MICRO-523: Optical Detectors

Week Seven: CCD Cameras: Electronics & Noise Sources – Exercises

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Outline

7.1 Noise Sources in Cameras

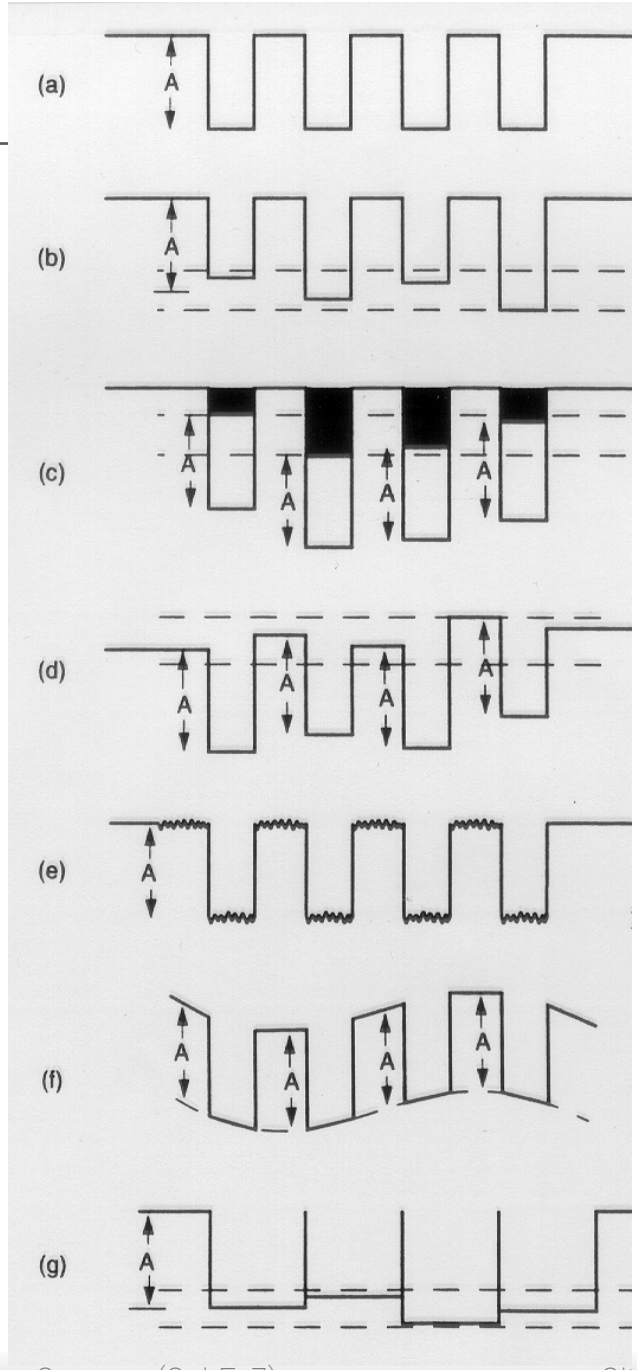
Calculation of SNR and DR values

7.2 Correlated Double Sampling

Exercise 7.1: Noise Sources in Cameras

Consider the signal in (a):

1. Name the different noise terms in b,c,d,e,f,g
2. Which noise terms depend on the wavelength of light?
3. Which noise terms depend on temperature, and which depend on capacitance ?



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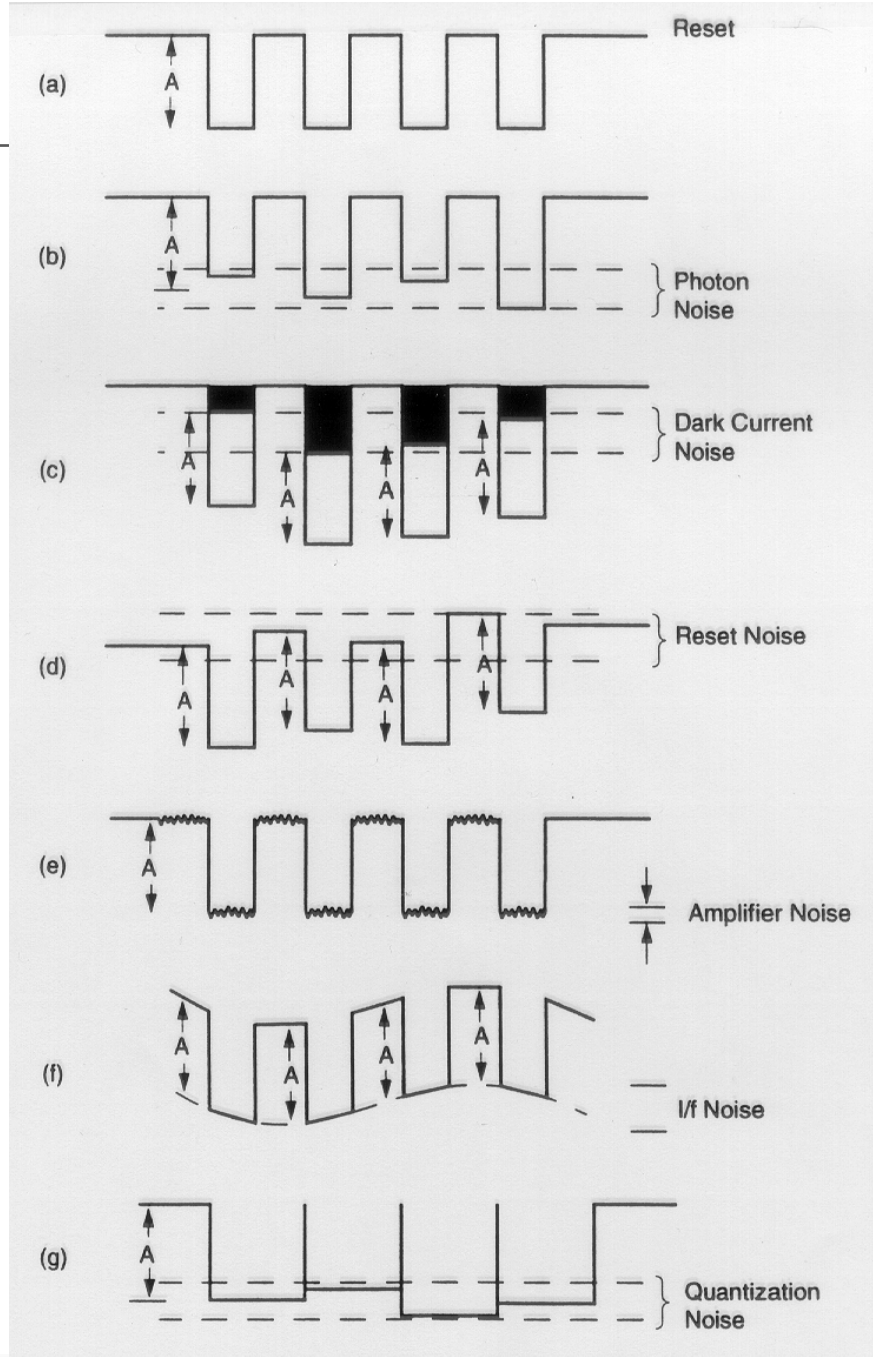
Time-dependent:

- Photon shot noise
- Dark current noise
- Reset noise
- Amplifier (MOSFET)
  - Readout noise
  - 1/f noise
- Electronic digitization noise



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- Photon shot noise $\Delta N_{photo} = \sqrt{\eta \cdot \frac{P_{photo}}{h\nu} \cdot T_{int} \frac{A}{A_{pixel}}}$
- Dark current shot noise $\Delta N_{dark} = \sqrt{\frac{J_{dark}}{q} \cdot T_{\mathrm{int}} \cdot A}$
- Reset noise $\Delta N_{kTC} = \sqrt{kTC/q^2}$
- readout noise $\Delta N_{MOS} \cong \sqrt{\frac{kTC}{q^2}} \cdot \sqrt{\frac{4C}{g_m} \cdot \Delta f}$
- Flicker (1/f) noise $\Delta N_{flicker} \cong \frac{C}{q} \sqrt{\alpha_H \cdot \frac{I}{g_m} \cdot \frac{q}{WL \cdot \overline{C}_{ox}} \cdot ln\left(\frac{f_{max}}{f_{min}}\right)}$
- Signal $N_{photo} = \eta \cdot \frac{P_{photo}}{h\nu} \cdot T_{int} \frac{A}{A_{pixel}}$

Homework: Noise Sources in Cameras

4. Suggest ways to reduce the noise

5. In which case decreasing noise leads to decreasing the signal?

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Homework: Calculation of SNR and DR values

6. Determine the S/N using the following values (neglect flicker noise):

Power=1 mW

Dark current $I_{dark} = 1\ \mathrm{pA}$

Photosensitive area: $1\ \mu\mathrm{m}^2$

Integration time: 10 ms

Fill factor: 1

Frequency: 193 THz

Quantum efficiency: 1

Capacitance: 10 fF

Readout resistance: 1 kOhm

Δf=1 MHz

T=25°C

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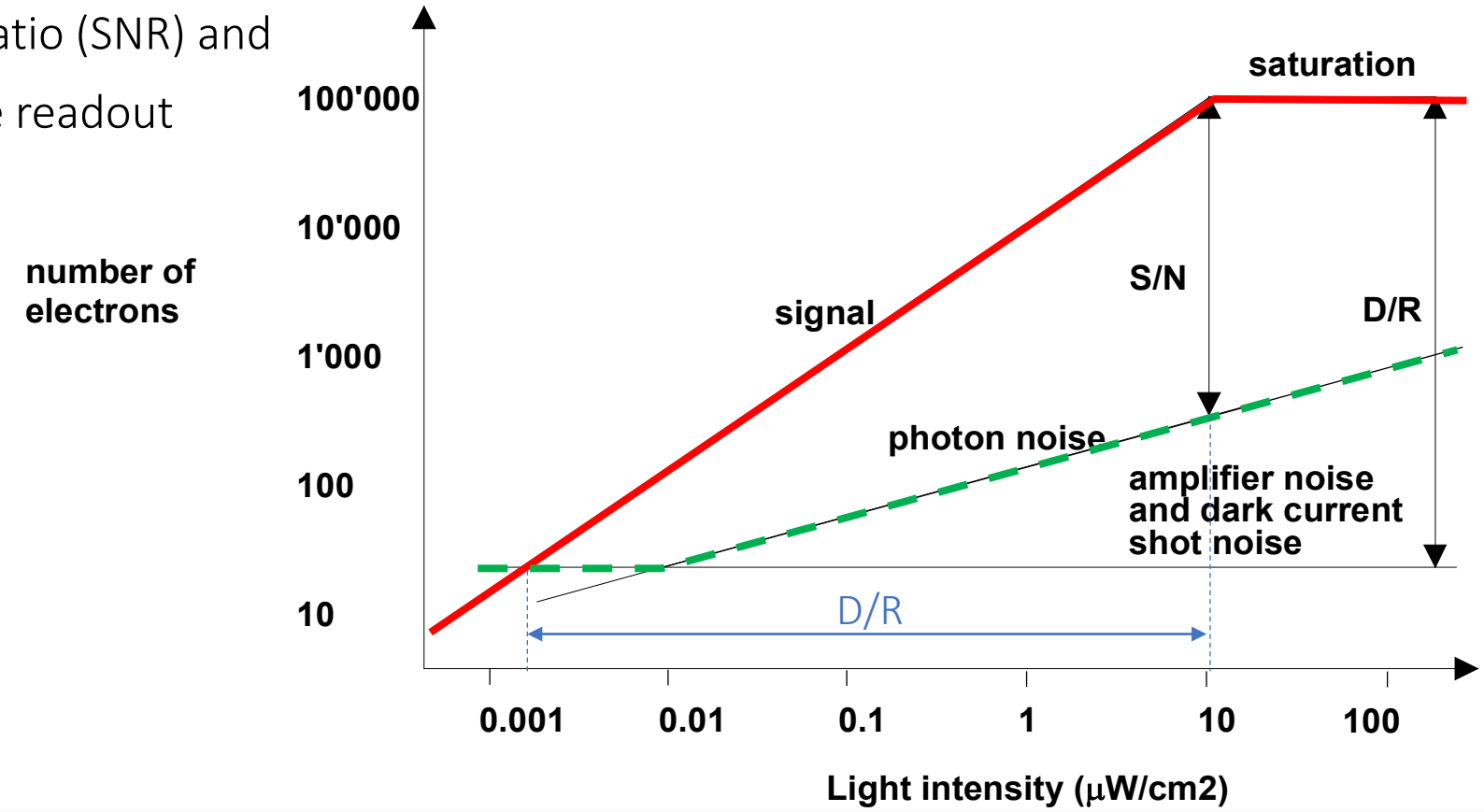
Exercise 7.1: Dynamic range

- Consider a camera with a full well capacity of 62’500 electrons
- Read noise: 25 electrons per pixel/readout
- Dark current: negligible

1. Calculate signal-to-noise ratio (SNR) and dynamic range (DR) for a single readout at full well capacity



Exercise 7.1: Dynamic range

- At saturation:

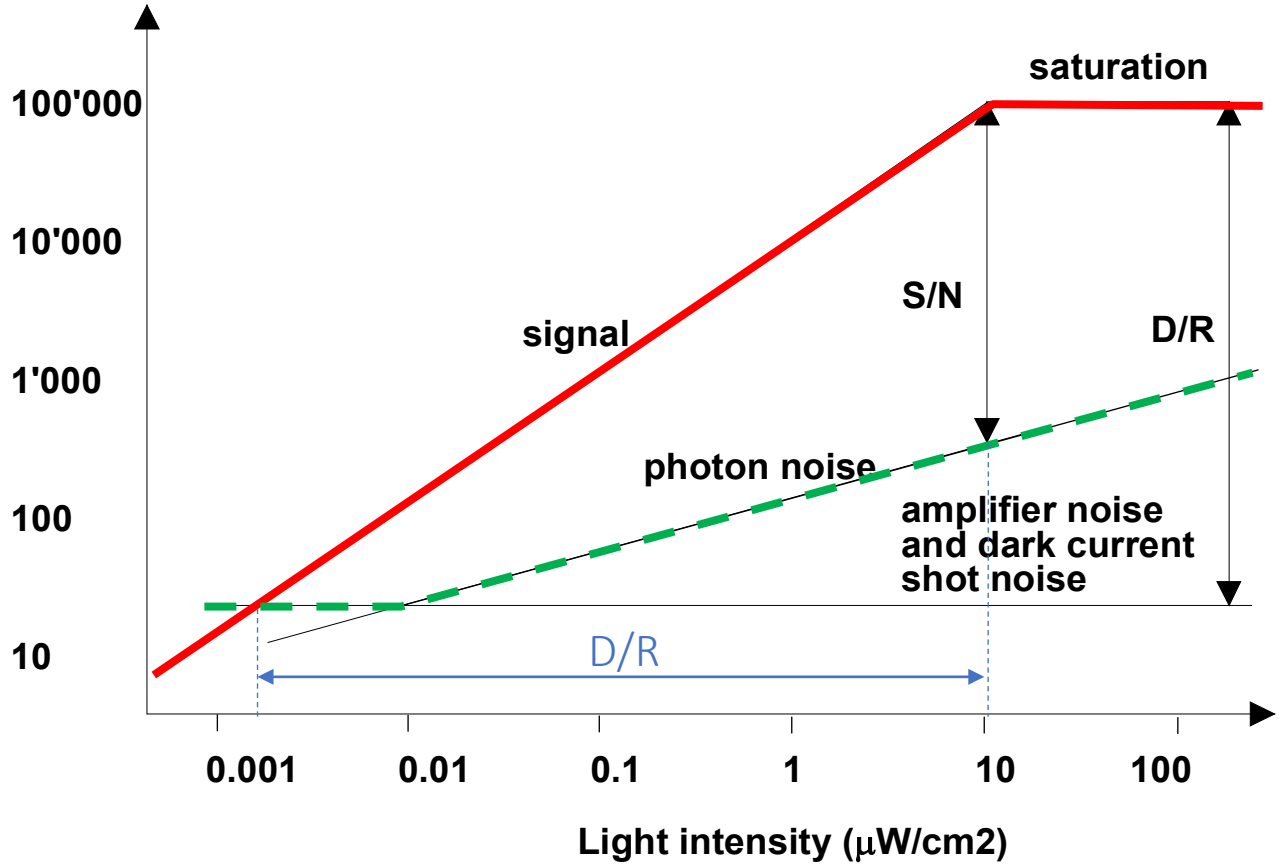
number of electrons

$$[S/N]_{dB} = 20\log_{10}\left(\frac{N_{photo}}{\sqrt{\Delta N_{photo}^2 + \Delta N_{readout}^2}}\right)$$

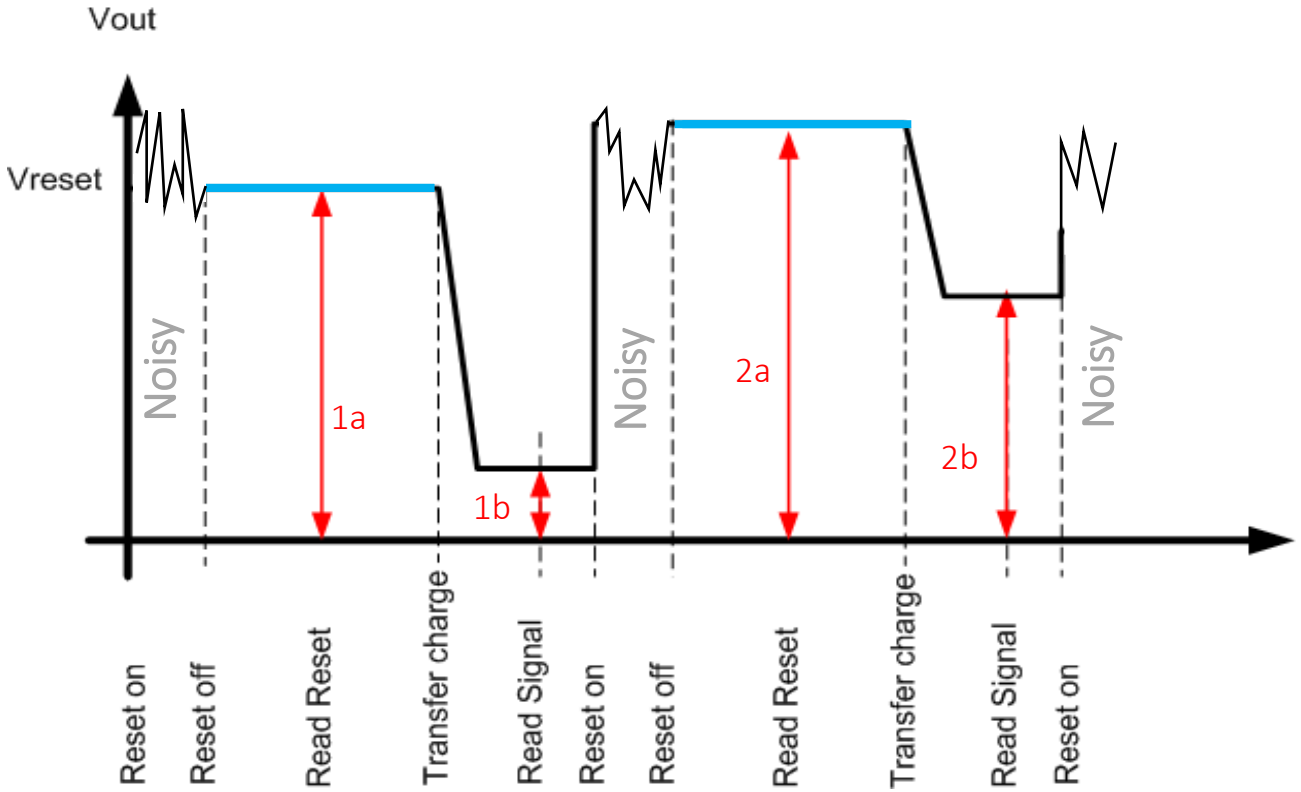
$$= 20\log_{10}\left(\frac{62500}{\sqrt{62500 + 625}}\right) = 48\ \text{dB}$$

$$[DR]_{dB} = 20\log_{10}\left(\frac{N_{MAX}}{\sqrt{\Delta N_{readout}^2}}\right)$$

$$= 68.0\ \text{dB}$$



Exercise 7.2: Correlated Double Sampling



How does CDS work?
What are its main advantages?
Can we improve on CDS?