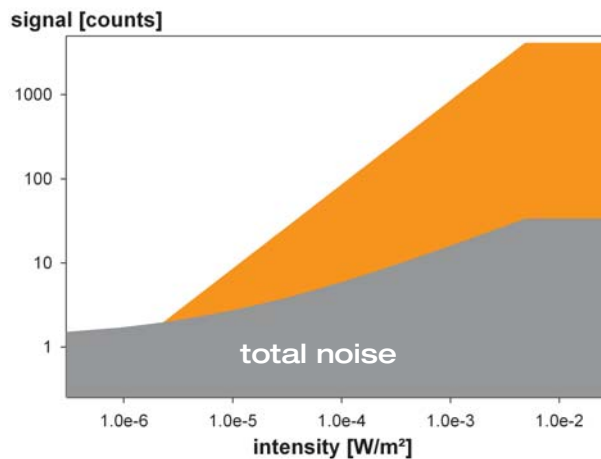


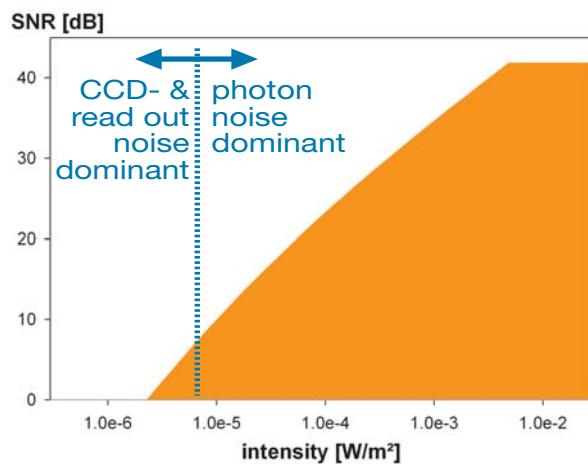
snr - signal-to-noise-ratio

The signal-to-noise-ratio (snr, S/N) is a technical term used to characterize the quality of the signal detection of a measuring system (e.g. a CCD camera). In the case of a system using a CCD image sensor and a read out unit, the snr is given by the ratio of the light signal to the sum of the noise signals. It is expressed as a ratio or factor in units of decibels [dB].

$$\text{ratio [dB]} = 20 \cdot \log(\text{ratio})$$



The upper curve (bright area) provides an example of the relationship between incoming light (x-axis: intensity), and the light signals that can be measured by a CCD camera (y-axis: signal). The lower curve (dark area) represents the total noise signal. The total noise signal is the sum of photon or shot noise, CCD noise and read out noise.



Using the two curves from the graph above, a corresponding snr-curve [dB] can be calculated, illustrated in the left graph. Although the numbers of the y-axis seem to be linear, it is clear from the unit [dB] that the scaling is logarithmic. The area below the curve indicates the maximum available dynamic range allowable for each amount of light that hits the CCD image sensor. The dotted line denotes the point where the photon noise is larger than CCD- and read out noise.

assumed specifications:

$\lambda = 540\text{nm}$, $A = 41.6\mu\text{m}^2$, $t = 50\text{ms}$, $\eta = (0.6 \text{ at } 540\text{nm})$,
 CCD read out noise = $5 e^-$, full well capacity = $16384 e^-$.

snr - signal-to-noise-ratio

Calculating snr

The signal-to-noise-ratio in a CCD image sensor, or in a CCD camera is given by the ratio of generated charge carriers (signal electrons) to the number of unwanted charge carriers (noise electrons):

$$\frac{S}{N} = \frac{n_{\text{signal}}}{n_{\text{noise}}}$$

Light signal

The number of signal electrons is dependent on the illumination intensity of the incoming photons described as:

$$n_{\text{signal}} = \frac{\Phi}{h \cdot \nu} \cdot t \cdot A \cdot \eta$$

with Φ - light power [W/m²], $h\nu$ - photon energy [Ws], t - exposure time [s], A - pixel area [m²] and η - quantum efficiency

Noise signal

The total noise signal comes from photon or shot noise.

n_{photon} ...noise electrons due to photon or shot noise

$$n_{\text{photon}} = \sqrt{\frac{\Phi}{h \cdot \nu} \cdot t \cdot A \cdot \eta}$$

with Φ - light power [W/m²], $h\nu$ - photon energy [Ws], t - exposure time [s], A - pixel area [m²] and η - quantum efficiency

CCD noise

n_{CCD} ...noise electrons due to CCD-image sensor

Read out noise

n_{readout} ...noise electrons due to read out of the CCD-image sensor

Since all noise sources are not correlated, the total number of noise electrons is given by:

$$n_{\text{noise}} = \sqrt{\left(\sqrt{\frac{\Phi}{h \cdot \nu} \cdot t \cdot A \cdot \eta} \right)^2 + n_{\text{CCD}}^2 + n_{\text{readout}}^2}$$

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Therefore the signal-to-noise-ratio (snr) is given by:

$$\frac{S}{N} = \text{SNR} = \frac{\frac{\Phi}{h \cdot \nu} \cdot t \cdot A \cdot \eta}{\sqrt{\left(\sqrt{\frac{\Phi}{h \cdot \nu} \cdot t \cdot A \cdot \eta}\right)^2 + n_{\text{CCD}}^2 + n_{\text{readout}}^2}}$$

Depending on the set-point of the CCD image sensor or the CCD camera the snr formula can be simplified:

[1] large light signal or high level:

$$\left(\sqrt{\frac{\Phi}{h \cdot \nu} \cdot t \cdot A \cdot \eta}\right)^2 \gg (n_{\text{CCD}}^2 + n_{\text{readout}}^2)$$

In this case the photon noise is dominant, resulting in the following simplification:

$$\frac{S}{N} = \text{SNR} \approx \frac{\frac{\Phi}{h \cdot \nu} \cdot t \cdot A \cdot \eta}{\sqrt{\left(\sqrt{\frac{\Phi}{h \cdot \nu} \cdot t \cdot A \cdot \eta}\right)^2}} = \sqrt{\frac{\Phi}{h \cdot \nu} \cdot t \cdot A \cdot \eta} = \sqrt{n_{\text{signal}}}$$

or, as the CCD image sensor properties are independent from the light signal, the snr is proportional to exposure time, pixel area and quantum efficiency:

$$\frac{S}{N} = \text{SNR} \sim \sqrt{A \cdot \eta}$$

[2] small light signal or low level:

$$(n_{\text{CCD}}^2 + n_{\text{readout}}^2) \geq \left(\sqrt{\frac{\Phi}{h \cdot \nu} \cdot t \cdot A \cdot \eta}\right)^2$$

In this case the CCD image sensor noise is dominant, resulting in the following simplification:

$$\frac{S}{N} = \text{SNR} \approx \frac{\frac{\Phi}{h \cdot \nu} \cdot t \cdot A \cdot \eta}{\sqrt{n_{\text{CCD}}^2 + n_{\text{readout}}^2}}$$

or, if the example is confined to CCD characteristics, the following proportionality is valid:

$$\frac{S}{N} = \text{SNR} \sim \frac{A \cdot \eta}{\sqrt{n_{\text{CCD}}^2 + n_{\text{readout}}^2}}$$

Hence, to achieve a good signal-to-noise-ratio, high quantum efficiency, large pixel area, small CCD image sensor noise and small readout noise are all desirable.