ABOUT TOTAL NOISE OF A CCD CAMERA:

First of all, when we talk about "read out noise", we refer to the sensor itself; such noise is 15 e^- rms typically. Instead, if you mean the total noise of the camera, as you well know for sure, there are different parameters that contribute to it. Among those, the most important are:

1) dark noise, N_d , due to the dark current;

2) the read out noise of the sensor, N_r (see above);

3) the quantization noise, N_Q generated by the signal coming from the CCD digitalisation; it is given by:

$$N_Q = \frac{FWC}{2^n \cdot \sqrt{12}} = \frac{gain}{\sqrt{12}}$$

where FWC = Full Well Capacity and n is the number of bit of the A/D converter.

4) the noise due to the electronics, N_e; in the case of HiRes, it is typically **< 1 e^- ADU** (Analog to Digital Unit).

The total noise of the system can be obtained by quadrature adding to all these parameters, as reported in the camera datasheets, obtained in typical experimental conditions.

As HiRes camera series are **programmable gains**, the quantization noise, and - as consequence - the total noise of the camera, change according to the gain you set.

Let's make an example: for the HR 1000E, with a KAF-1001E, 16 bit A/D converter, there are two outputs:

1) High Sensitivity Output: **FWC=240,000 e^-/pix/s:**

Optimizing the FWC and the maximum counts, a possible gain is:

$$gain = \frac{240{,}000}{65{,}536} = 4 \quad \text{(it is an integer number);}$$

so, the quantization noise is:

$$N_Q = \frac{gain}{\sqrt{12}} = \frac{4}{\sqrt{12}}\, ADU$$

where ADU = analog to digital converter.

By this gain and with a sensor read out noise of 15 e^- rms, the readout noise of the camera is:

$$N_r(ADU) = \frac{N_r(\text{e}^- \text{ rms})}{gain} = \frac{15}{4}\, ADU$$

The other parameters are shown in the datasheets of the sensor:

N_d=0.5 ADU (@ -5°C)

N_e=1 ADU.

Considering these sources of noise (neglecting any other contribute), we obtain:

$$N_T = \sqrt{(\frac{4}{\sqrt{12}})^2 + (\frac{15}{4})^2 + 0.5^2 + 1)} = 4ADU$$

$$N_T(e^- rms) = N_T(ADU) \cdot gain = 16(e^- rms)$$

So, the dynamic range is:

$$DR = 20\log\frac{FWC}{16} = 83.5dB\,.$$

2) High Dynamic output Range: **FWC=650,000 e⁻/pix/s:**

$$gain = \frac{650{,}000}{65{,}536} = 10$$

$$N_Q = \frac{gain}{\sqrt{12}} = \frac{10}{\sqrt{12}}\ \text{ADU}$$

$$N_r(ADU) = \frac{N_r(\text{e}^- \text{ rms})}{gain} = \frac{15}{10}ADU$$

N_d=0.5 ADU (@ -5°C)

N_e=1 ADU.

As above:

$$N_T = \sqrt{(\frac{10}{\sqrt{12}})^2 + (\frac{15}{10})^2 + 0.5^2 + 1)} = 3.4ADU$$

$$N_T(e^- rms) = N_T(ADU) \cdot gain = 34(e^- rms)$$

The dynamic range is:

$$DR = 20\log\frac{FWC}{34} = 85.6\ dB$$

For that concerns the dark current, it changes according to the temperature of the sensor. Typically, it halves every 6-7 °C of temperature decreasing. For HR1000E, the dark current value is 550 e^-/pix/s @ 25°C, so it decreases to 17 e^-/pix/s @ -5°C.

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