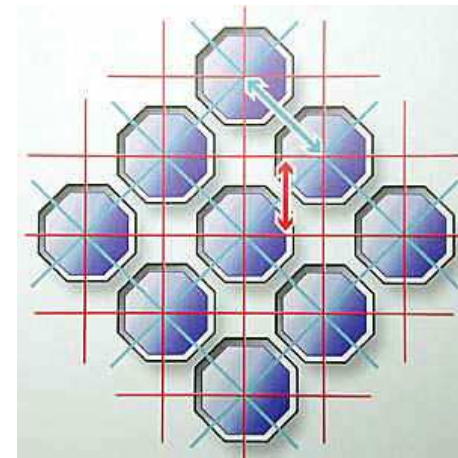
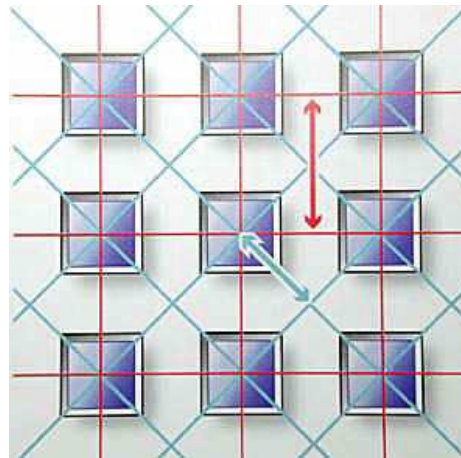
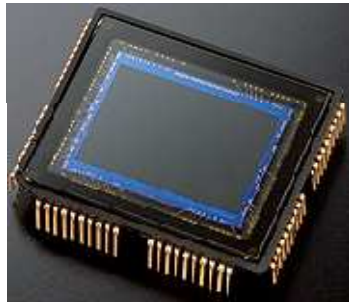


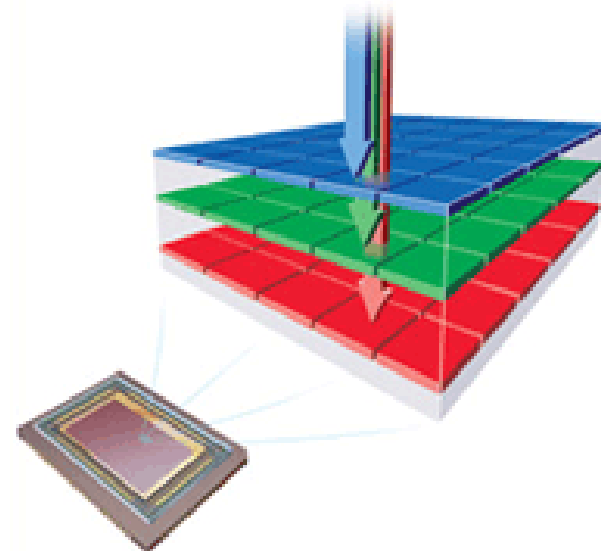
Camera Sensors

- A digital image is made up of tiny elements called *pixels*
- Photosites on the sensor capture the *brightness* of a single pixel
- The typical layout is a rectangular grid



Technologies

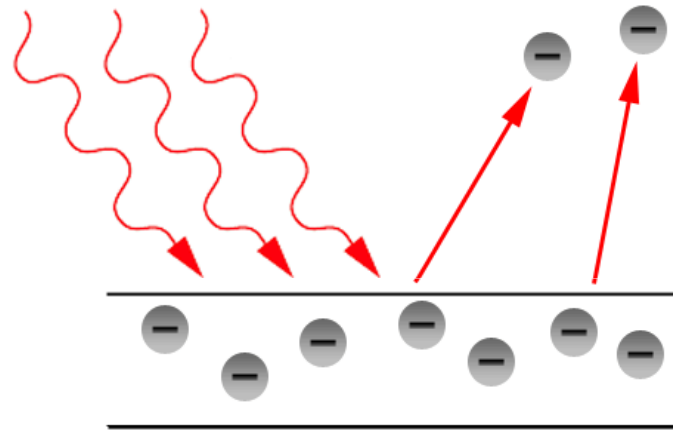
- CCD consists in photosensitive cells able to store charge produced by the light-to-electron conversion; in addition, the charge can be transferred to an interconnected, adjacent cell. In this case charges are shifted out of the sensor (bigger sensors, better quality, but additional circuitry)
- CMOS, transistors within the photosite perform charge-to-voltage conversion and allow the pixels to be read individually (higher integration, less power consumption, but less sensitive, higher noise)
- In both CMOS and CCD all photosites are sensitive to visible light, detect only brightness, not color
- Foveon: three layers of CMOS



CCD technology

- Analog shift register that enables charge to be transported through stages (capacitors) under the control of a clock signal
- BTW: and in fact was invented for totally different reasons (memory, delay lines)
- CCD refers to how the read out is performed
- Photons are converted into electrons by a special monocrystalline layer of silicon – photoelectric effect
- The photoactive region can be seen as an array of capacitors

Photoelectric effect



- The effect on the semiconductor is to kick electrons from the valence to the conducting band (still inside the material)

Types of CCD

- Three architectures
 - Full frame: requires mechanical shutter, no further electronic circuitry
 - Frame transfer
 - Interline transfer
- Different approaches to the problem of shuttering
- Negative effect: smearing

CCD, Frame Transfer

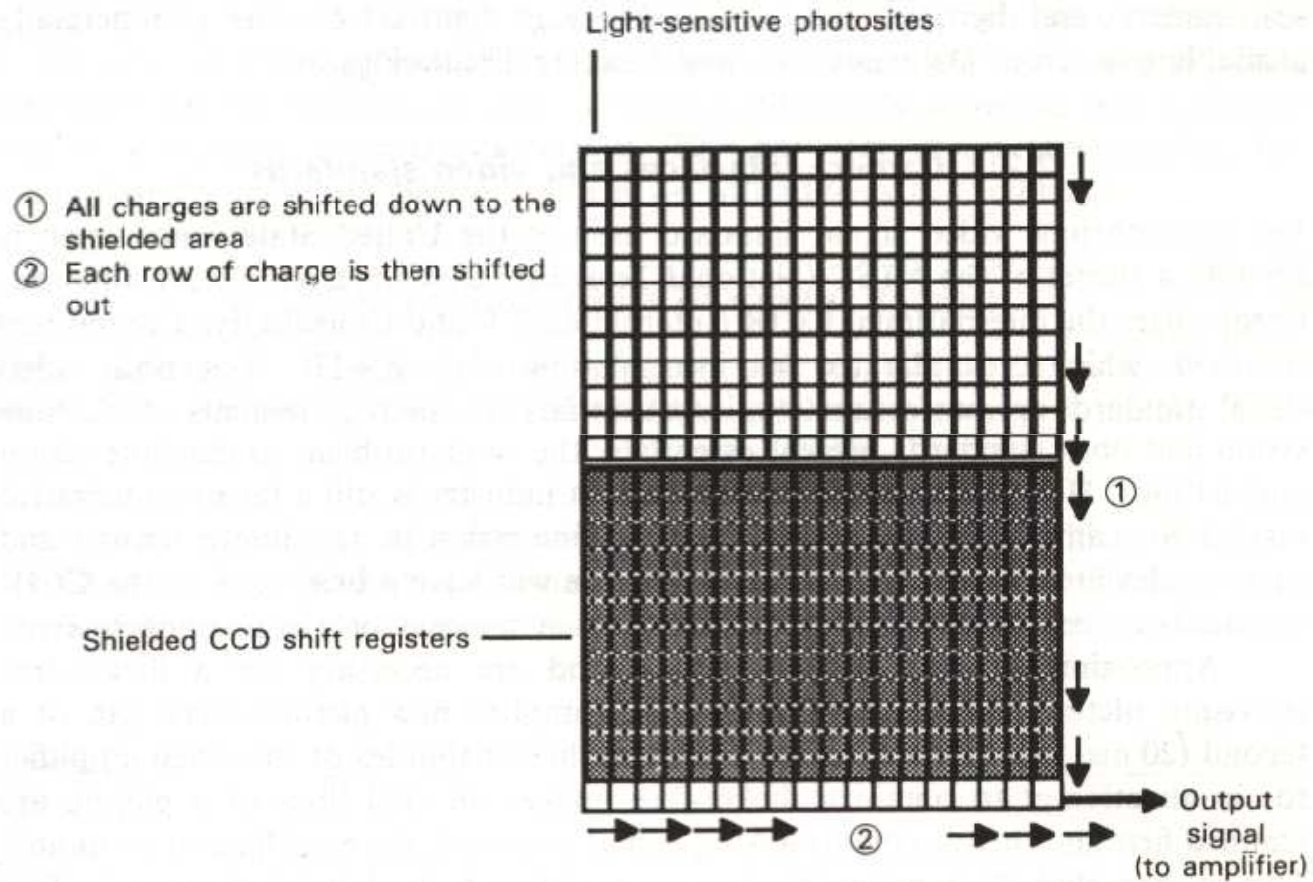
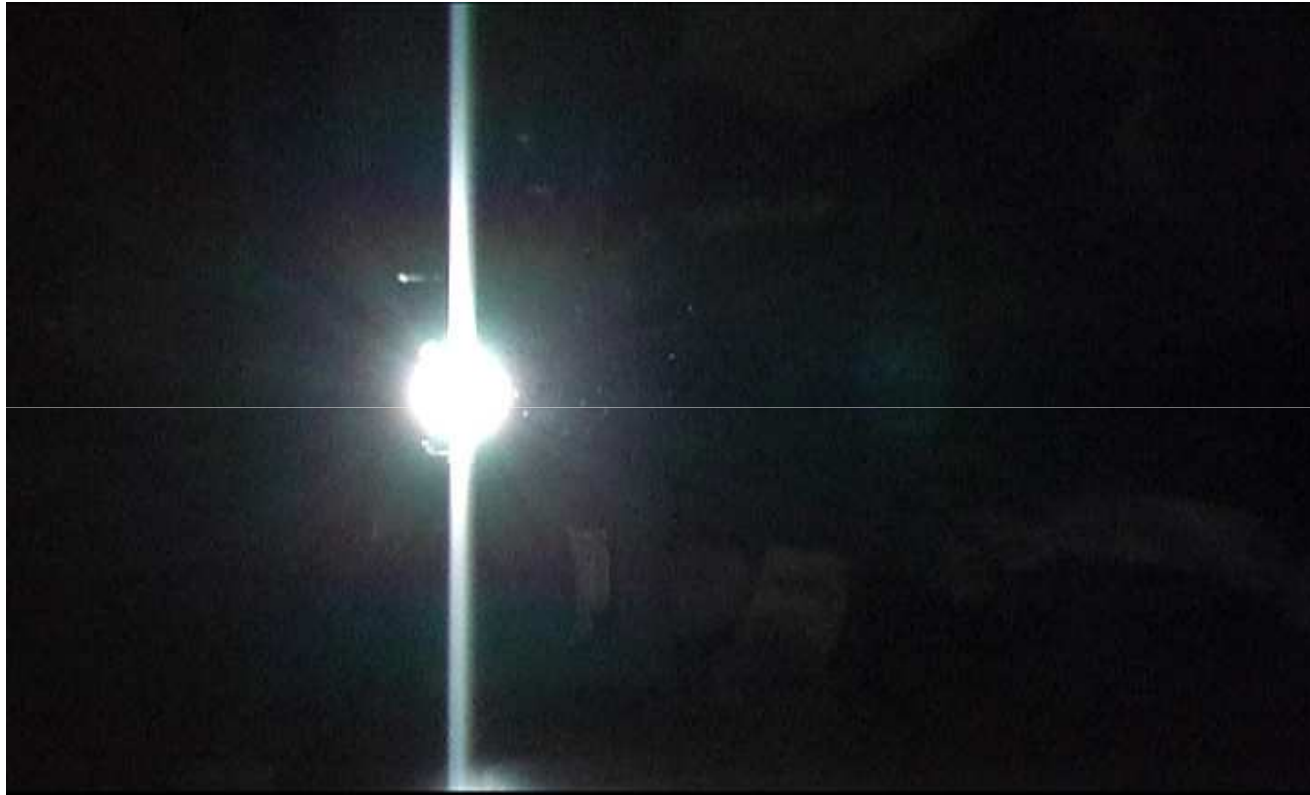


Figure 2.3 Frame transfer of charge in CCD sensors.

Example: vertical smearing



CCD, Interline Transfer

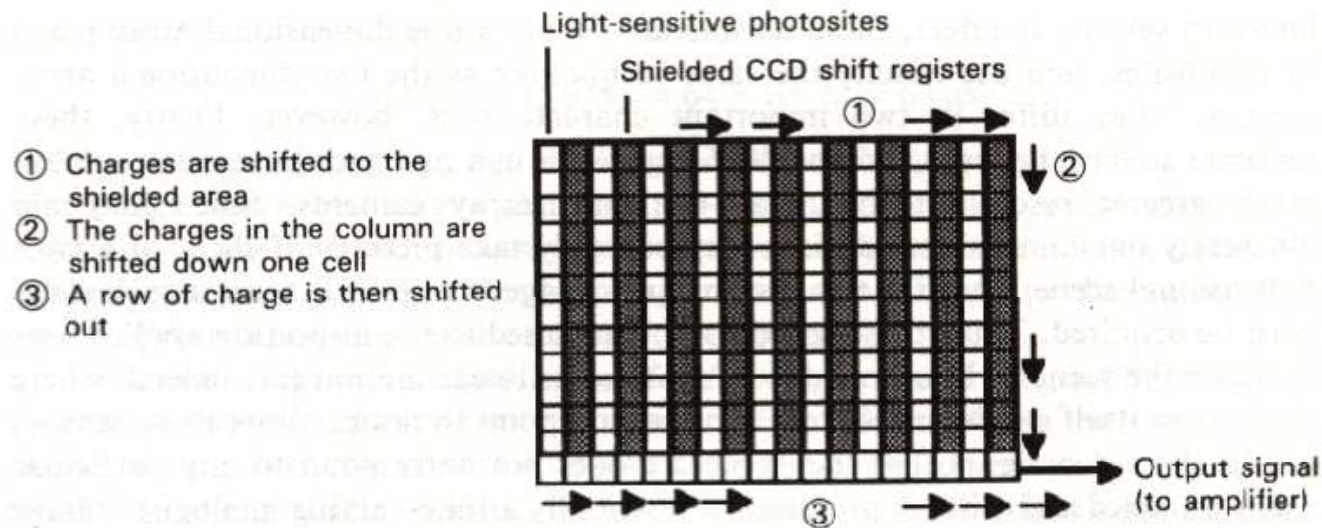


Figure 2.2 Interline transfer of charge in CCD sensors.

faster, 1 pixel transfer, $< 1\mu\text{s}$

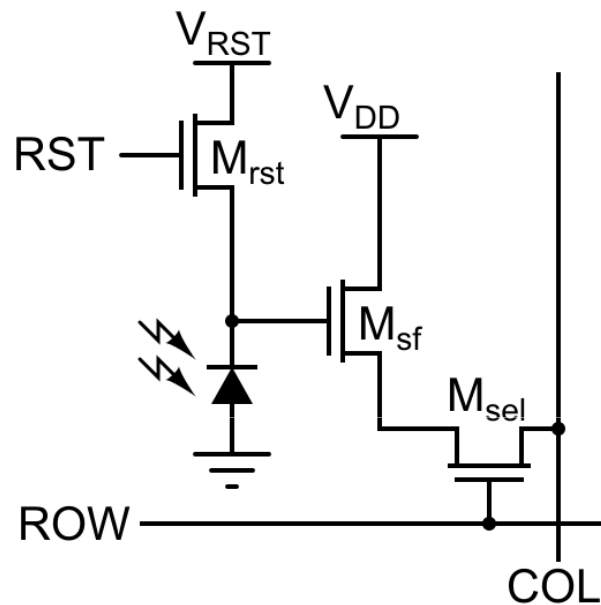
fill factor 50%

modern design: use microlenses to increase fill factor up to 90%

Common parameters

- Quantum efficiency 70% -> film only 2% (of course it depends on the film sensitivity, ISO): photons to electrons ratio (depends further on the channel/color)
- Fill factor: up to 90-100% depending on the arrangement (full frame preferred for example in astronomy, minimum smear)
- Smear: < few percentage points
- Dark current (no light): thermal, should be small

CMOS technology



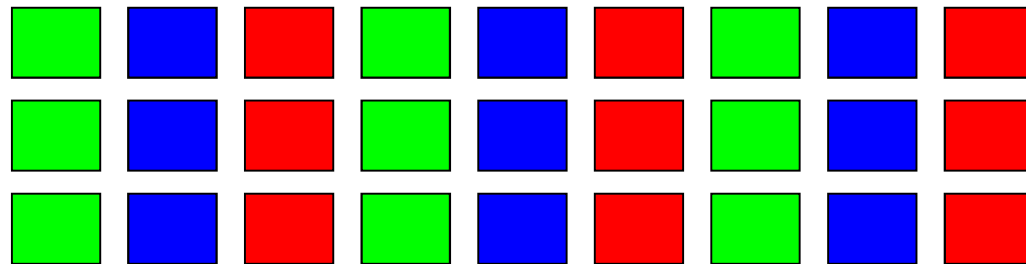
- Photodiode, the converter
- RST, reset signal, discharges the diode
- M_{sf} is the read out transistor (source follower), reads the voltage, very small current, preserves charge
- M_{sel} , selector (addressed from ROW)
- COL, output

CMOS parameters

- Smallest number of transistors
- Greater sensitive area (read out circuitry take space, use microlenses to increase efficiency)
- Tradeoff: reset mechanism vs. image lag
 - Better reset → lower noise
 - .. but also more complicated electronics (affecting the fill factor)
 - ... and more time, larger lags

How to sense a color image

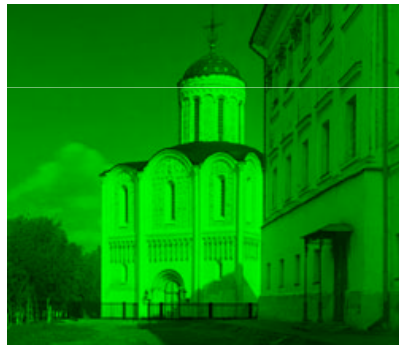
- Take 3 shots (temporal multiplexing or three different sensors)
- 3 detectors (e.g. Foveon, photographic film)
- Spatial multiplexing
 - human eye
 - sensors are made sensitive to red, green or blue using a filter coating that blocks the complementary light



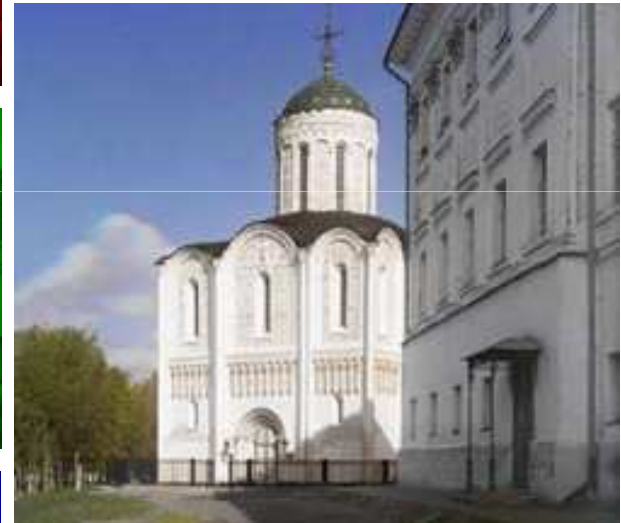
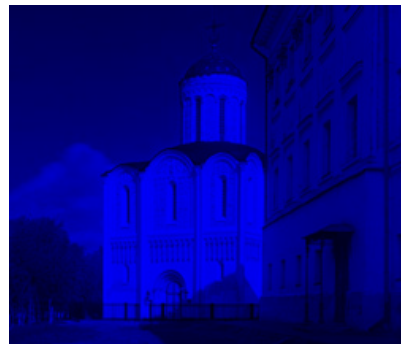
Field sequential



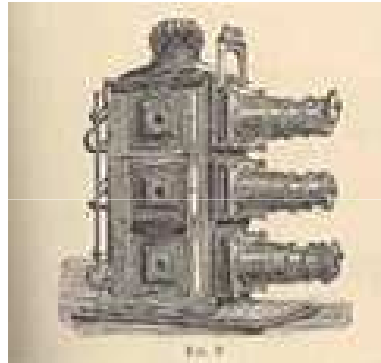
Field sequential



Field sequential



Prokudin-Gorskii (early 1900's)



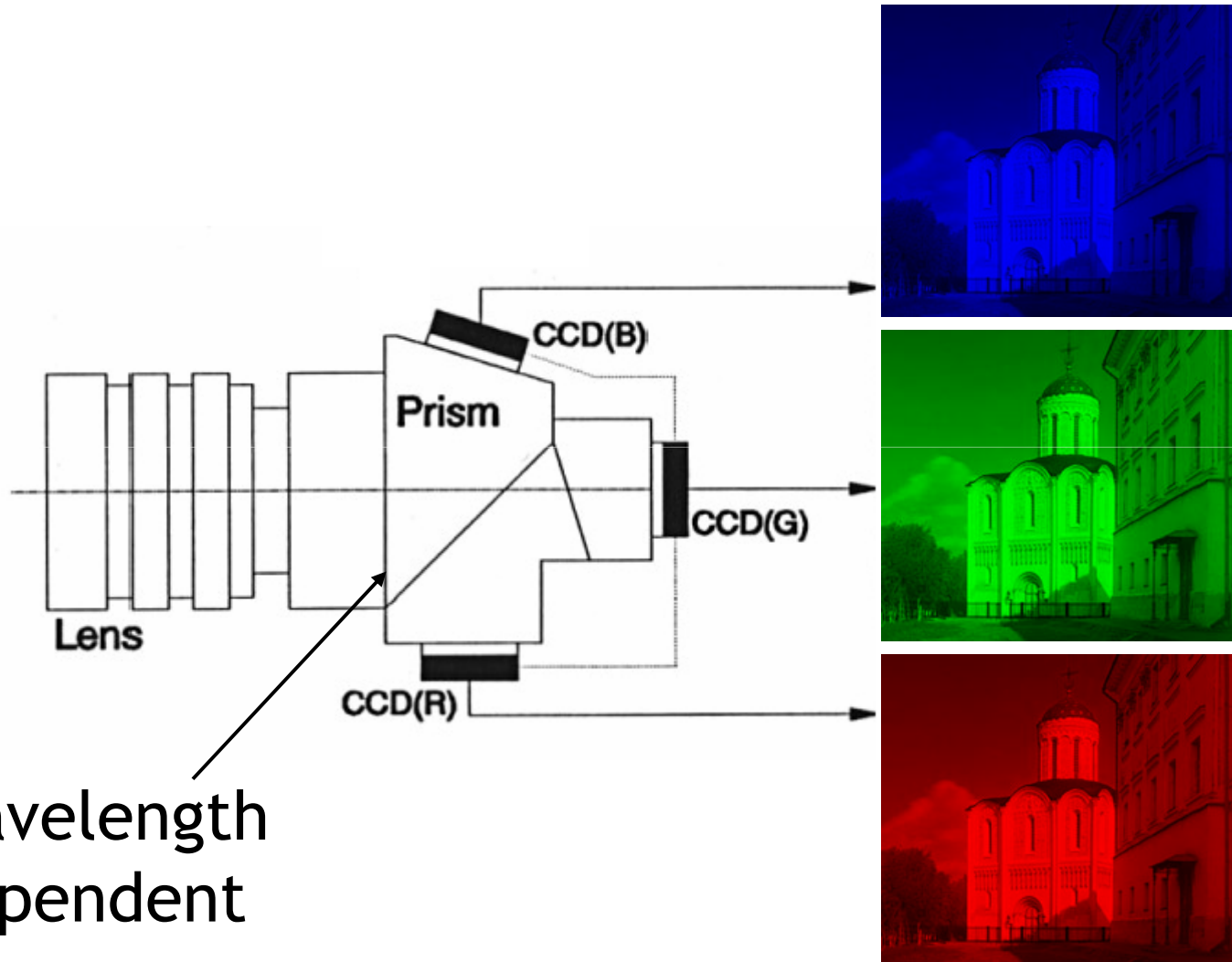
Lantern projector



Prokudin-Gorskii (early 1900's)



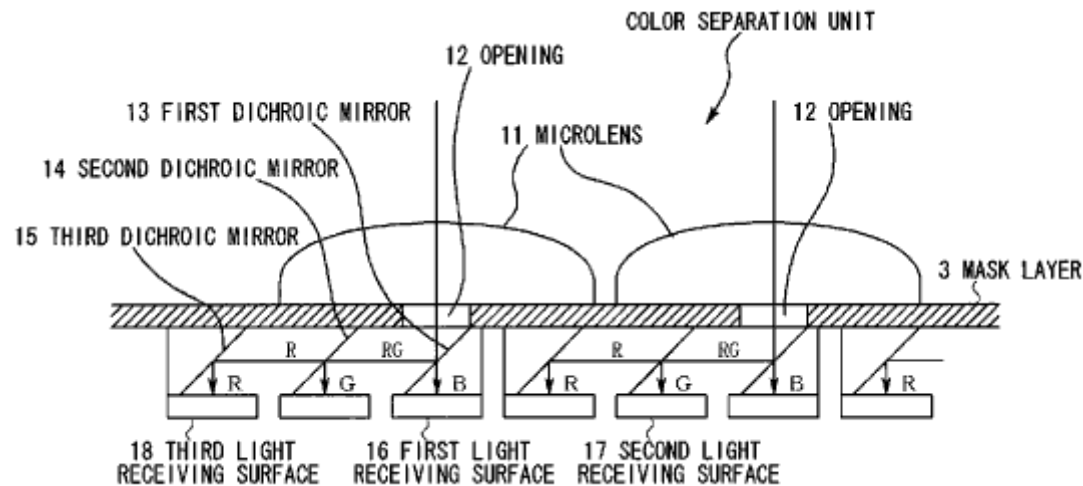
Multi-chip (3CCD)



wavelength
dependent

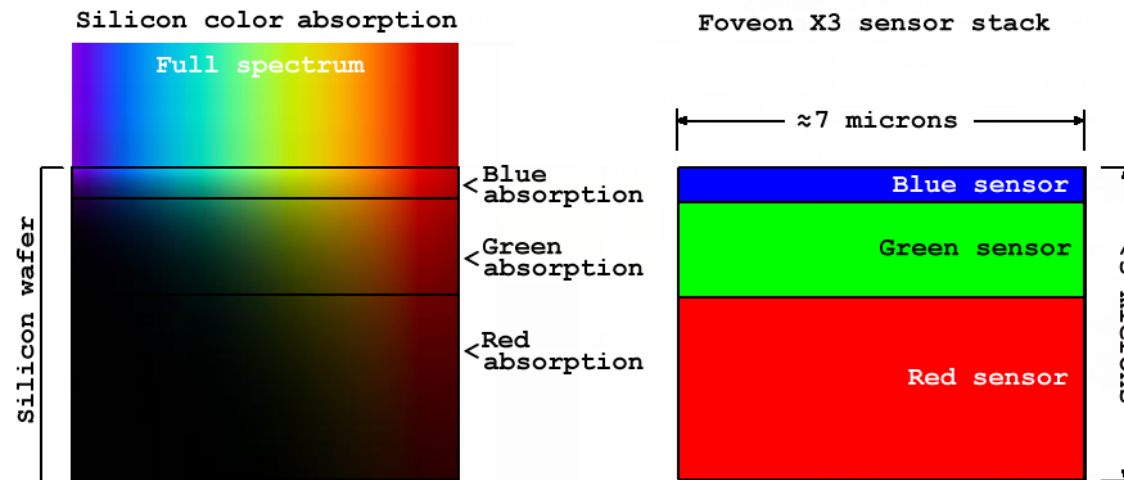
Nikon Dichronic

- Emulates multi-chip solution
- Microlense on top of triplet of photoreceptors
- Using dichroic filters wavelengths of light are separated to reach specific photoreceptors which record red, green, and blue wavelengths



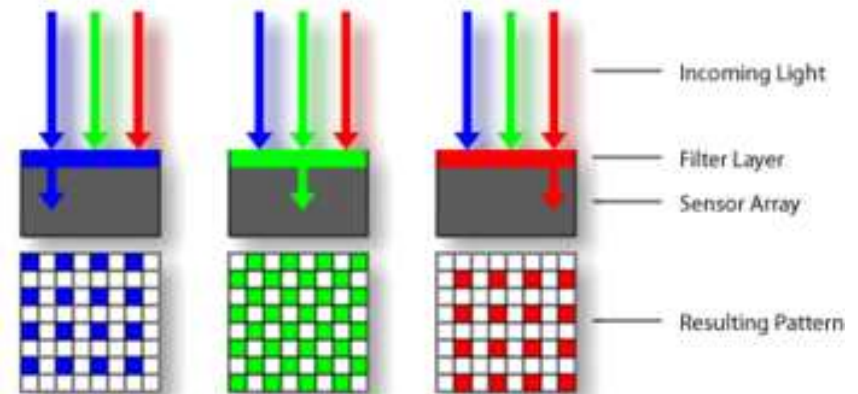
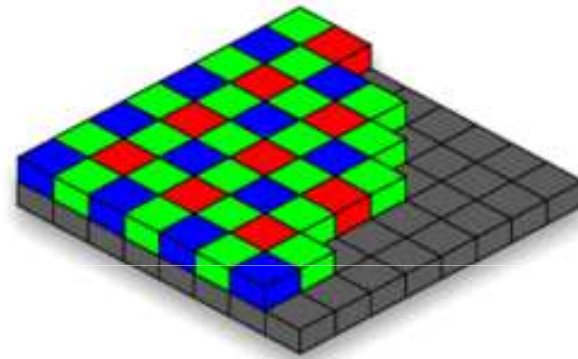
Foveon X3

- Employed in cameras by Sigma
- CMOS technology
- Three layers of photodiodes
- Silicon absorbs different “colors” at different depth, each layer captures a different color
- Advantage: no spatial multiplexing

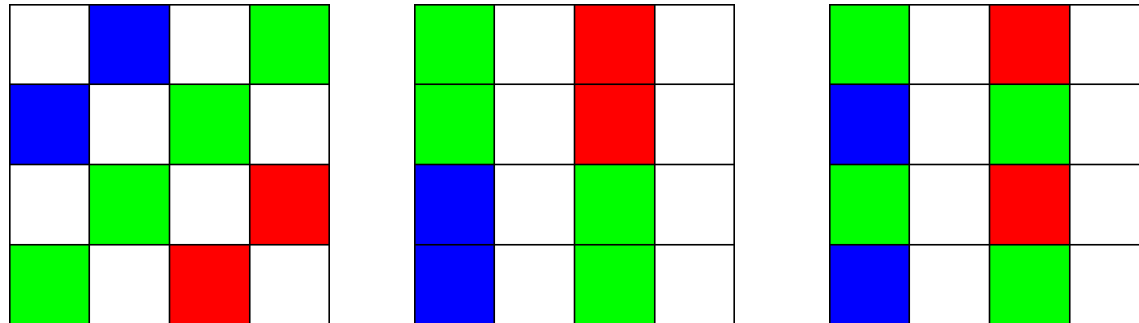


Bayer Pattern

- Invented by E. Bayer at Kodak in 1976, it is a way to arrange RGB filter on a squared grid of photosensors
- 50% green, 25% red, 25% blue
- mimic eye's greater sensitivity to green wavelengths
- need *demosaicing* to interpolate the color information from neighbor units



- Alternative sensor announced in 2007 by Kodak, add “panchromatic”, that are sensitive to all wavelengths
- Increase sensitivity to light, because panchromatic cells do not filter light



Demosaicing

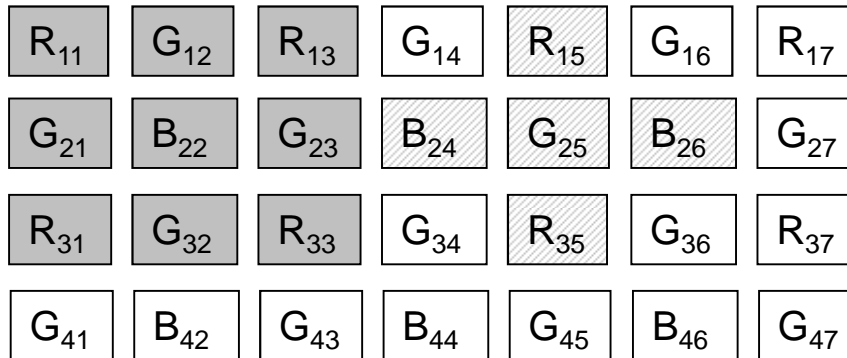
- Reproduce the original image
- Avoid artifacts
- Often must be efficient

1 Simple nearest neighbor, take the missing colors from the nearest pixel

R_{11}	G_{12}	R_{13}	G_{14}	R_{15}	G_{16}	R_{17}
G_{21}	B_{22}	G_{23}	B_{24}	G_{25}	B_{26}	G_{27}
R_{31}	G_{32}	R_{33}	G_{34}	R_{35}	G_{36}	R_{37}

$$\begin{aligned} R_{11} &= R_{11} & R_{12} &= R_{13} \\ G_{11} &= G_{12} & G_{12} &= G_{12} \\ B_{11} &= B_{22} & B_{12} &= B_{22} \quad \dots\text{etc} \end{aligned}$$

2 Bilinear interpolation



$$R_{22} = 0.25 \cdot (R_{11} + R_{13} + R_{31} + R_{33})$$

$$R_{25} = 0.5 \cdot (R_{15} + R_{35})$$

$$G_{22} = 0.25 \cdot (G_{12} + G_{21} + G_{23} + G_{32})$$

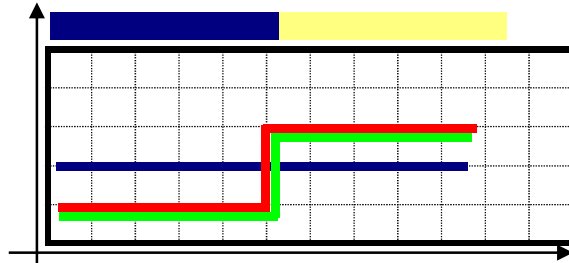
$$G_{25} = G_{25}$$

$$B_{22} = B_{22}$$

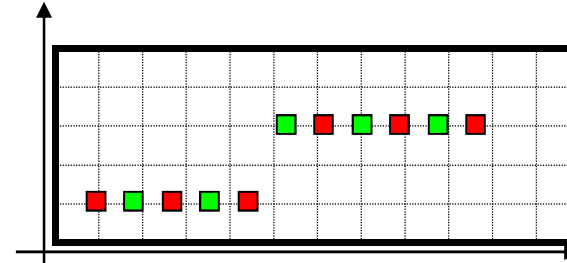
$$B_{25} = 0.5 \cdot (B_{24} + B_{26})$$

3 More sophisticated methods to reduce artifacts (but computationally more expensive)...

Artifacts: color “fringes”

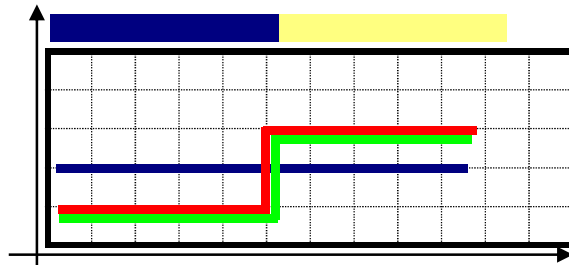


Original signal, an edge from blue (0,0,128) to yellow (255,255,128). Only one scanline shown.

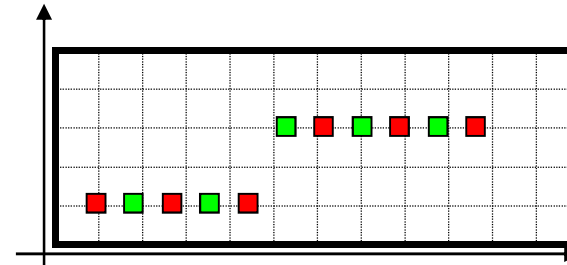


Subsampled Bayer pattern (red scanline)

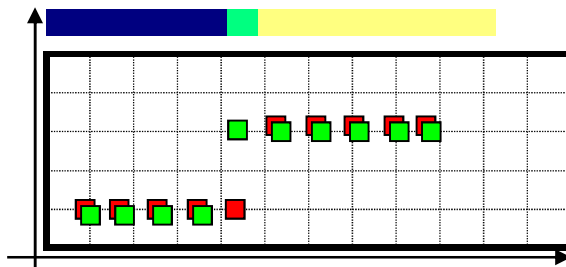
Artifacts: color “fringes”



Original signal, an edge from blue (0,0,128) to yellow (255,255,128). Only one scanline shown.

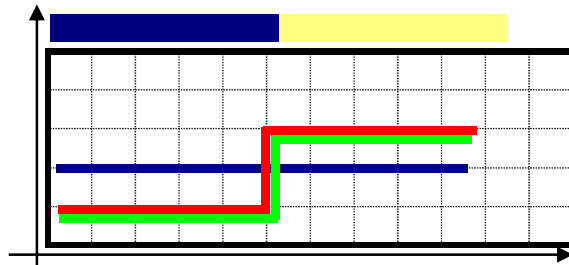


Subsampled Bayer pattern (red scanline)

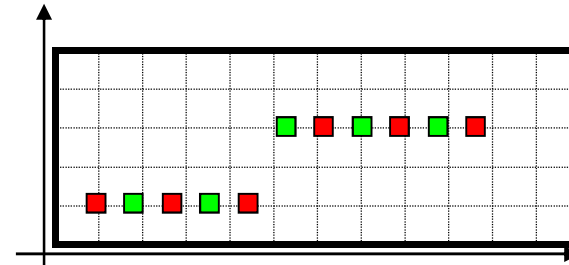


Nearest neighbor color reconstruction.

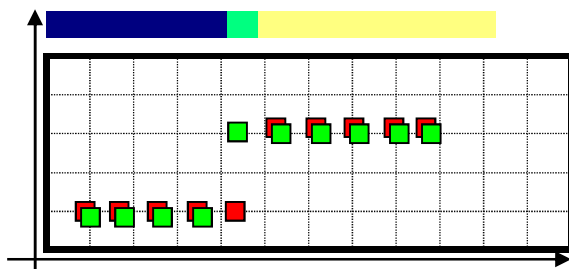
Artifacts: color “fringes”



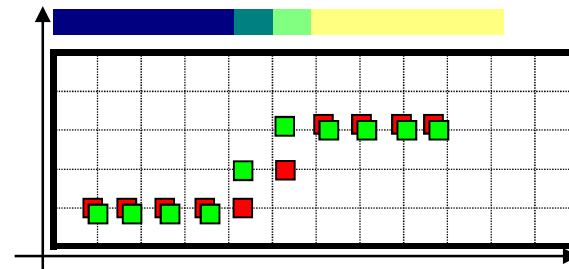
Original signal, an edge from blue (0,0,128) to yellow (255,255,128). Only one scanline shown.



Subsampled Bayer pattern (red scanline)

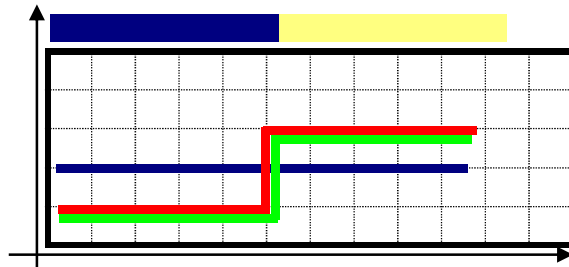


Nearest neighbor color reconstruction.

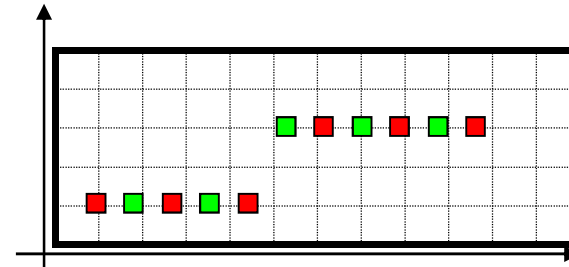


Linear interpolation.

Artifacts: color “fringes”

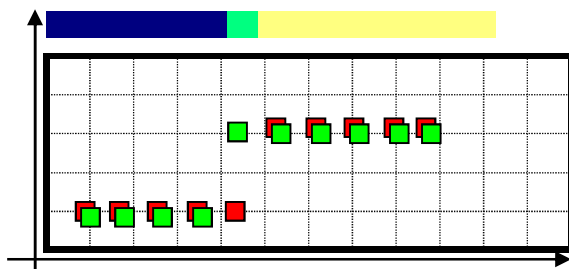


Original signal, an edge from blue (0,0,128) to yellow (255,255,128). Only one scanline shown.

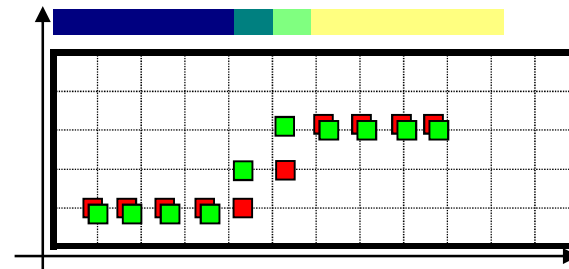


Subsampled Bayer pattern (red scanline)

color fringes



Nearest neighbor color reconstruction.



Linear interpolation.



adapted form: A.Lukin, D.Kubasov, Graphicon 2004

SINA – 10/11

Constant Hue-Based Interpolation

Limit abrupt hue changes (“fringes”) across pixels.

Consider R and B the chrominance values, G is assigned the luminance.

Define hue as: (R/G, B/G)

- First, G values are computed by bilinear interpolation
- Bilinear interpolation of the **hue values** for the R and B channels
- R and B values reconstructed accordingly:

R_{11}	G_{12}	R_{13}	G_{14}	R_{15}
G_{21}	B_{22}	G_{23}	B_{24}	G_{25}
R_{31}	G_{32}	R_{33}	G_{34}	R_{35}
G_{41}	B_{42}	G_{43}	B_{44}	G_{45}

$$R_{22} = G_{22} \cdot 0.25 \cdot (R_{11}/G_{11} + R_{13}/G_{13} + R_{31}/G_{31} + R_{33}/G_{33})$$

$$G_{22} = 0.25 \cdot (G_{12} + G_{21} + G_{23} + G_{32})$$

$$B_{22} = B_{22}$$

$$R_{33} = R_{33}$$

$$G_{33} = 0.25 \cdot (G_{23} + G_{34} + G_{43} + G_{32})$$

$$B_{33} = G_{33} \cdot 0.25 \cdot (B_{22}/G_{22} + B_{24}/G_{24} + B_{44}/G_{44} + B_{42}/G_{42})$$

Median-Based Interpolation

- Perform bilinear interpolation of all channels
- Filter differences R-G and B-G, with a median filter
- Add the median filtered image to the sampled data

