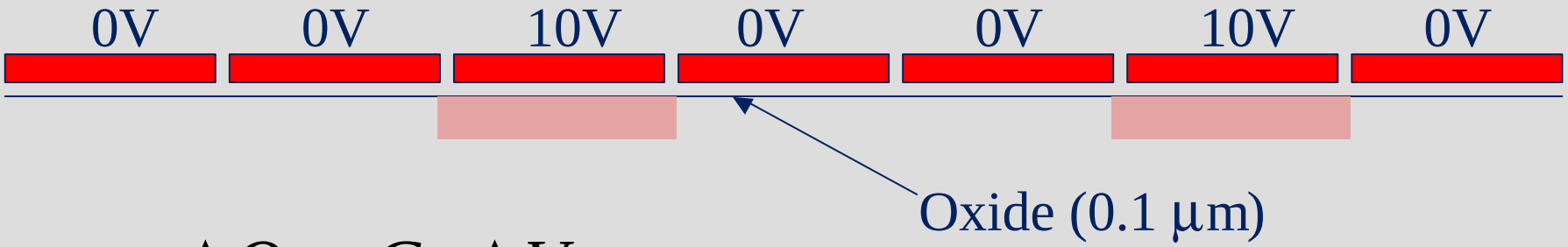


Transport – comparison with water





Surface CCD



$$\Delta Q = C \cdot \Delta V$$

$$C = C_{ox}$$

$$N = \frac{C_{ox}}{q} \cdot \Delta V$$

$C_{ox} = 0.345$ fF/µm²

$\Delta V = 10$V

$N \approx 20\,000$ e⁻/µm²

Buried channel CCD

$$\Delta Q = C \cdot \Delta V$$

$$C_{eff} = \frac{C_{ox} \cdot C_{Si}}{C_{ox} + C_{Si}} < C_{ox}$$

$$N = \frac{C_{eff}}{q} \cdot \Delta V$$

$C_{eff} = 0.15$ fF/µm²

$\Delta V(bulk) = 7$

$N \approx 6\,500$ e⁻/µm²

Overview

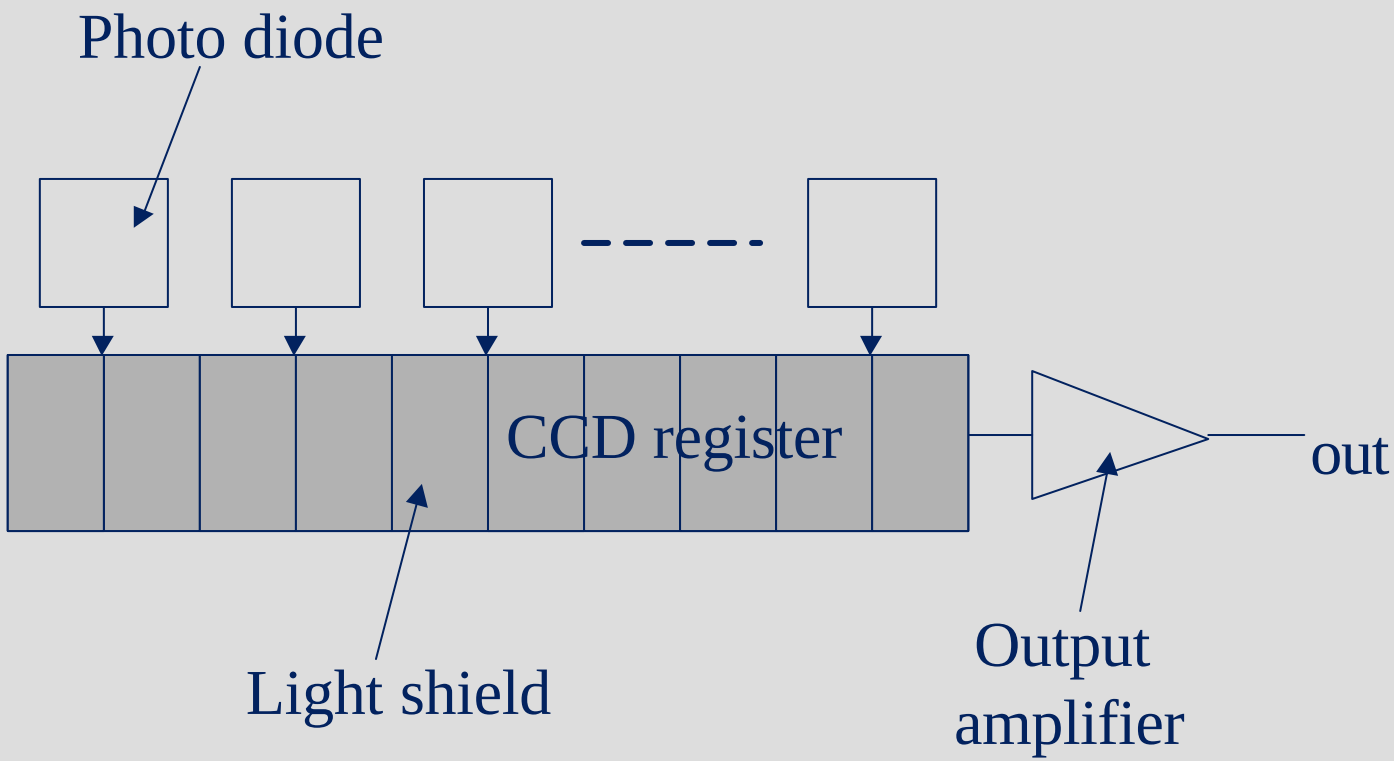
CCD Principles

Device Architectures: Frame Transfer and Interline

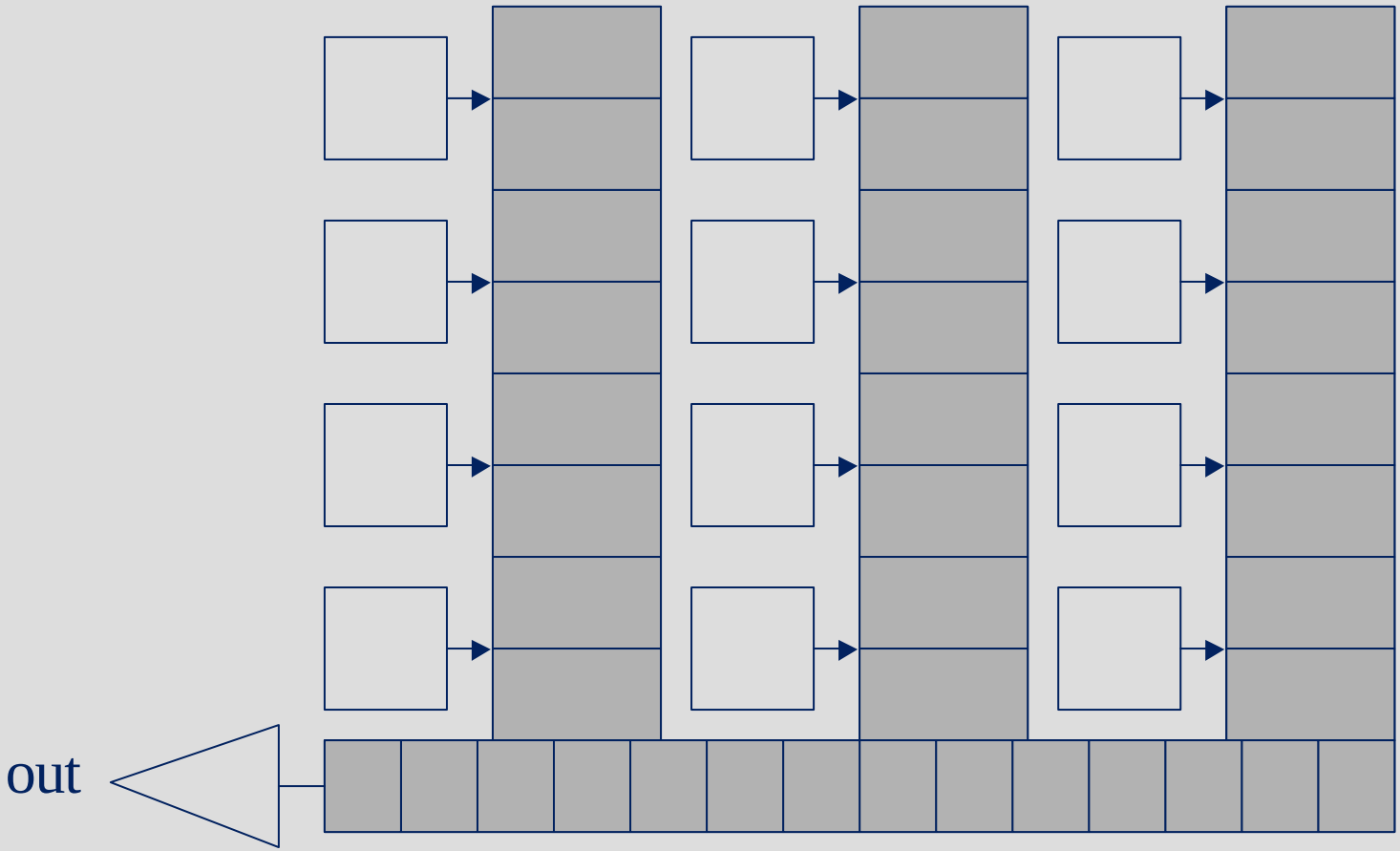
Special Aspects

CMOS Principles

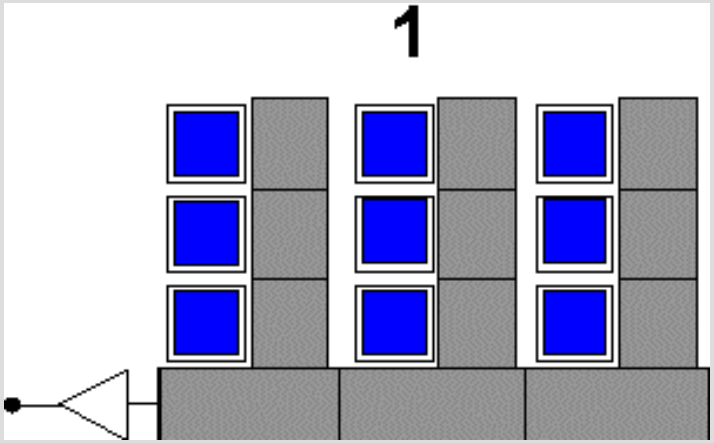
Linear Imager (1D)



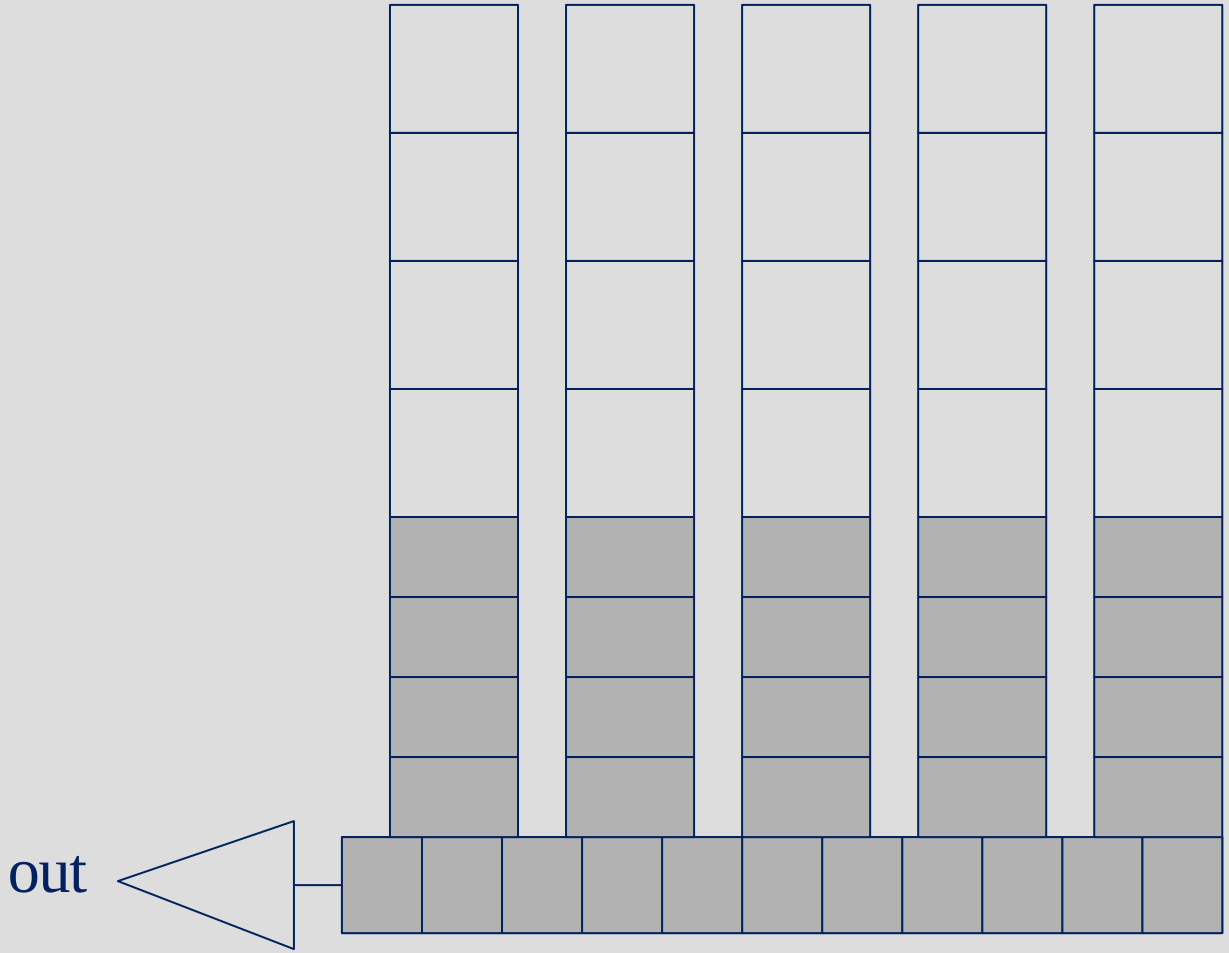
Interline Imager: IL-CCD (2D)



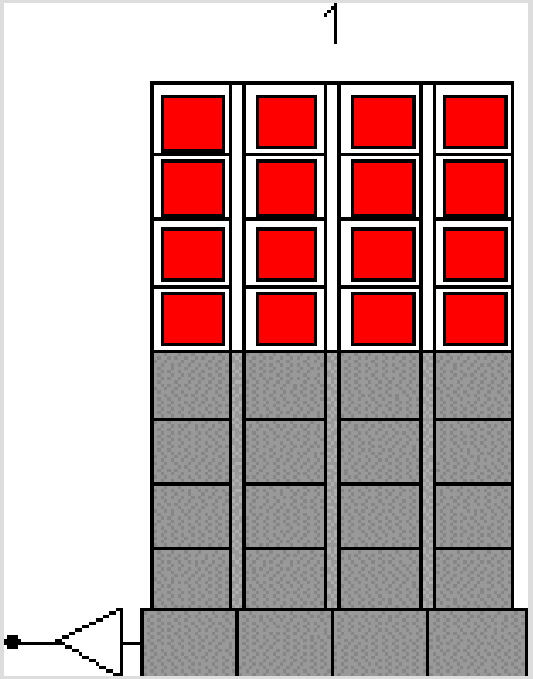
Interline CCD: Basic operation



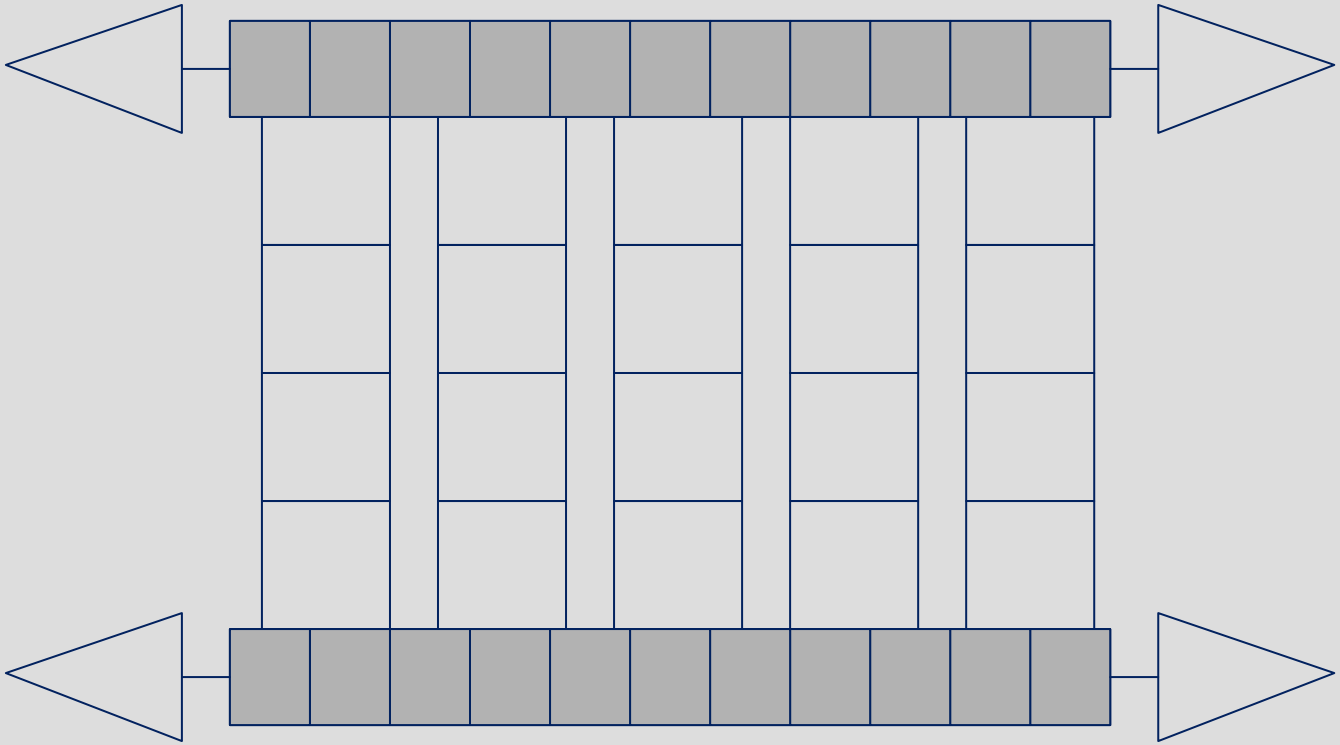
Frame Transfer FT-CCD (2D)



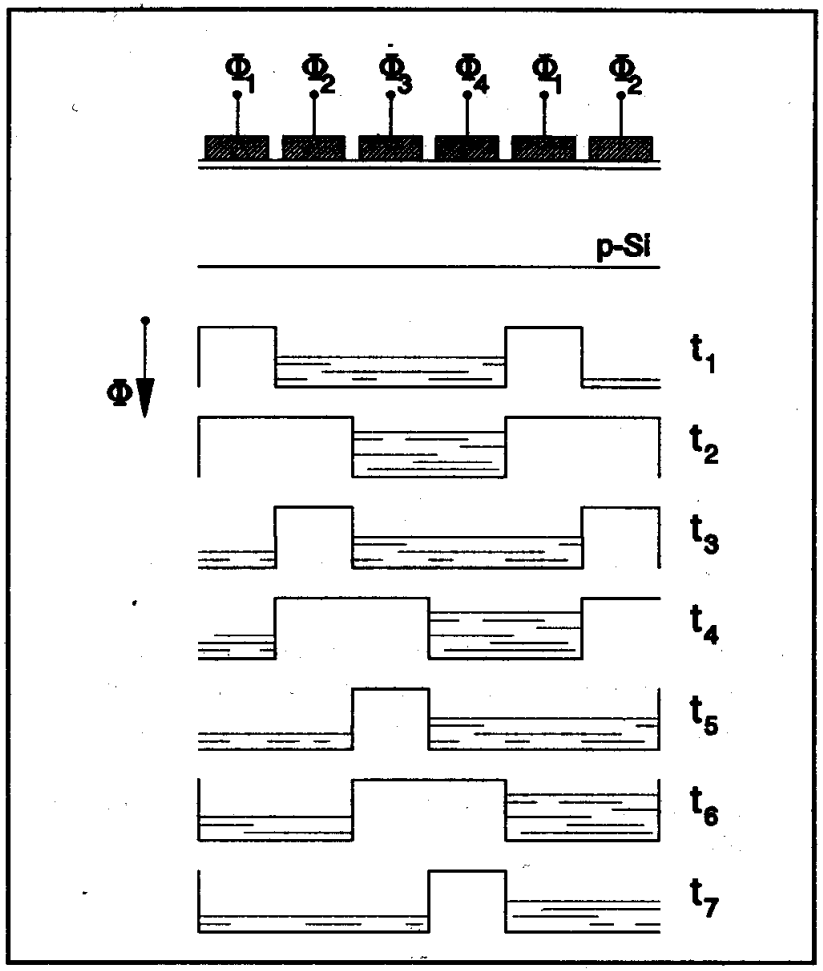
Frame Transfer CCD: Basic operation

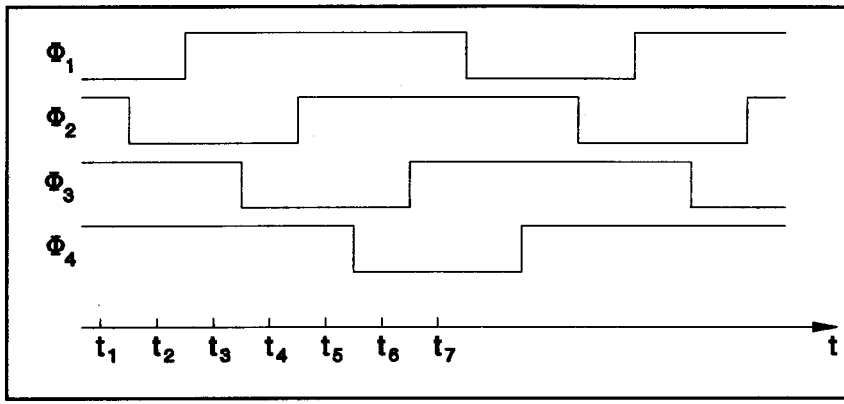


Full Frame CCD (FF-CCD)



Transport Systems : Four-phase CCD





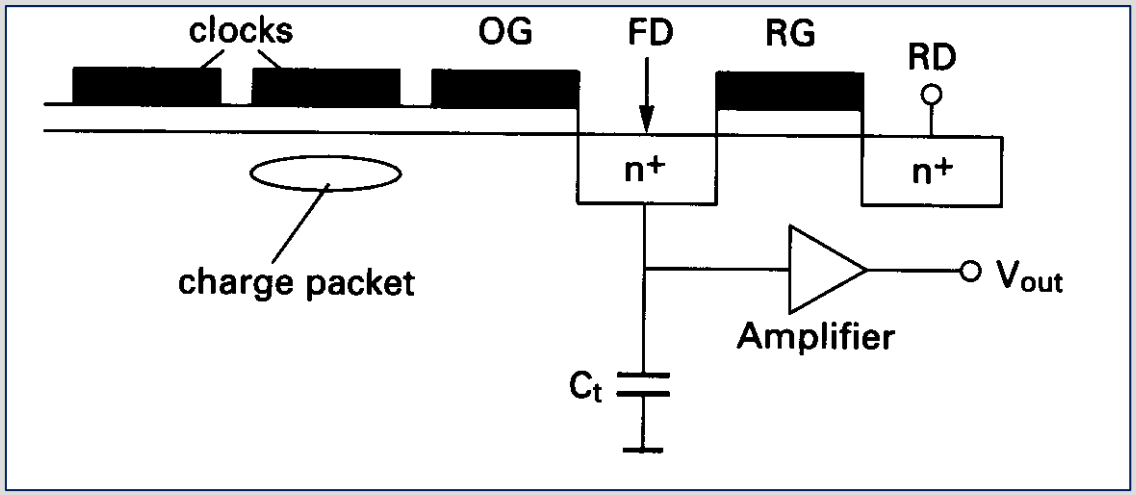
Timing diagram

Source: „Solid-State Imaging with Charge-Coupled Devices, A.J.P. Theuwissen, Kluwer 1995

Output structure

Example: Floating diffusion amplifier (FDA):

- charge packet is transported into the floating diffusion
- sensed by an amplifier
- reset via a MOS-transistor



Overview

CCD Principles

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Special Aspects

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Color Imaging: Spectral Sensitivity of the human eye

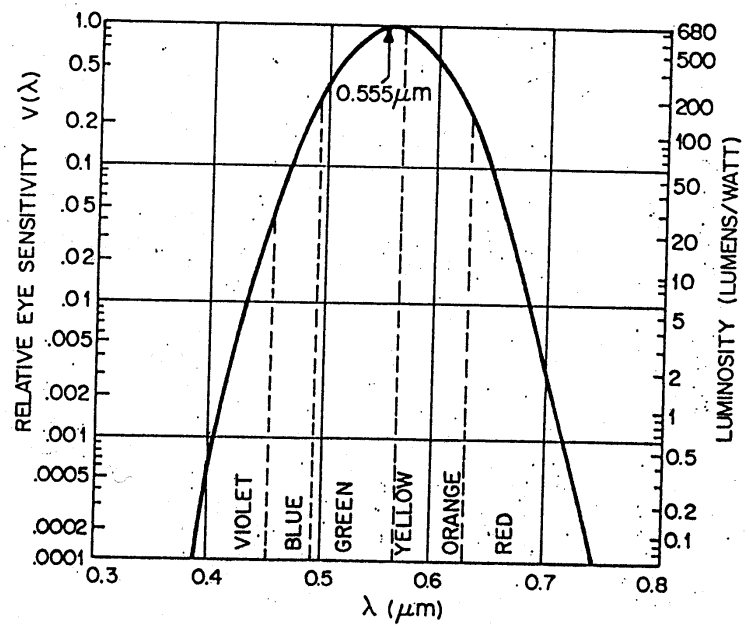


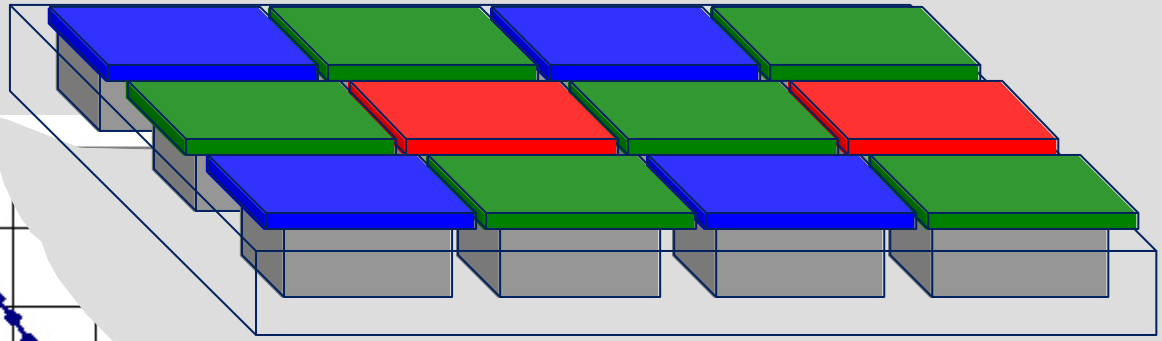
Fig. 6 Relative luminosity function as defined by the CIE for normal photopic vision. Major color bands are also indicated.

Source: „Physics of Semiconductor Devices“, S.M.Sze, Wiley 1981

Color and image sensors

Quantum Efficiency

$$\eta = \frac{n_{elektron}}{n_{photon}}$$



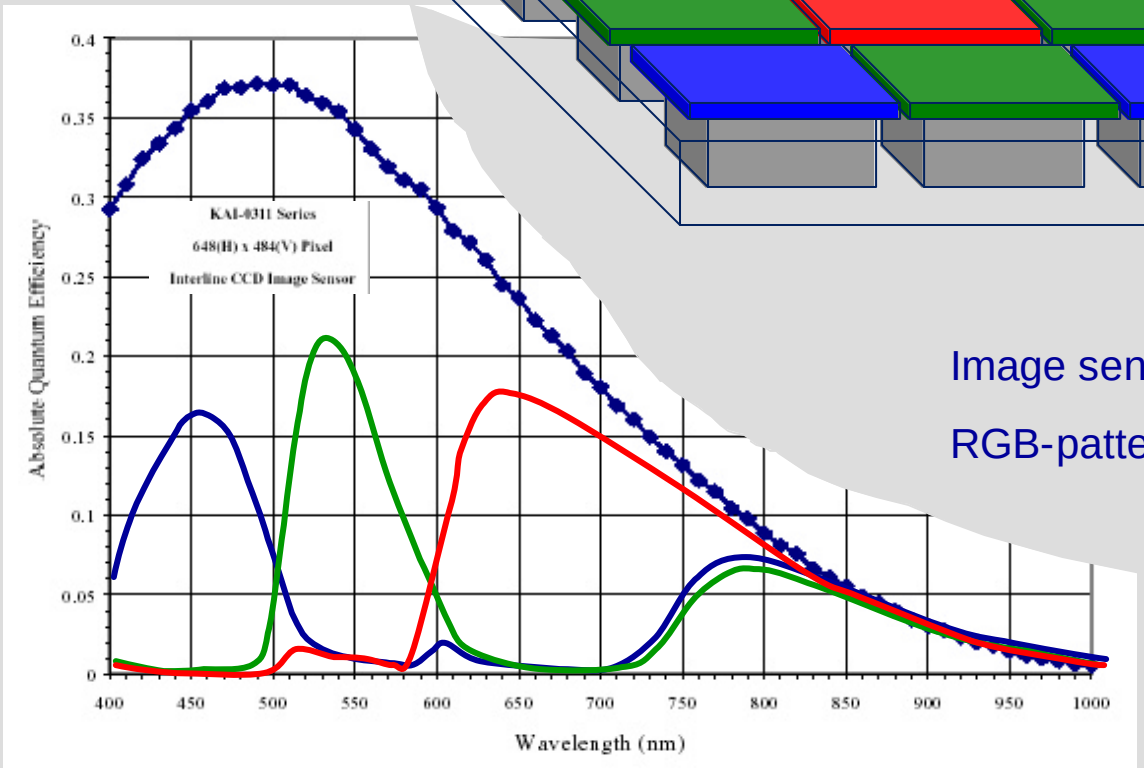
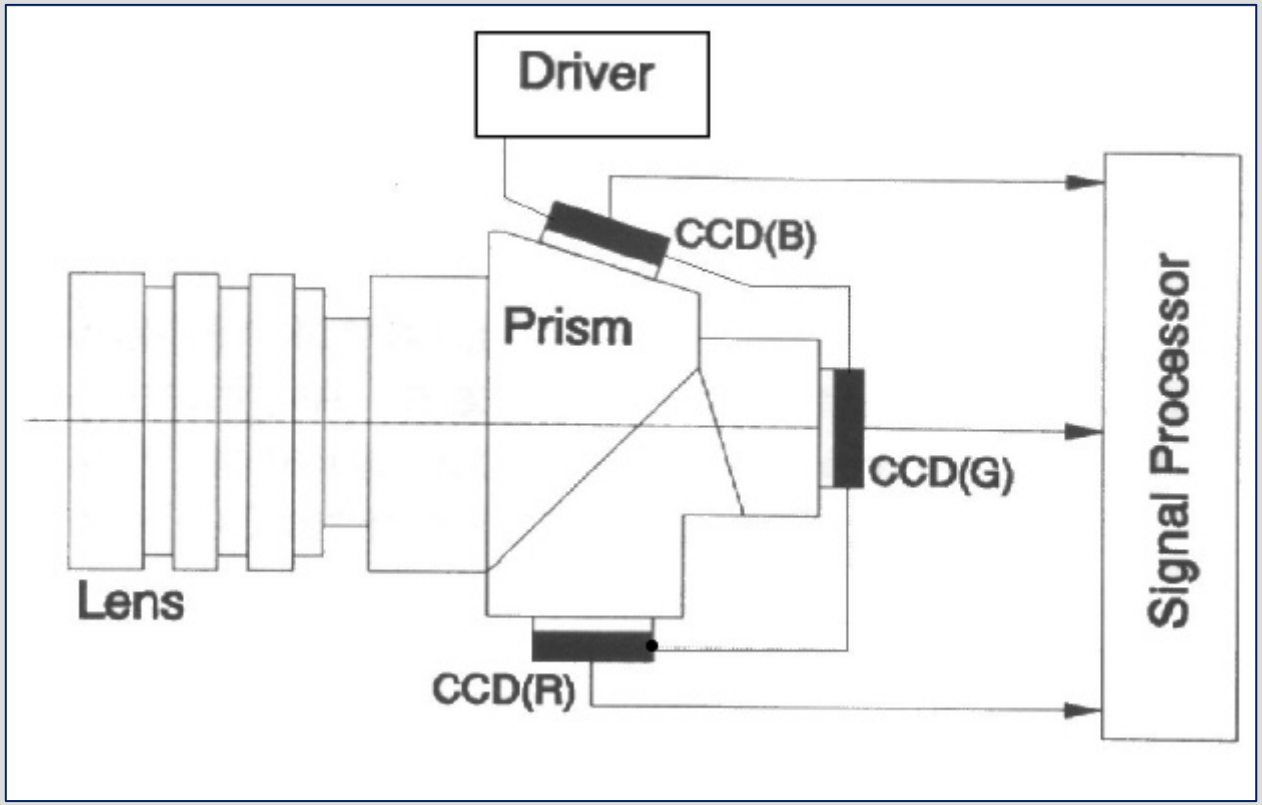


Image sensor with colour filters:

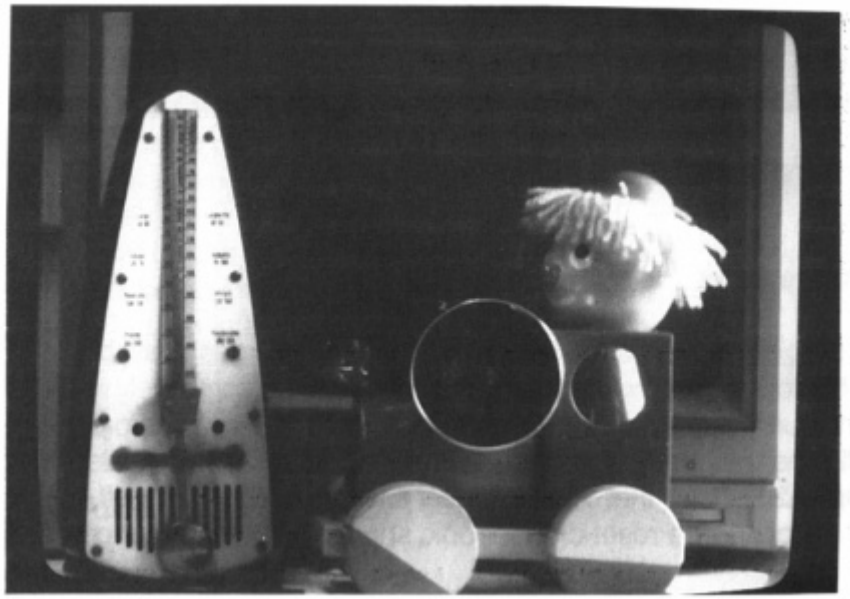
RGB-pattern („Bayer Pattern“)

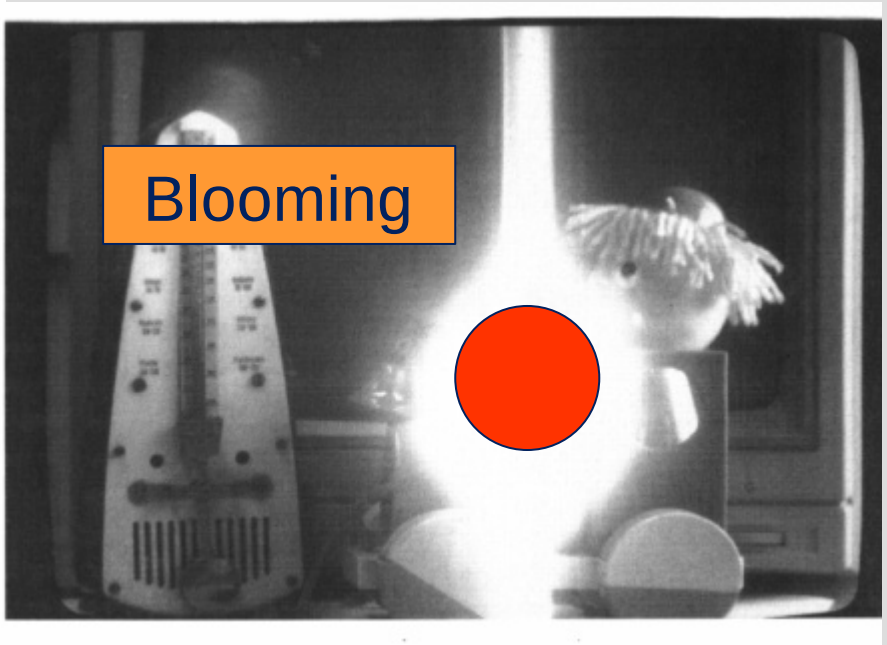
λ

3 Chip Camera



Blooming



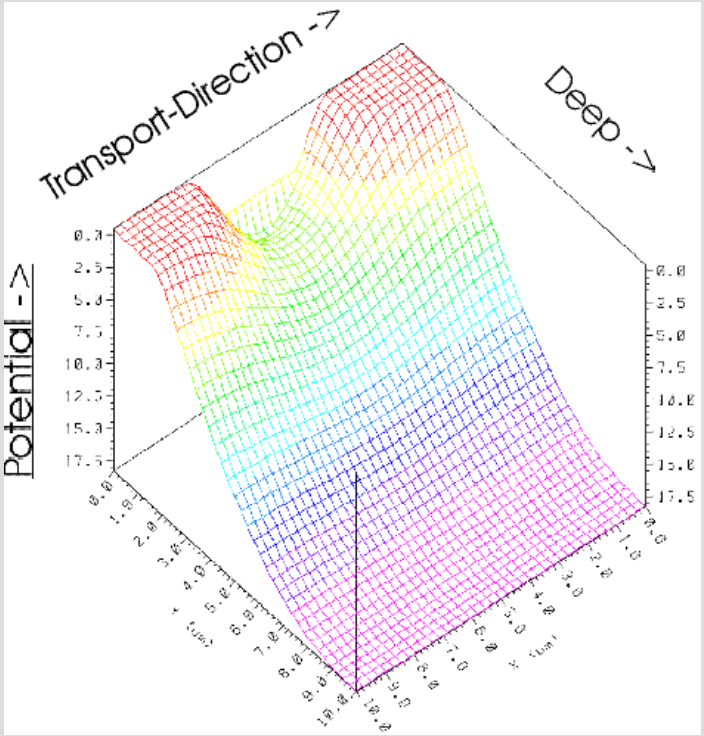


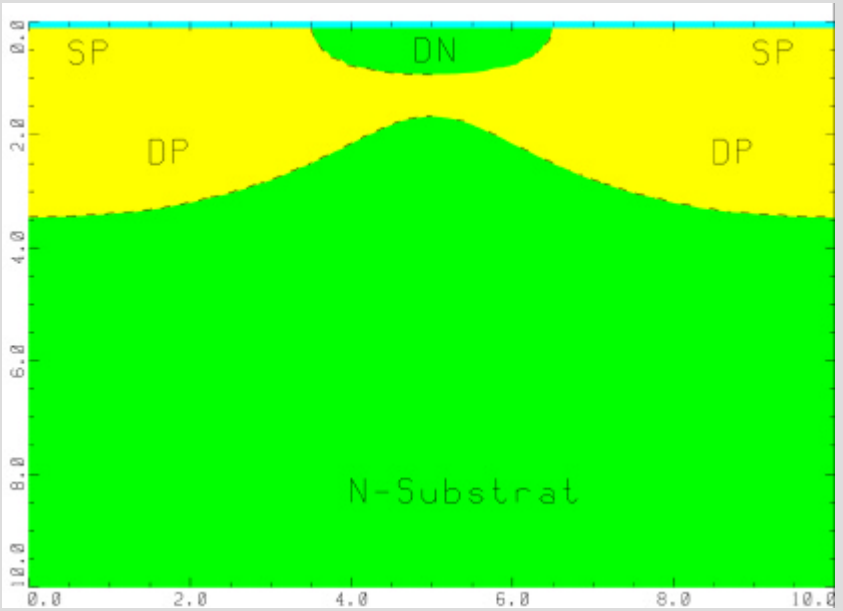
Reference Picture

Bright light spot

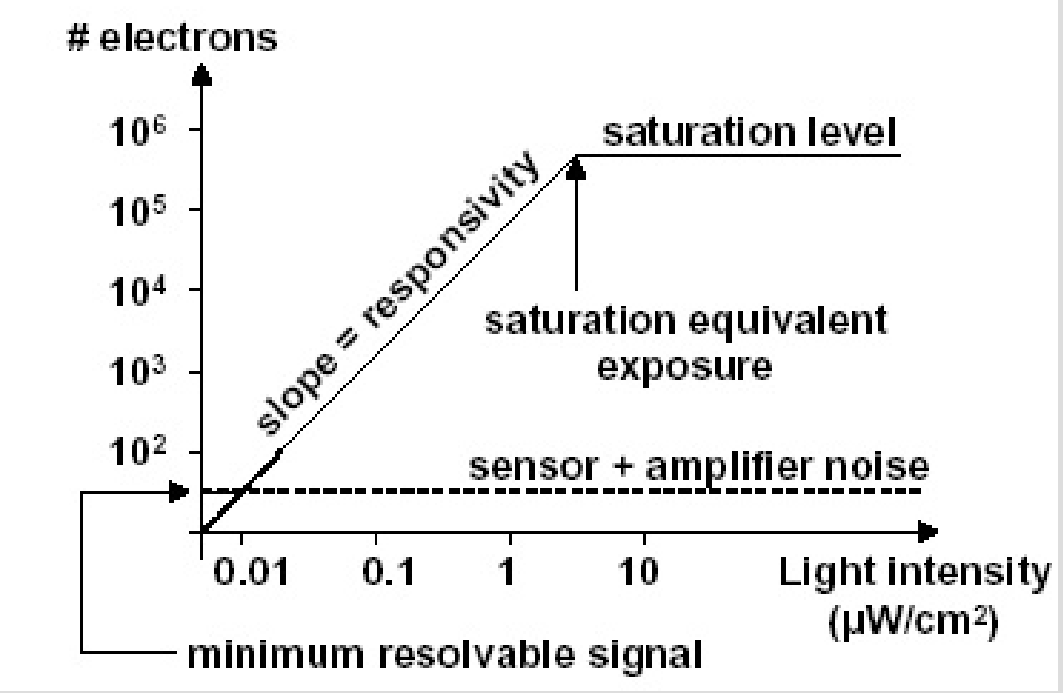
Source: „Solid-State Imaging with Charge-Coupled Devices, A.J.P. Theuwissen, Kluwer 1995

Antiblooming: Vertical antiblooming



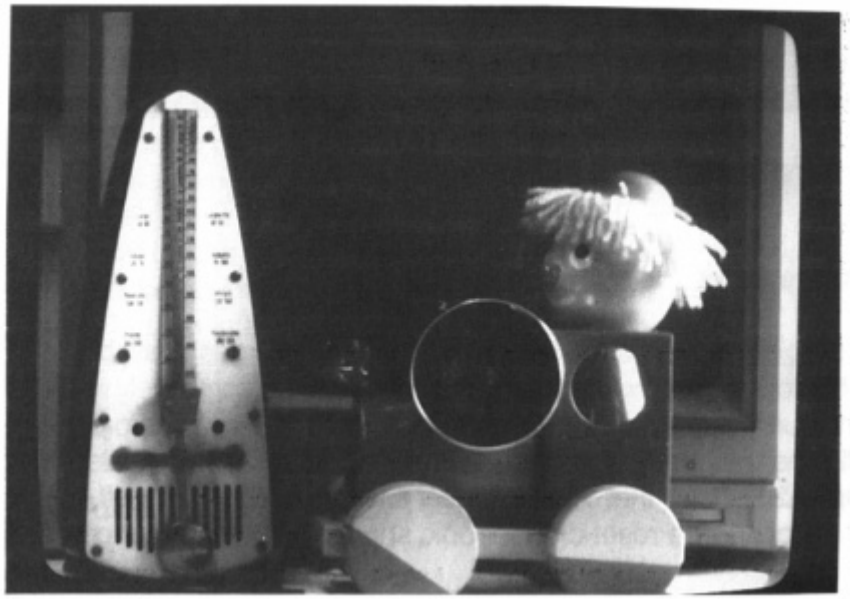


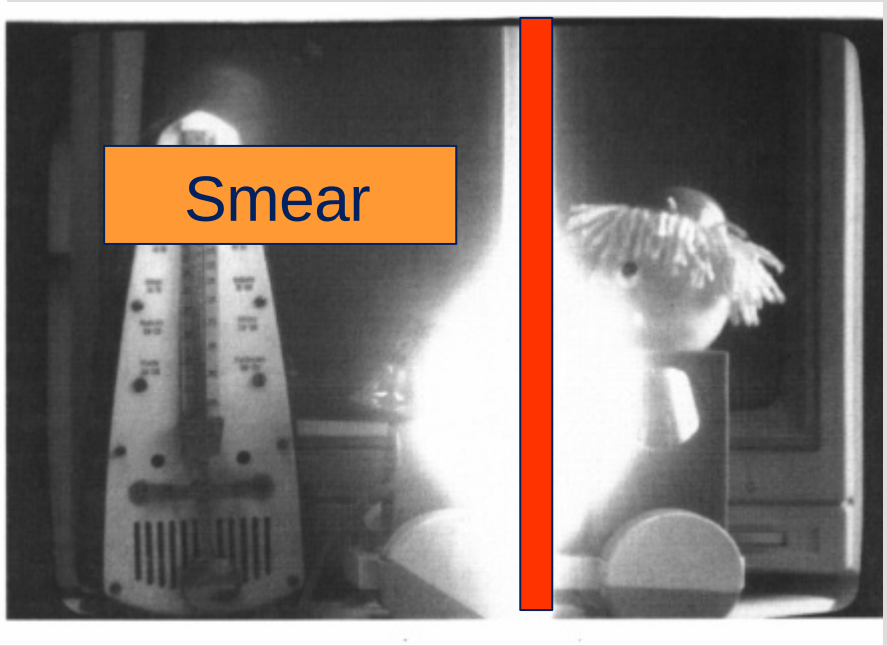
Number of electrons versus light intensity (overview)



Source: „Design and Fabrication of Integrated Image Sensors“, Course of R.I. Hornsy, University of Waterloo

Smear





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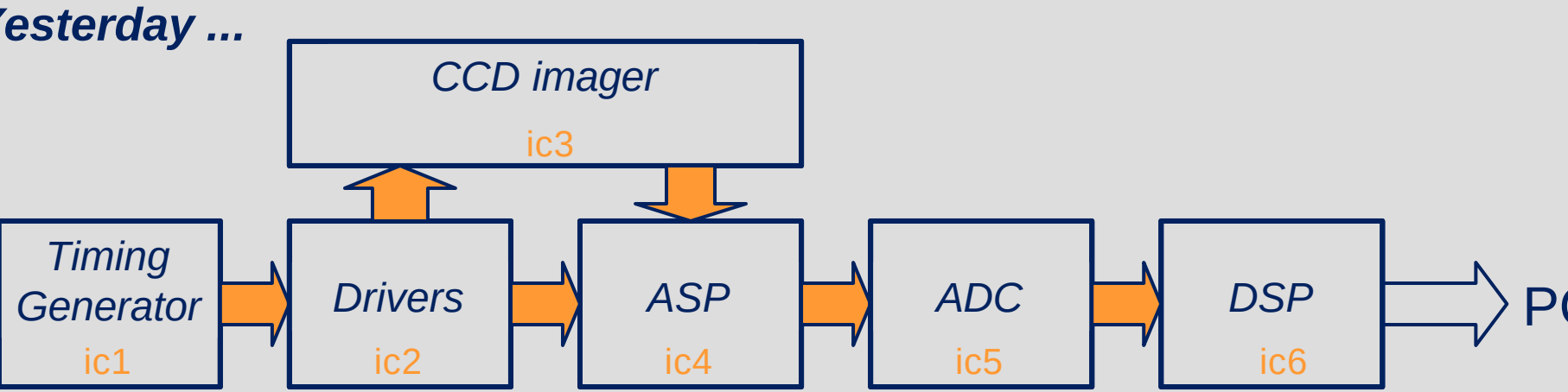
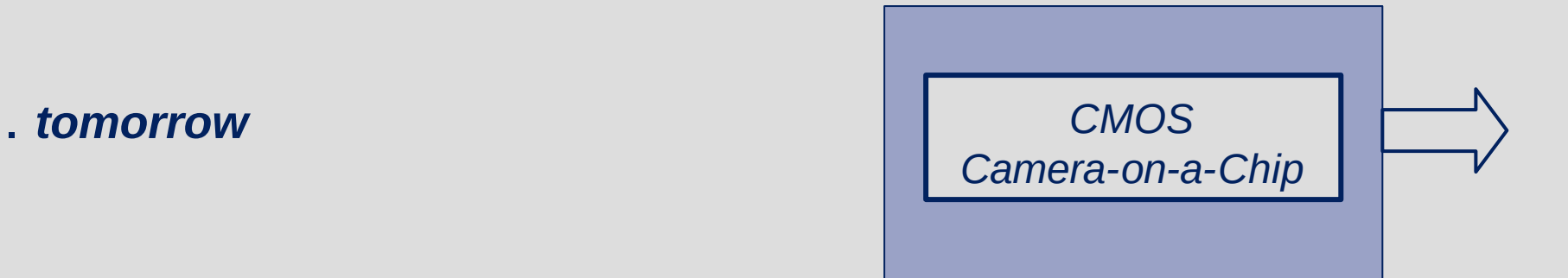
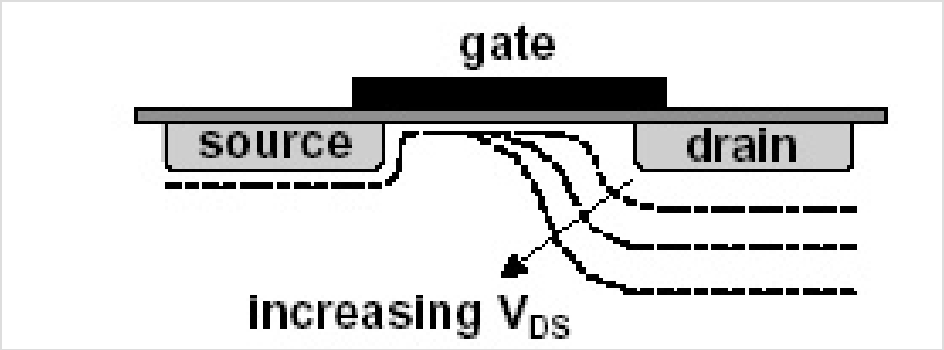
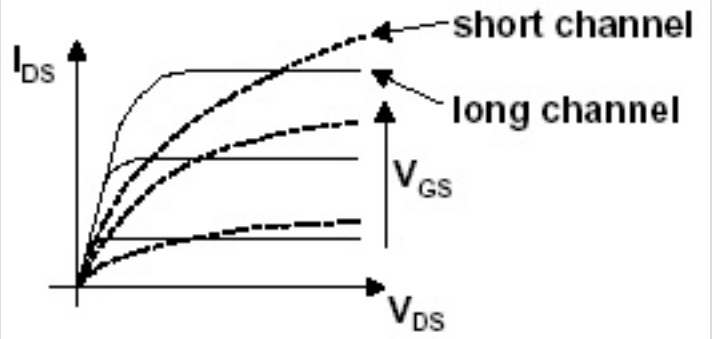
System technology

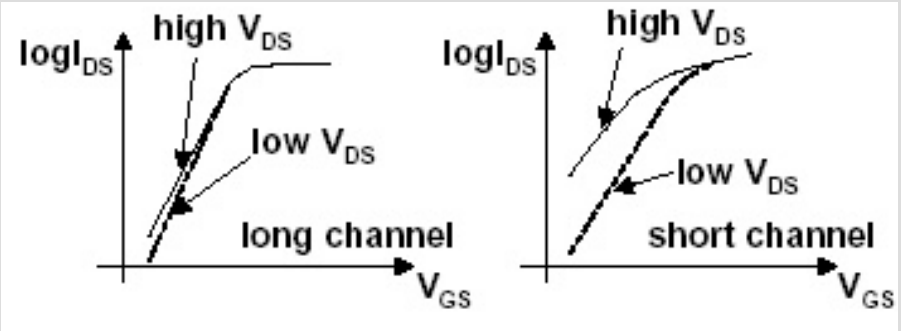




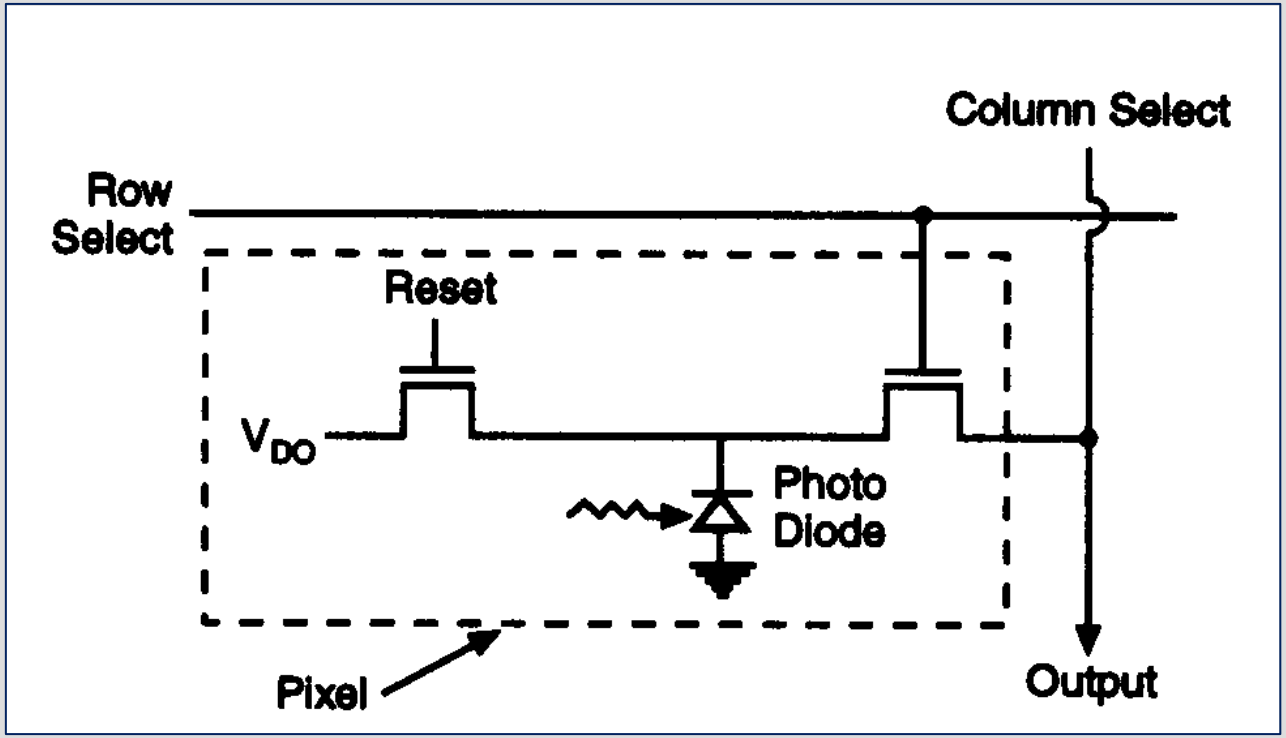
MOS characteristics



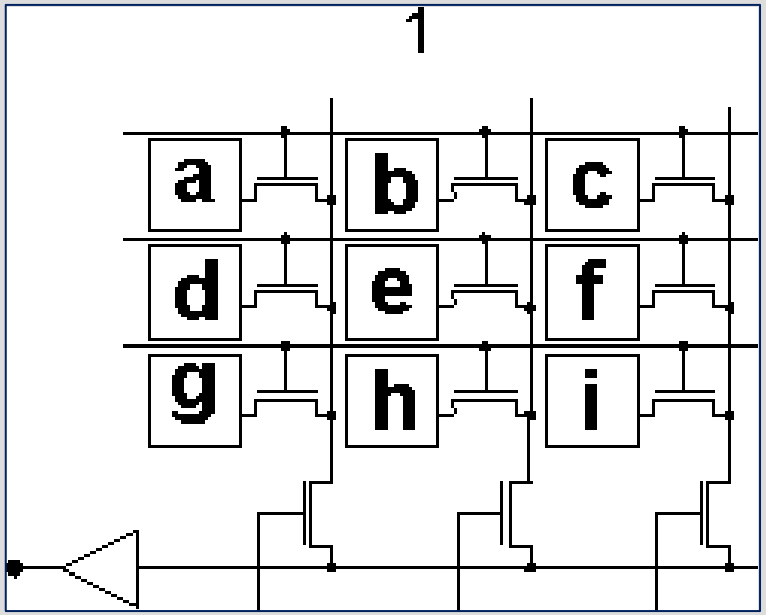




Example of a pixel structure: Passive pixel sensor (PPS)

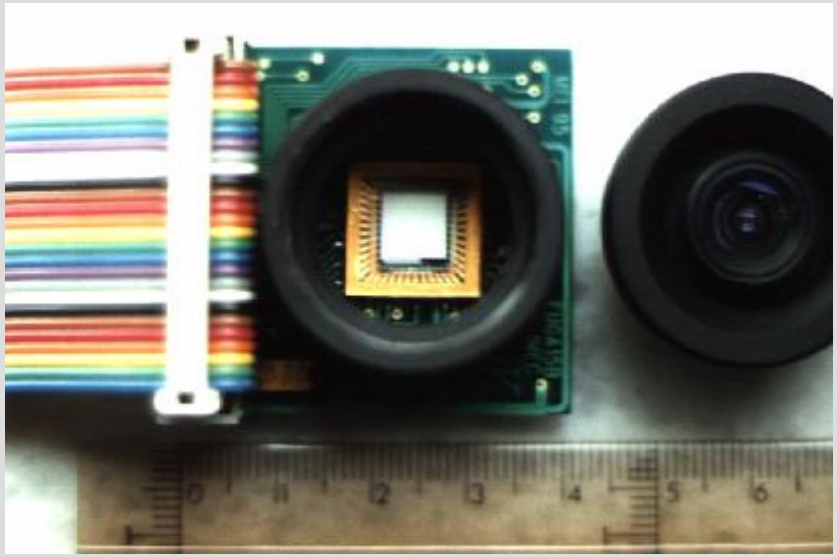


CMOS image sensors: general items



- ☺ Low Cost (2002: 😐)
- ☺ System integration
- ☹ Complexity
- ☺ Adressability
- ☺ Programmable frame rate
- ☺ Automatic gain control
- 😐 Image quality (1999: ☹)

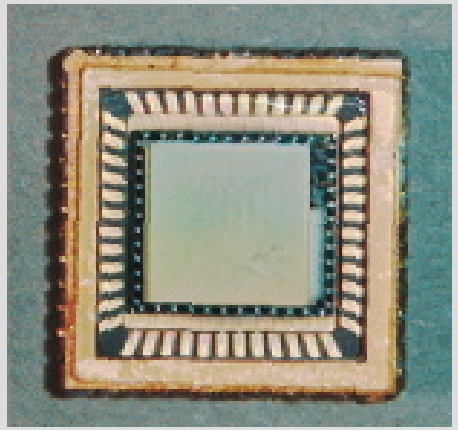
Example: CMOS imager



CMOS-camera „FUGA15“

Example: CMOS imager

FUGA-camera

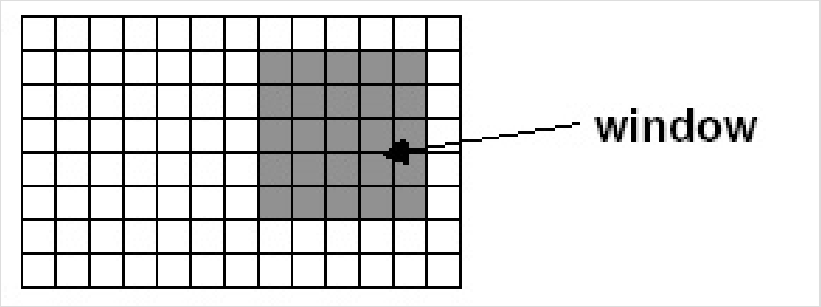


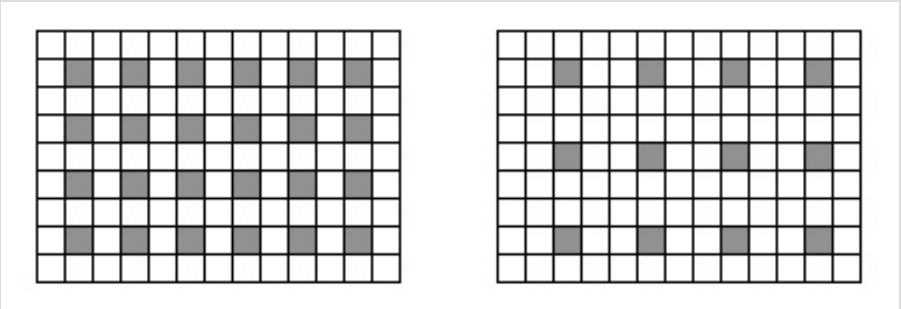
CMOS APS in 0.7µm technology
512 * 512 random addressable pixels
pixel pitch 12.5 * 12.5µm²
dye size 7.5 * 7.5 mm²
non-integrating, with logarithmic response
5 MHz pixel rate
on chip 8 bit AD converter
spectral range 400 - 1 050 nm
pixel fill factor 15%
packaging 48 pin ceramic with glass cover, plastic in option,
B/W & RGB available
5 Volt single power line

Source: IMEC/ Belgium, Internet: www.imec.be, 1998

Logarithmic response (example)

Windowing and subsampling (every n^{th} pixel)

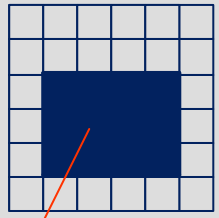


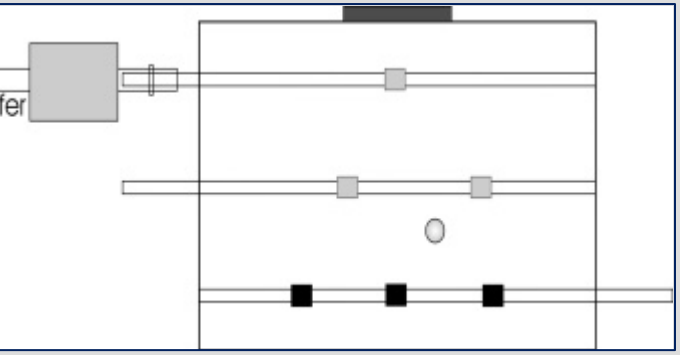


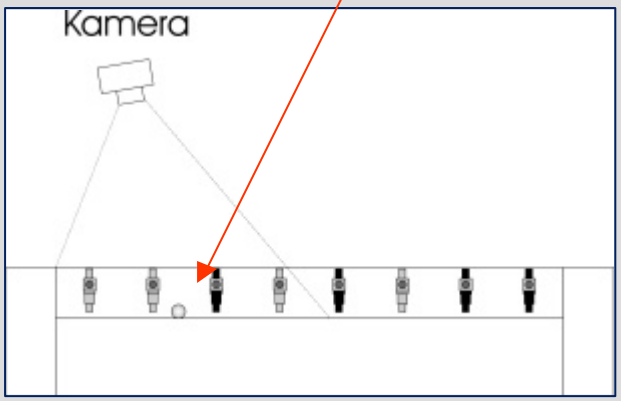
Camera-controlled goalkeeper

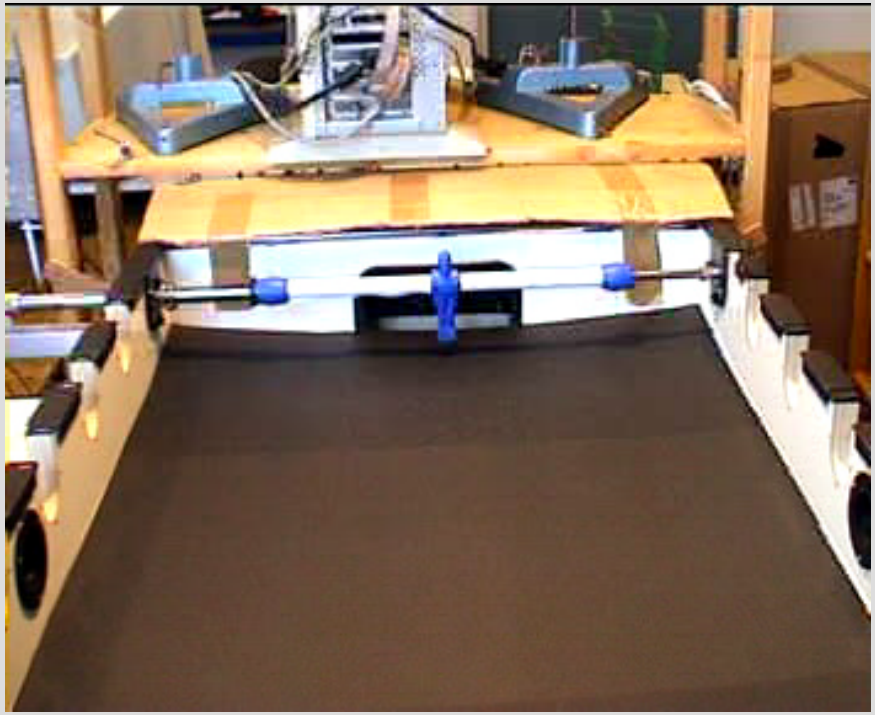
Windowing/ROI:

(Region of Interest)










Speed Master 2000