Output Amplifiers in the Kodak KAF-1001E and KAF-0261E CCDs (Alta U6 and U260 cameras)

The Kodak KAF-0261E and KAF-1001E CCDs in the U260 and U6 cameras have two output amplifiers. One amplifier provides lower read noise, but lower charge capacity; the other amplifier provides much higher charge capacity but with much higher noise. The customer chooses the amplifier when he orders the camera. The camera is then wired to support the customer's chosen amplifier. The customer cannot change from one amplifier to the other without rebuilding the camera.

For the KAF-1001E CCD in the U6, Kodak gives the following specifications:
Onset of parallel blooming (smearing): 500K electrons (same for KAF-0261E in the U260)
Maximum charge capacity of low noise output amplifier: 200K electrons (same for KAF-0261E)
Maximum charge in high dynamic range amplifier: 1500K electrons (628K for the KAF-0261E).

If the customer chooses the low noise output amplifier, the maximum charge per pixel (500K e) before blooming does not change. But any pixel value >200K e will saturate the output amplifier. A charge of 300K electrons in a pixel does not cause blooming, but the output amplifier cannot differentiate between any signal above 200K electrons.

If the customer chooses the high dynamic range output amplifier, the maximum charge for the output amplifier is much higher than an individual pixel. So the customer can use all the capacity of the pixels, and even do some binning without exceeding the capacity of the output amplifier. Using all of the 1500K e is ONLY possible with binning because each pixel can only have 500K e maximum before blooming.

All of the above statements are Kodak CCD specifications. However, the gain set in the camera is another important variable.
For customers who choose the low noise output amplifier, the most important feature is low noise for low signal levels.
We set the gain of the camera to about 1.7 electrons per analog-to-digital converter unit in 16 bit mode.
16 bits is > 65K possible levels of gray. Gain of 1.7e/ADU gives a maximum signal of 111K electrons.
The maximum charge in a pixel before blooming is still 500K, and the maximum charge in the output amplifier is still 200K, but our AtoD converter will only measure to 110K e. All signals above 110K = white.
The read noise is typically 8 e. So the maximum dynamic range is 110K/8, or about 14K:1.

For customers who choose the high dynamic range output amplifier, we think the most important feature is high full well capacity.
We set the gain of the camera to about 8-9e per ADU. Maximum signal is therefore 65K x 8 = about 520K e.
This level matches the full well capacity of an individual pixel.
If the customer has 500K e in each pixel, and bins 2x2, the total signal 2000K e is too much for the output amplifier (1500K e max).
Typical readout noise is about 25e. Maximum dynamic range is 500K/25 = 20K:1.
In actual practice, the signal to noise ratios progress as seen in the chart below (a total dark signal of 10e was assumed for this example, which is about a 20 second exposure with a standard U6 or about 200 seconds with a U6 in a D09 housing.)

Total Signal	Total Noise (Low noise amp.)	SNR (LN amp.)	Total noise (HDR amp.)	SNR (HDR amp.)
50 e	11.1 e	4.5	25.2	2
100 e	13.2 e	7.6	26.2	3.8
200 e	16.5 e	12.1	28	7.1
400 e	21.8 e	18.4	31.4	12.7
1000 e	32.8 e	30.5	39.8	25.1
2000 e	45.5 e	44	50.8	39.3
5000 e	71.2 e	70.2	74.7	67

For signal levels of 1000e or less, the SNR of the low output amplifier is much better than the high dynamic range output amplifier.
For higher signal levels, the HDR amplifier has a lower SNR, but for practical purposes, the difference between SNR 70 and SNR 67 is not important. The difference between SNR of 4.5 and 2 is very important. Please note that the "signal" is the total signal. The customer may only be interested in a fluorescent signal, for example, but this fluorescence may be on top of a background signal. For most applications, 1000e of total signal is a low signal level, using only 1% of the capacity of our 16-bit converter in low noise mode.

Apogee Imaging Systems
151 N. Sunrise Ste 902
Roseville CA 95661 USA
tel 916 218 7450
fax 916 218 7451
www.ccd.com