Metrology and Sensing

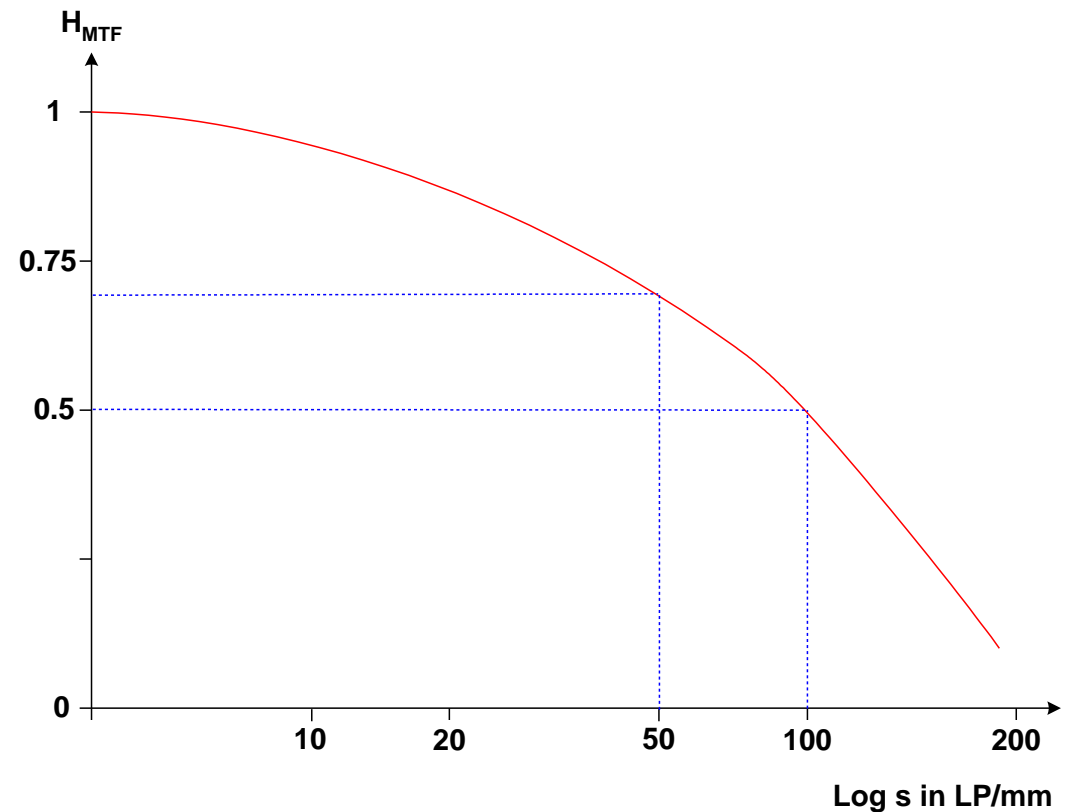Lecture 3-2: Sensors

2020-11-17

Herbert Gross

Content

- Different sensor types

- CCD

Photographic Film

- Chemical detector

- Photons change silver salt atom

- Size of grains defines spatial resolution

- MTF depends on spectrum

- Typical:
  50% contrast at 100 Lp/mm

- Contrast for limiting frequency
  1000 Lp/mm

H_{MTF}

1

0.75

0.5

0

10   20   50   100   200

Log s in LP/mm

Photo Layer

- Photolayer darkening
  Linearity in medium range of brightness

- Description of sensitivity with the optical density D

$$\gamma = \frac{\Delta D}{\Delta Log(H)}$$
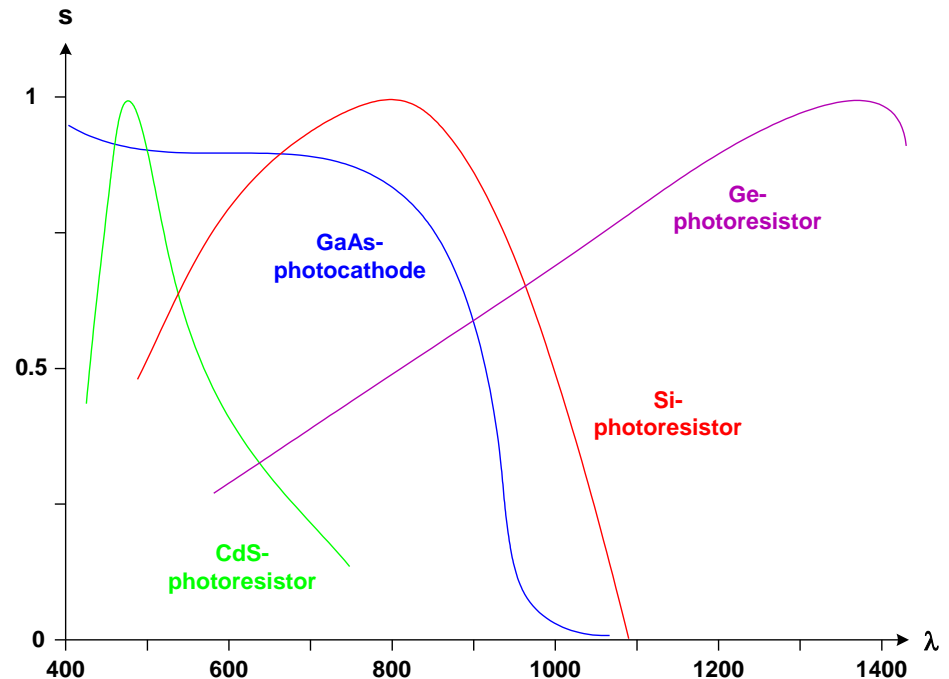
- Solarization at higher density

Photo Diode
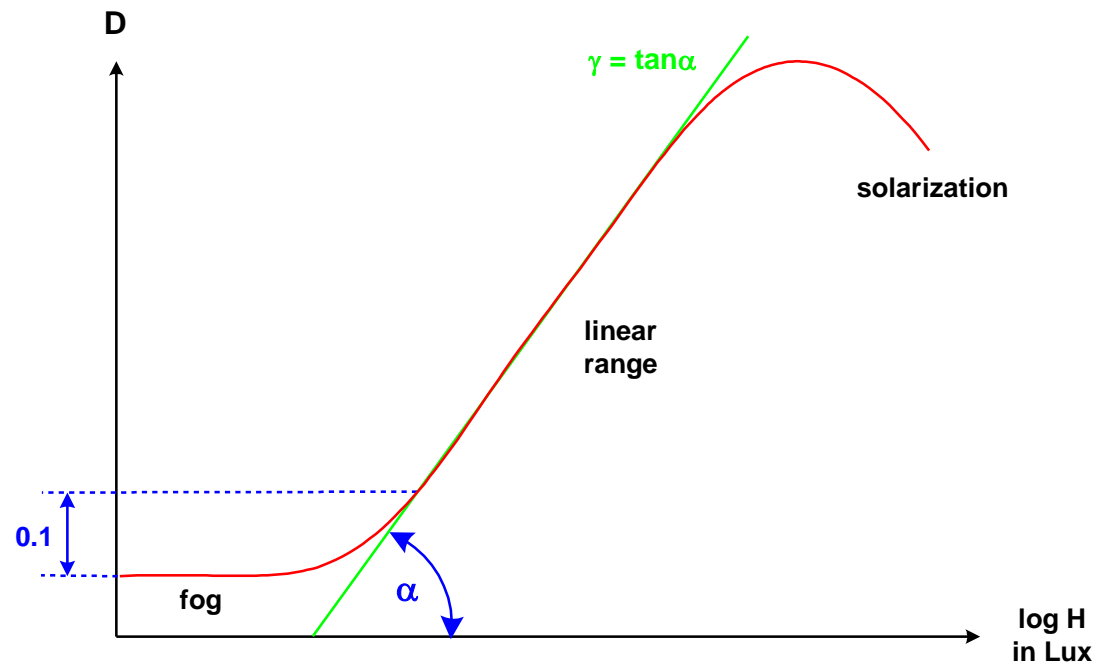
- Photoconductive sensors:
  inner and outer photo effect
  photon extracts electron out of the binding
  photo current measured

$$\Phi_{ph} = \frac{J}{e \cdot \eta(\lambda)}$$

- Important:
  - materials
  - gain
  - geometry

Semiconductor Materials

- Photon excites an electron from the valence into the conduction band

- Electrons in the conduction band move

- Density of state regulates the current dependent on temperature

- Indirect semiconductors need an additonal k-vector for momentum conservation

CCD Sensor
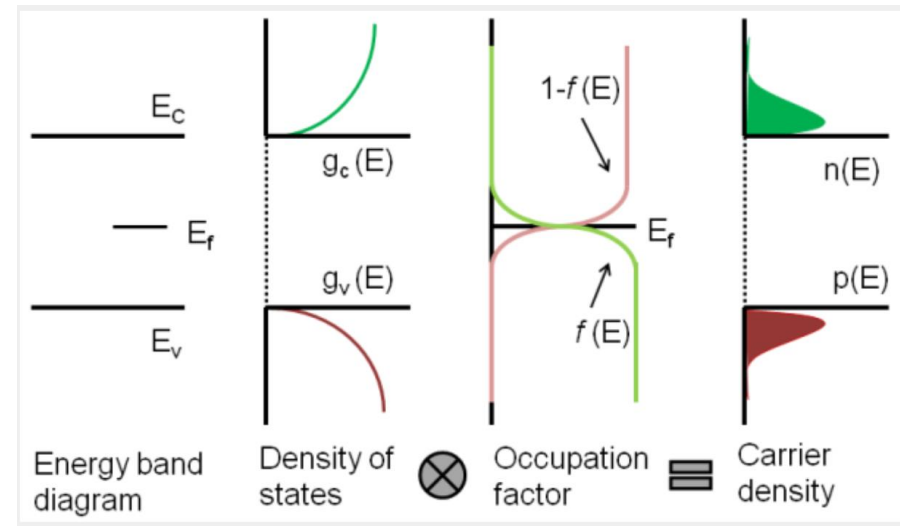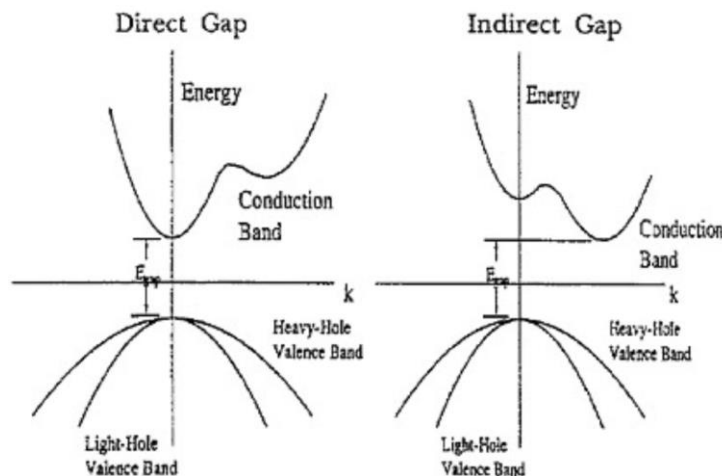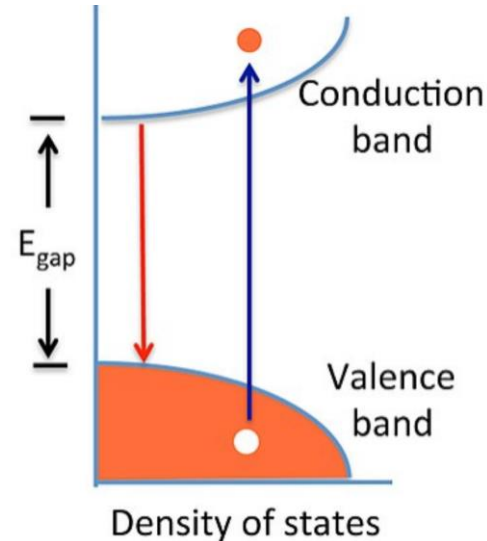
- Solid state array of sensitive pixels, silicon based

- Types:
  CCD   charge coupled device (semiconductor)
  CMOS   complementary metal oxide semiconductor (on chip processing,
                  higher dark current)
  CID   charge injection device (overlapping pixels)

- Typical size:
  pixel length 1.2 - 20 μm

CCD Sensors
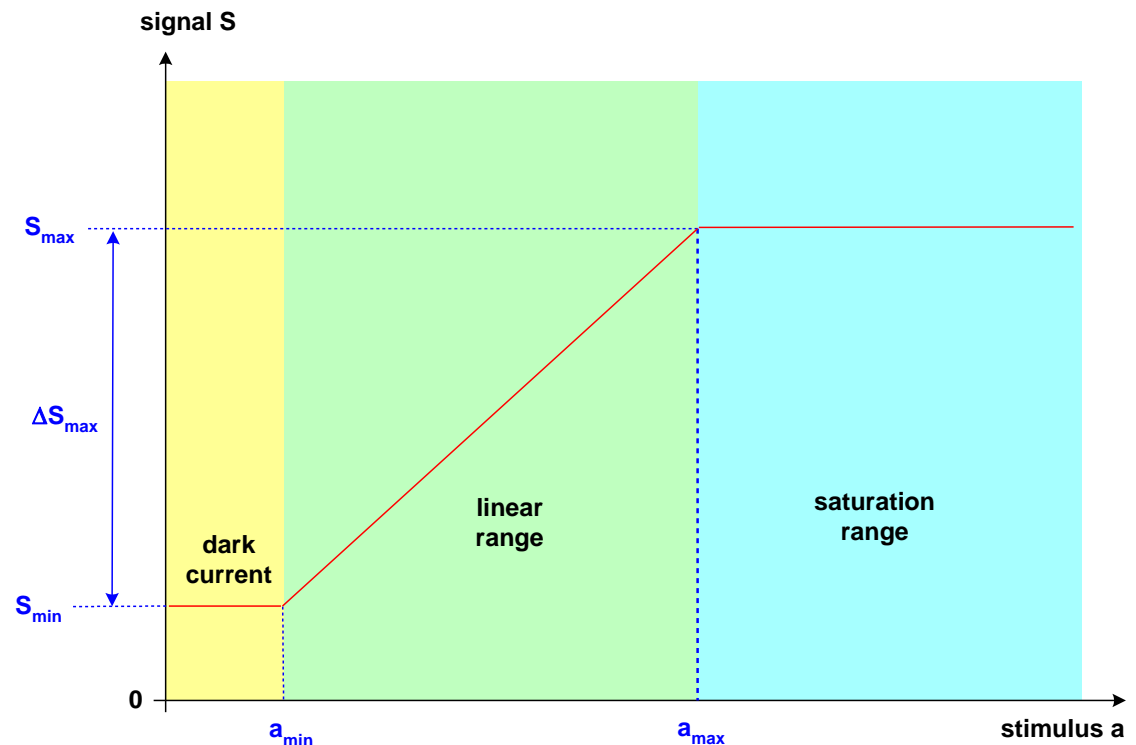
- Spectral properties:
  sensitive in VIS and NIR

- Degrading effects:
  1. diffusion of electrons, blooming
  2. dead zones, reduced efficiency
  3. noise of reading process
  4. dark current
  5. quantum efficiency, 80%
  6. time delay, hysteresis
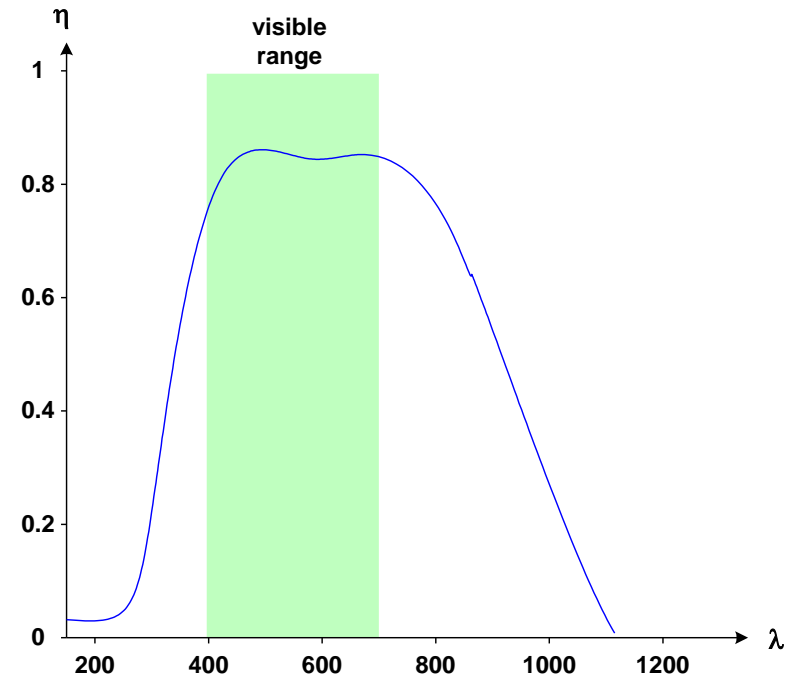
Spectral Sensitivity of a CCD Sensor
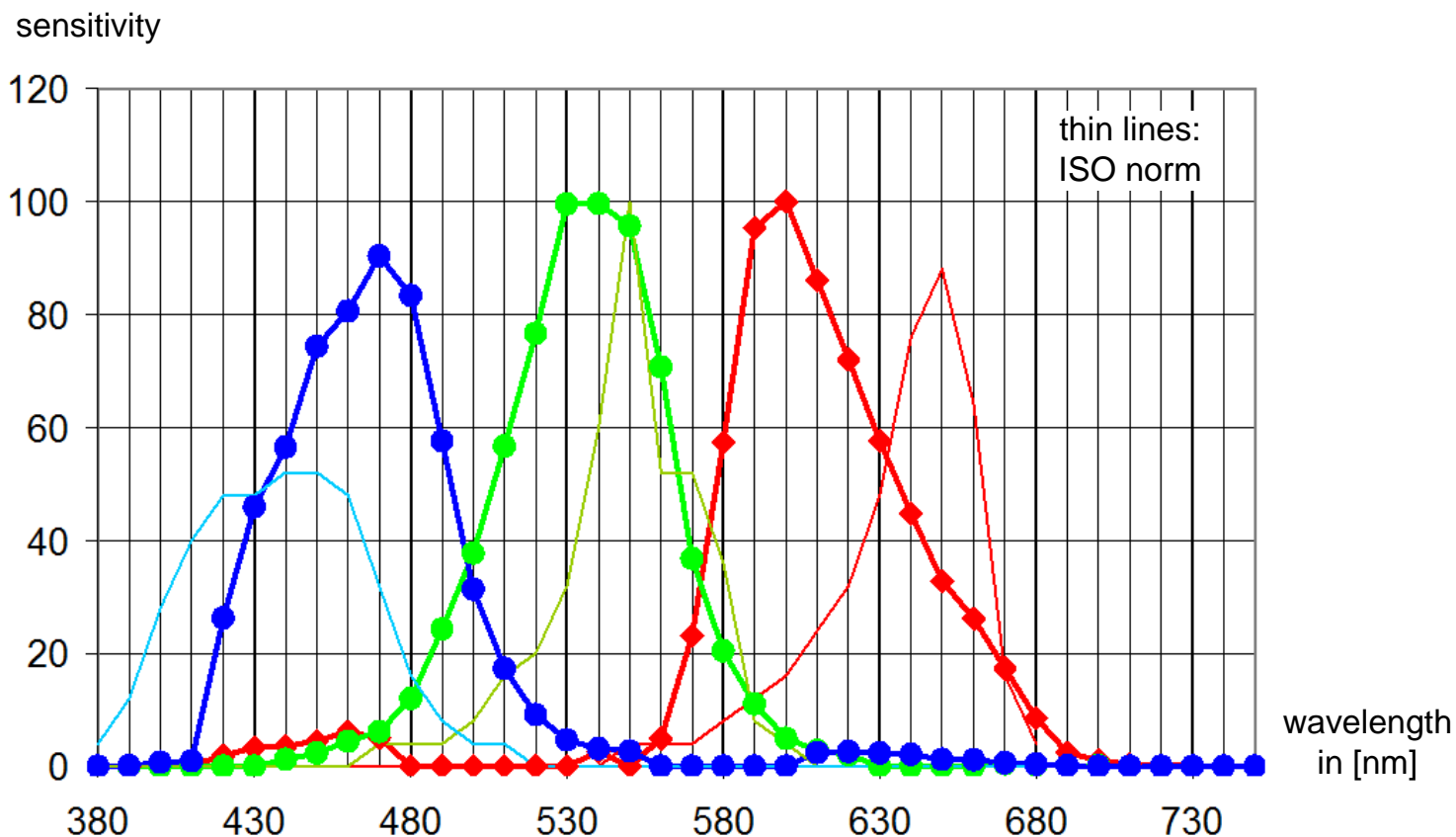
- Typical sensor of a SLR photo camera:
  Canon 5D
- RGB sensitivity curves at daylight

Ref: D. Gängler

Color Sensor

Bayer mask of color sensor

Possible algorithms in signal processing:

G1	R2	G3	R4	G5
B6	G7	B8	G9	B10
G11	R12	G13	R14	G15
B16	G17	B18	G19	B20
G21	R22	G23	R24	G25

Non-adaptive	Adaptive
Nearest neighbor replication	Edge scaling interpolation
Bilinear interpolation	Interpolation with color correction
Cubic convolution	Variable number gradient method
Smooth hue transition	Pattern recognition
Smooth logarithmic hue transition	Pattern matching interpolation

Ref: E. Derndinger

Detection of Color

- Wavelength sensitive detection with CCD:
  - array structures with different spectral sensitivity
  - reduced spatial resolution

- Alternatives:
  - depth resolved layers
  - time multiplexing
  - spatial separation by filter

Bayer Color Filter Array

R	G	R	G	R	G
G	B	G	B	G	B
R	G	R	G	R	G
G	B	G	B	G	B

Sony Color Filter Array

G	R	G	R	G	R
G	B	G	B	G	B
G	R	G	R	G	R
G	B	G	B	G	B

Hitachi Color Filter Array

C	W	C	W	C	W
G	G	G	G	G	G
C	W	C	W	C	W
G	G	G	G	G	G

Sensor Formats

Digital sensor formats

Type	Aspect Ratio	Sensor (mm) Dia. tube (mm)	Diagonal	Width	Height
1/3.6"	4:3	7.056	5.000	4.000	3.000
1/3.2"	4:3	7.938	5.680	4.536	3.416
1/3"	4:3	8.467	6.000	4.800	3.600
1/2.7"	4:3	9.407	6.721	5.371	4.035
1/2.5"	4:3	10.160	7.182	5.760	4.290
1/2.3"	4:3	11.044	7.70	6.16	4.62
1/2"	4:3	12.700	8.000	6.400	4.800
1/1.8"	4:3	14.111	8.933	7.176	5.319
1/1.7"	4:3	14.941	9.500	7.600	5.700
2/3"	4:3	16.933	11.000	8.800	6.600
1"	4:3	25.400	16.000	12.800	9.600
4/3"	4:3	33.867	22.500	18.000	13.500
Cine 35mm	4:3		31.15	24.9	18.7
1.8" APS-C	3:2	45.720	28.400	23.700	15.700
35 mm film	3:2	n/a	43.300	36.000	24.000

Ref: D. Gängler

CCD Sensor

- Architecture:
  3 different types of carrier transport
  1. full frame
  2. interline
  3. frame transfer

full frame

interline transfer

frame transfer

1. shift to the right by one column

1. shift row-wise downwards

1. shift row-wise downwards

2. shift read out columns downwards

2. shift row-wise downwards

2. read out serially pixel by pixel

3. read out serially pixel by pixel

3. read out serially pixel by pixel

not optically active

CCD-Sensors
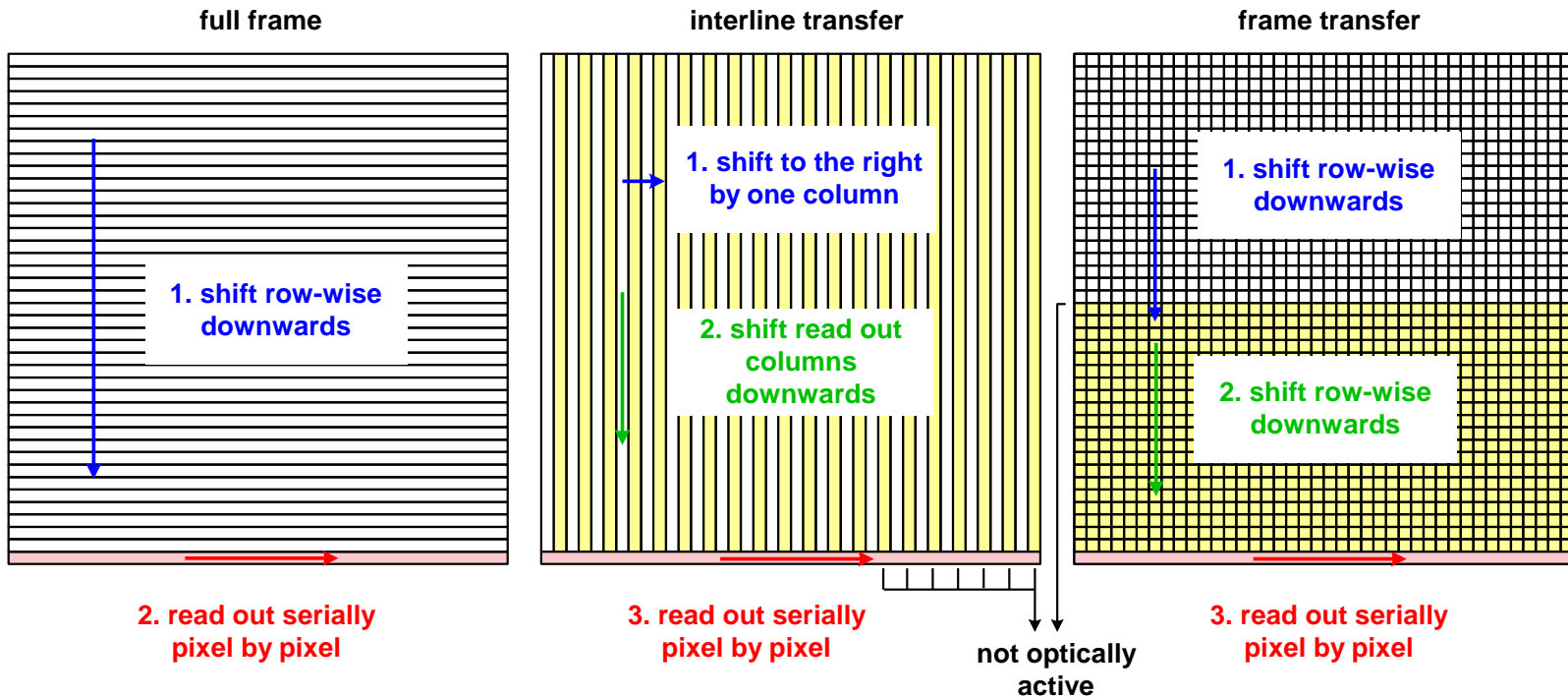
- Typical dimensions

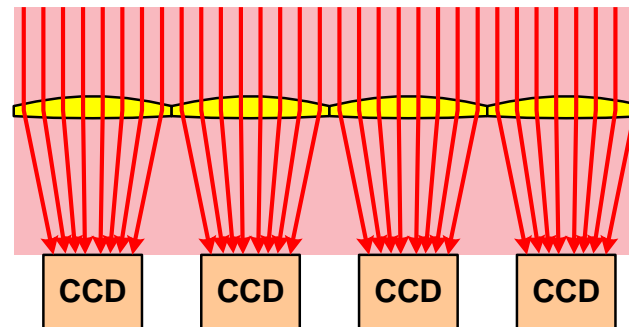| Size [mm]		Diagonal [mm]	Pixel size [μm]		Pixel number	
12.8	9.6	16	16.7	20	768	480
8.8	6.6	11	11.4	13.8	768	480
6.4	4.8	8	8.33	10	768	480
4.8	3.6	6	6.25	7.5	768	480
3.2	2.4	4	4.17	5	768	480

- Optical effect of arrays:
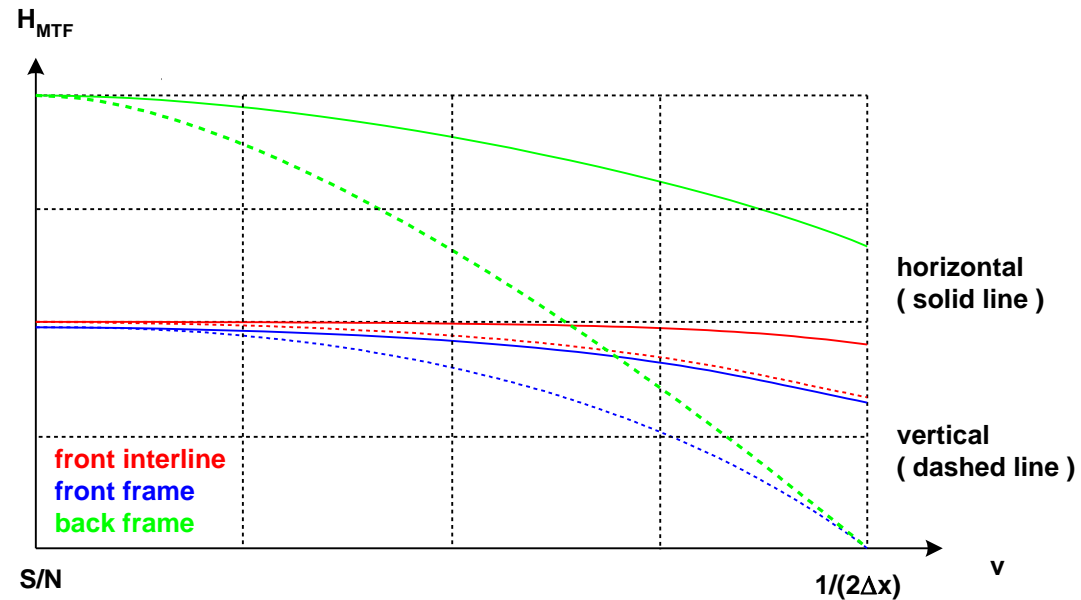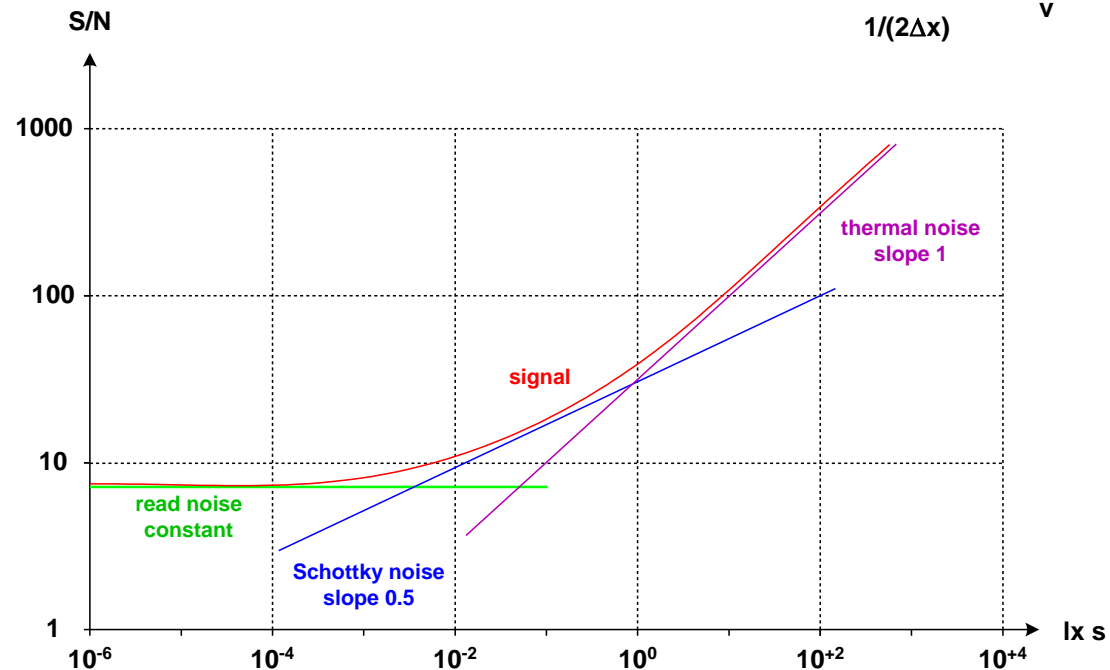 dead zone and change of acceptance angle
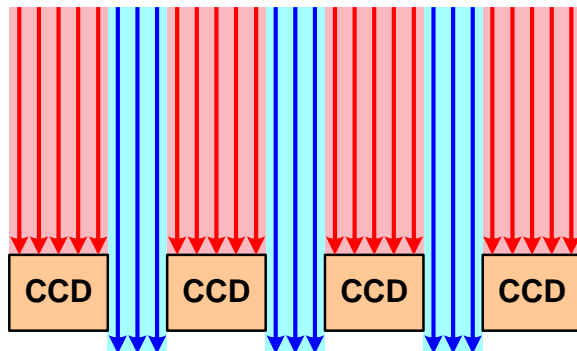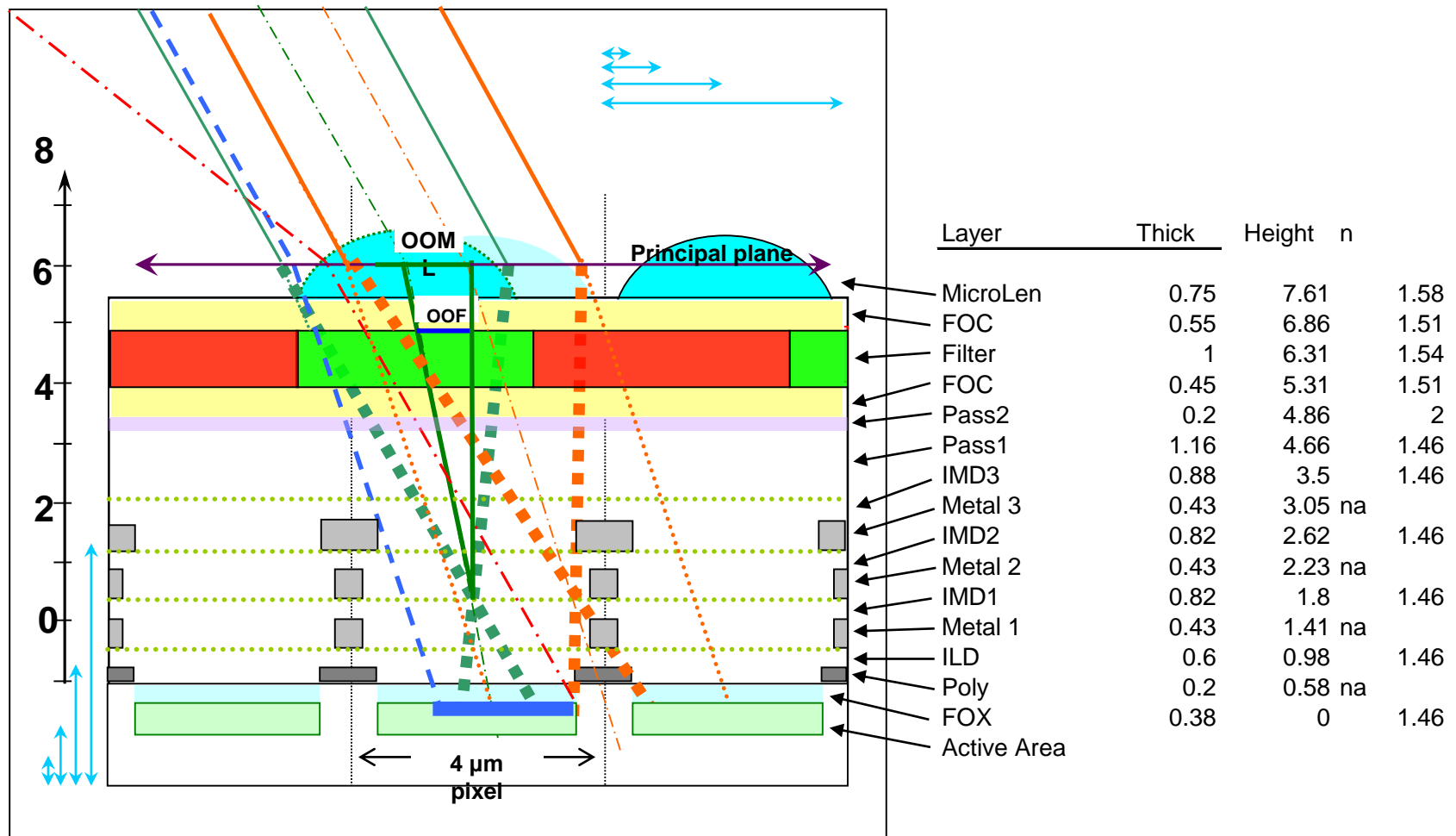

active detector areas

active detector areas

CCD-Sensors

- Spatial transfer function:
depends on shape and direction
of illumination

- Noise behavior

CMOS Sensor Element

Setup of internal elements

Layer	Thick	Height	n
MicroLen	0.75	7.61	1.58
FOC	0.55	6.86	1.51
Filter	1	6.31	1.54
FOC	0.45	5.31	1.51
Pass2	0.2	4.86	2
Pass1	1.16	4.66	1.46
IMD3	0.88	3.5	1.46
Metal 3	0.43	3.05	na
IMD2	0.82	2.62	1.46
Metal 2	0.43	2.23	na
IMD1	0.82	1.8	1.46
Metal 1	0.43	1.41	na
ILD	0.6	0.98	1.46
Poly	0.2	0.58	na
FOX	0.38	0	1.46
Active Area			

Ref: D. Gängler

Detector

Layout of a modern CCD camera