Andor Camera Evaluation Report

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Camera Model: **iXon 897**

Specifications:

Frame Transfer EMCCD
Pixel array: 512×512
Pixel size: 16µm×16µm
Image area: 8.2mm×8.2mm
Operating Temp. 0 to 30°C
Cooling (air) -85°C, (liquid)-100°C
Readout noise: 8e @1MHz and <1 @Multiplication gain
Max Frame rate: 35fps
Dark current: 0.001 e-/pixel/sec @-85°C

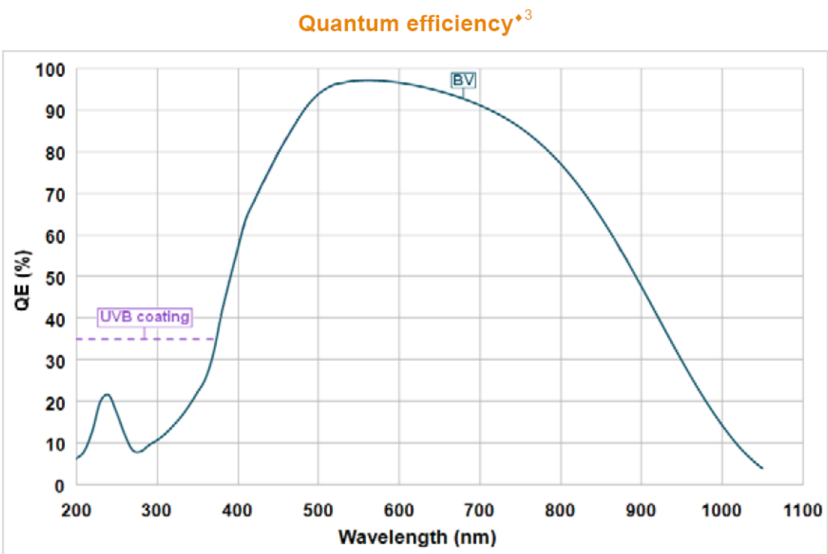


Figure 1. Quantum efficiency

Title of measurements

1- Dark field stability
2- Readout noise, Conventional and EM Gain measurement (Variance versus mean counts)

3- Discussion

1. Dark field stability

Experiment 1 (Without Gain and long time monitoring)

Following parameters were set before recording:

Exposure: 1s

Delay between exposures: 60s

Vertical shift speed: 1.7us

Vertical clock voltage: normal

Readout Rate: 1MHz

Pre Amplification Gain: 1x

Conventional output

Baseline clamp (it will try to stabilize the baseline of image)

Temperature: -85^{o}C

By averaging the total counts over each image dark current value is calculated. Figure 2 illustrates the average dark current versus the time.

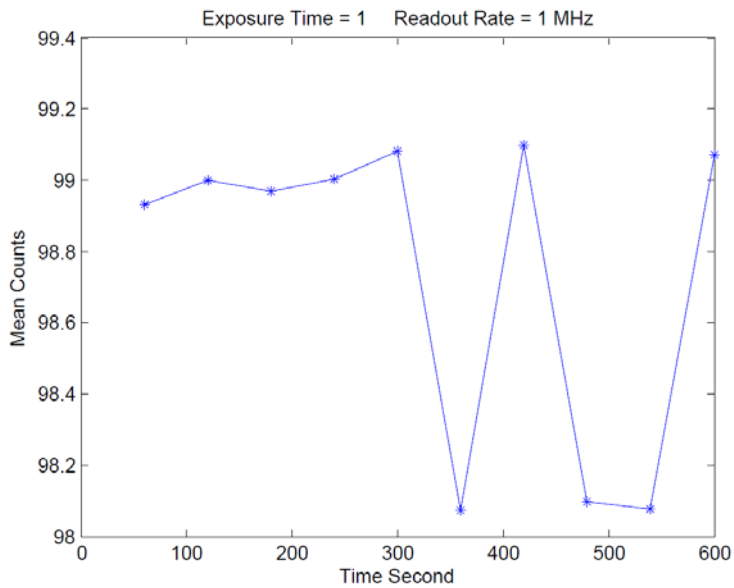


Figure 2. Dark stability for conventional amplification at 1x gain and 1MHz readout rate.

Experiment 2 (Without Gain and short time monitoring)

Following parameters were set before recording:

Exposure: 0.28485s

Delay between exposures: in sequence

Vertical shift speed: 1.7us

Vertical clock voltage: normal

Readout Rate: 1MHz

Pre Amplification Gain: 1x

Conventional output

Baseline clamp (it will try to stabilize the baseline of image)

Temperature: -85^{o}C

By averaging the total counts over each image dark current value is calculated. Figure 3 illustrates the average dark current versus the time.

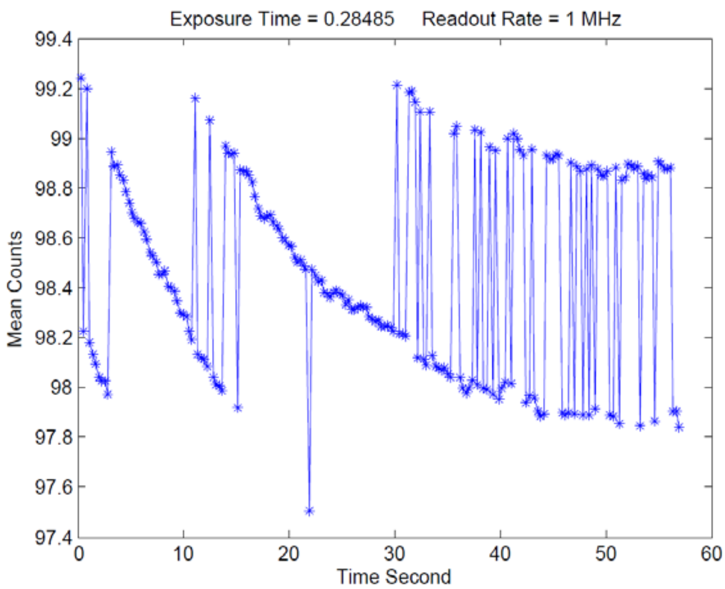


Figure 3. Dark stability for conventional amplification at 1x gain and 1MHz readout rate.

Experiment 3 (Some gain and short time monitoring)

Following parameters were set before recording:

Exposure: 0.28485s

Delay between exposures: in sequence

Vertical shift speed: 1.7us

Vertical clock voltage: normal

Readout Rate: 1MHz

Pre Amplification Gain: 2.5x

Conventional output

Baseline clamp (it will try to stabilize the baseline of image)

Temperature: -85^{o}C

By averaging the total counts over each image dark current value is calculated. Figure 4 illustrates the average dark current versus the time.

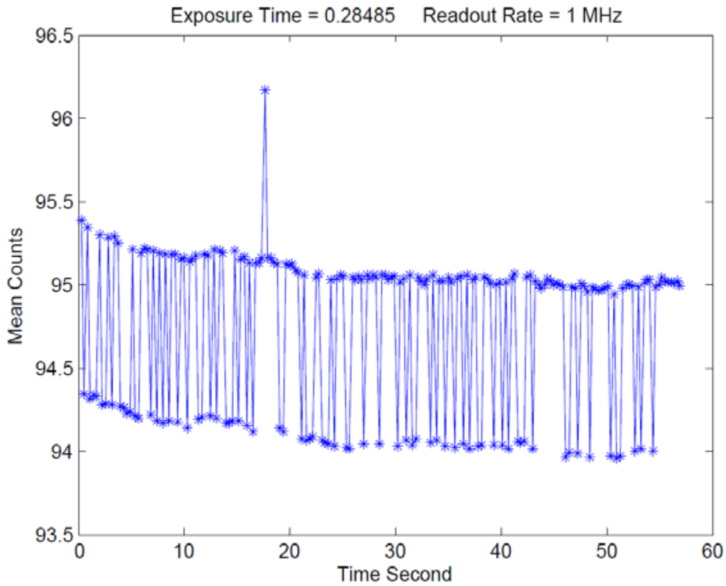


Figure 4. Dark stability for conventional amplification at 2.5x gain and 1MHz readout rate.

2. Gain measurement

At following sections we used the method presented at Reference (1). The algorithm for data recording and analysis are presented here briefly.
In order to provide a uniform illumination an integration sphere is used and a 12v light bulb connected to a digital precise power supply to provide stable light source. Measurements prove that the stability is better than 0.1% for 1min.

Algorithm for Gain measurement

In this strategy, the flat field no uniformity is removed by subtracting one image from another at each signal level. For each intensity level, here is the procedure:

1. Obtain 2 images in succession at the same light level. Call these images A and B.
2. Subtract the bias level from both images. Keep the exposure short so that the dark current is negligibly small. If the dark current is large, you should also remove it from both frames.
3. Measure the mean signal level S in a region of pixels on images A and B. Call these mean signals S_A and S_B. It is best if the bounds of the region change as little as possible from one image to the next. The region might be as small as 50x50 to 100x100 pixels but should not contain obvious defects such as cosmic ray hits, dead pixels, etc.
4. Calculate the ratio of the mean signal levels as $r = S_A / S_B$.
5. Multiply image B by the number r. This corrects image B to the same signal level as image A without affecting its noise structure or flat field variation.
6. Subtract image B from image A. The flat field effects present in both images should be cancelled to within the random errors.
7. Measure the standard deviation (σ) over the same pixel region you used in step 3. Square this number to get the Variance (σ^2). In addition, divide the resulting variance by 2.0 to correct for the fact that the variance is doubled when you subtract one similar image from another.
8. Use the Signal from step 3 and the Variance from step 7 to add a data point to your Signal - Variance plot.
9. Change the light intensity and repeat steps 1 through 8.

The accuracy for Variance (σ^2) measurement is given by:

$$\Delta\sigma^2 \approx 2\sigma^4/N \,. \qquad (1)$$

Where N is number of pixel included in each calculation. By recording 2×K frame at each intensity and selecting M×M pixels in each frame, the N will be equal to M×M×K.

Readout Noise Measurement

To calculate the readout noise, the "Two Bias" method is used and the gain value determined from previous section is applied. In the Two Bias Method, 2 bias frames are taken in succession and then subtracted from each other. The standard deviation inside a region of, say 100x100 pixels is measured and divided by 1.4142. This gives the readout noise in units of counts. Multiply this by the gain factor to get the Readout Noise in units of electrons.

Experiment 1 (Conventional gain)

Following parameters were set before recording:

Exposure: 0.28485s
Delay between exposures: in sequence
Vertical shift speed: 1.7us

Vertical clock voltage: +1

Readout Rate: 1MHz

Pre Amplification Gain: 1x

Conventional output
Baseline clamp (stabilize the baseline of image)
Temperature: -85°C
Averaging box: 100×100
Number of frames: 50

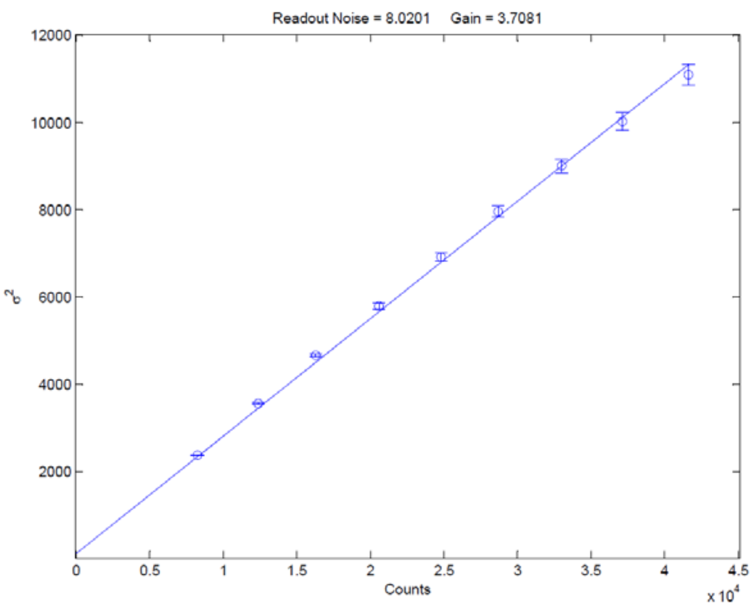


Figure 5. Gain measurement for Gain 1x and conventional output, the vertical error bar calculated from Eq(1)

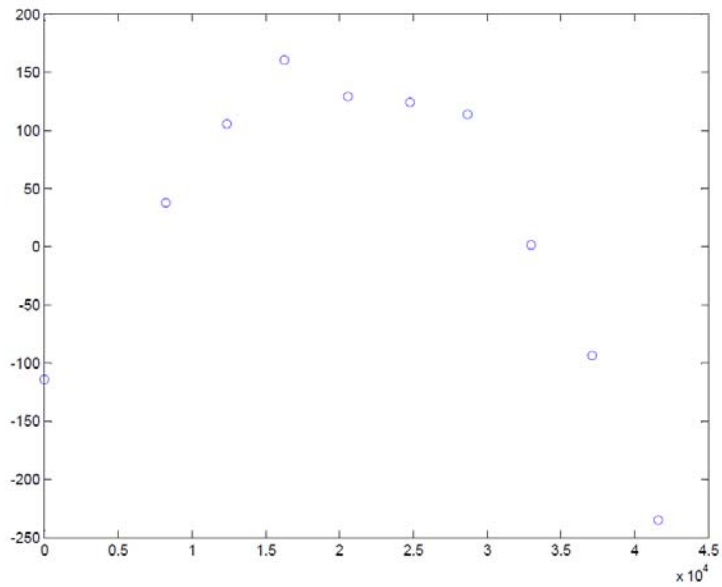


Figure 6. Deviation of data points from linear fit.

Experiment 2 (Conventional gain)

Following parameters were set before recording:

Exposure: 0.28485s

Delay between exposures: in sequence

Vertical shift speed: 1.7us

Vertical clock voltage: normal

Readout Rate: 1MHz

Pre Amplification Gain: 1x

Conventional output

Baseline clamp (stabilize the baseline of image)

Temperature: -85^{o}C

Averaging box: 250×250

Number of frames: 10

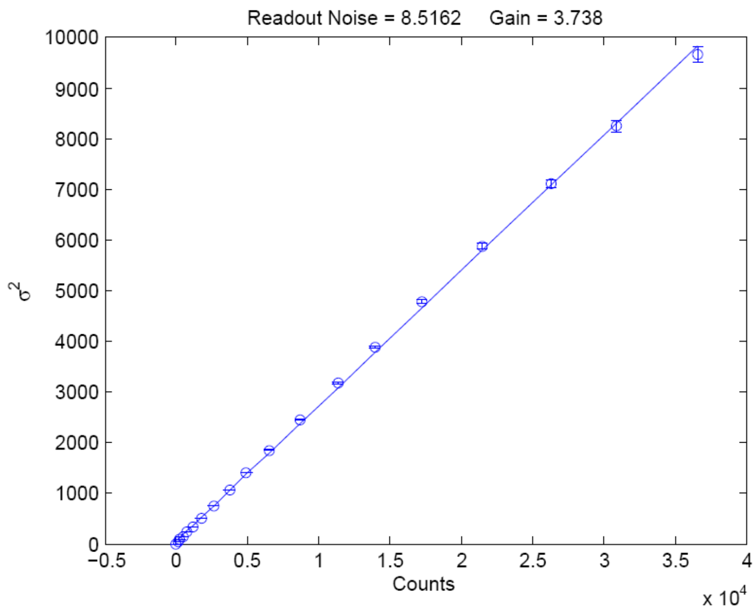


Figure 7. Gain measurement for Gain 1x and conventional output, the vertical error bar calculated from Eq(1)

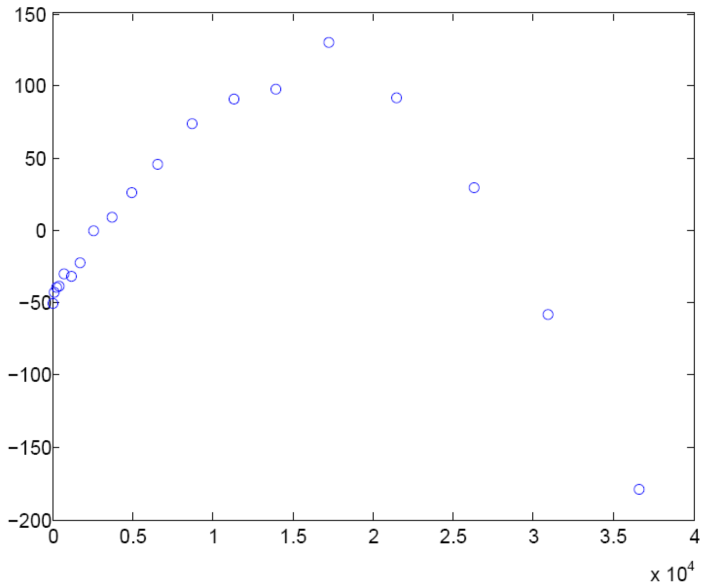


Figure 8. Deviation of data points from linear fit.

Experiment 3 (Conventional gain)

Following parameters were set before recording:

Exposure: 0.28485s

Delay between exposures: in sequence

Vertical shift speed: 1.7us

Vertical clock voltage: normal

Readout Rate: 1MHz

Pre Amplification Gain: 2.5x

Conventional output

Baseline clamp (stabilize the baseline of image)

Temperature: -85°C

Averaging box: 250×250

Number of frames: 10

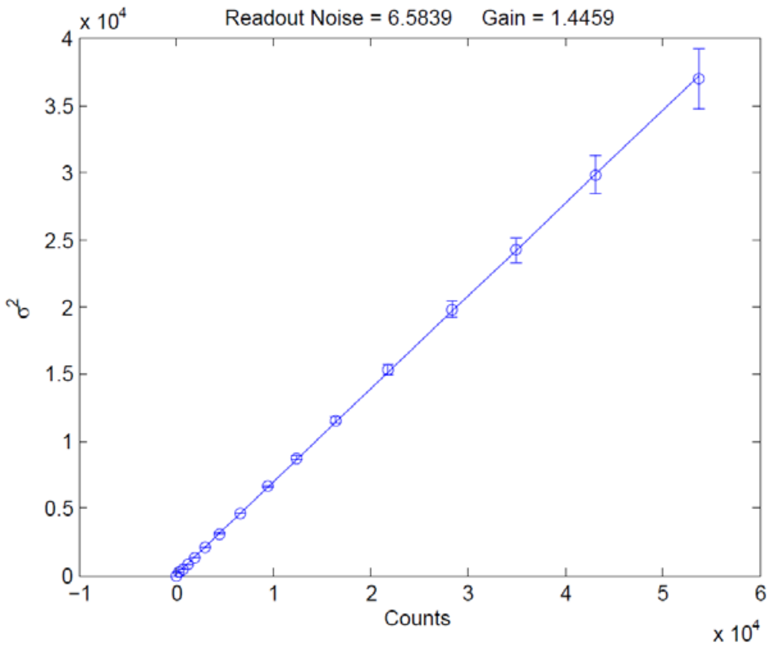


Figure 9. Gain measurement for Gain 2.5x and conventional output, the vertical error bar calculated from Eq(1)

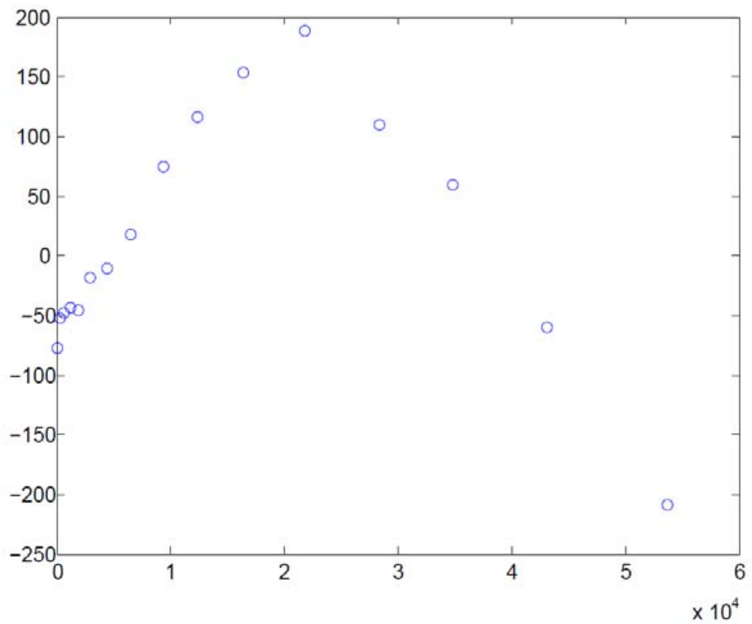


Figure 10. Deviation of data points from linear fit.

Experiment 4 (Conventional gain)

Following parameters were set before recording:

Exposure: 0.28485s
Delay between exposures: in sequence
Vertical shift speed: 1.7us
Vertical clock voltage: normal
Readout Rate: 1MHz

Pre Amplification Gain: 5.1x

Conventional output
Baseline clamp (stabilize the baseline of image)
Temperature: -85°C
Averaging box: 250×250
Number of frames: 10

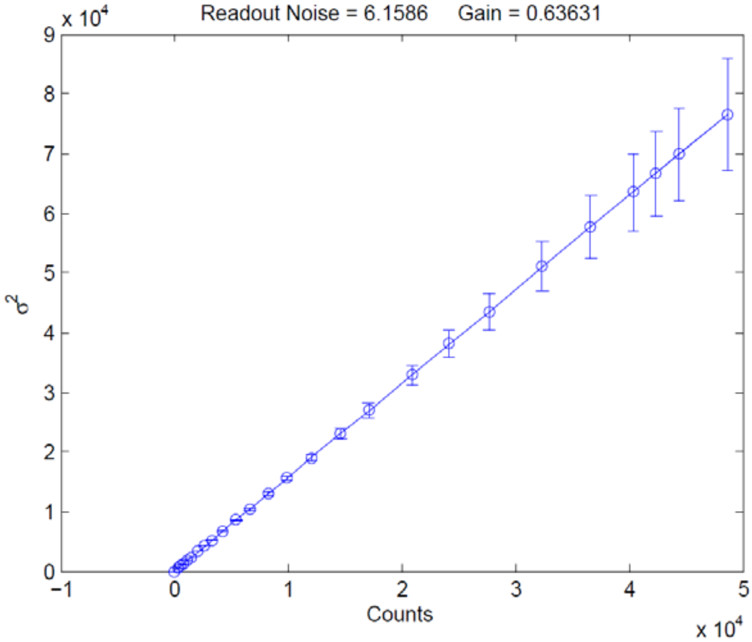


Figure 11. Gain measurement for Gain 5.1x and conventional output, the vertical error bar calculated from Eq(1)

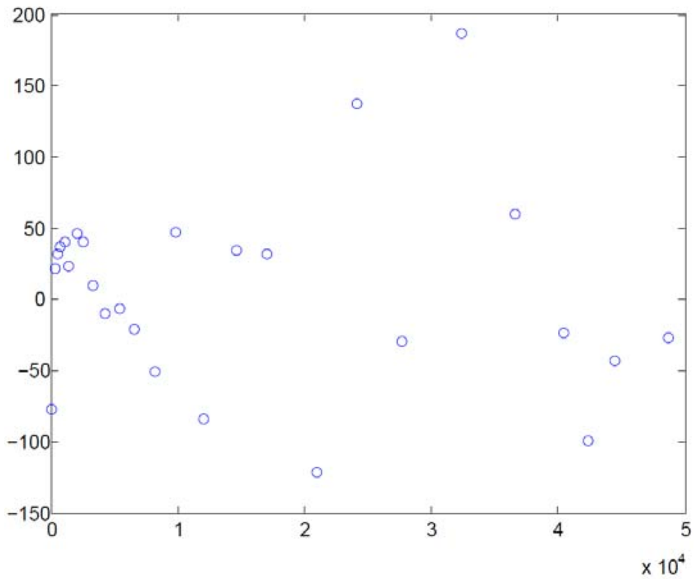


Figure 12. Deviation of data points from linear fit.

Experiment 5 (Conventional gain)

Following parameters were set before recording:

Exposure: 50ms

Delay between exposures: in sequence

Vertical shift speed: 1.7us

Vertical clock voltage: +4

Readout Rate: 1MHz

Pre Amplification Gain: 1x

Conventional output

Baseline clamp (stabilize the baseline of image)

Temperature: -85°C

Averaging box: 250×250

Number of frames: 10

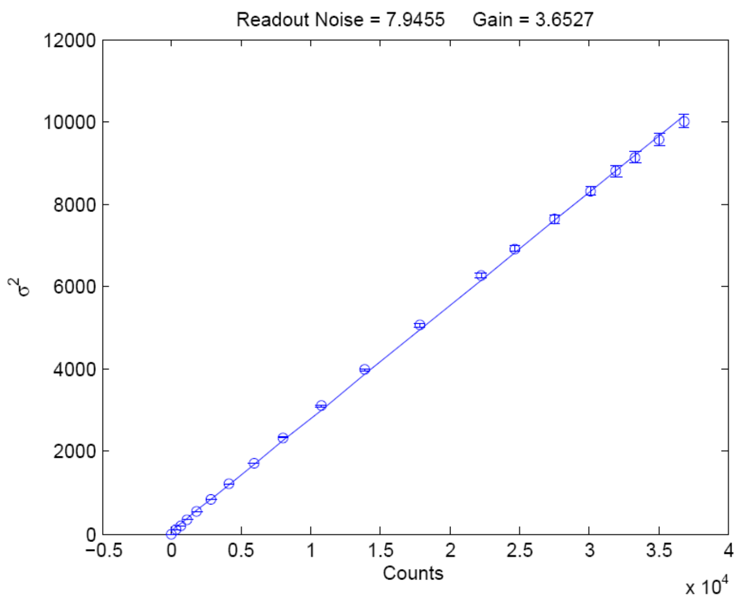


Figure 13. Gain measurement for Gain 1x and conventional output, the vertical error bar calculated from Eq(1)

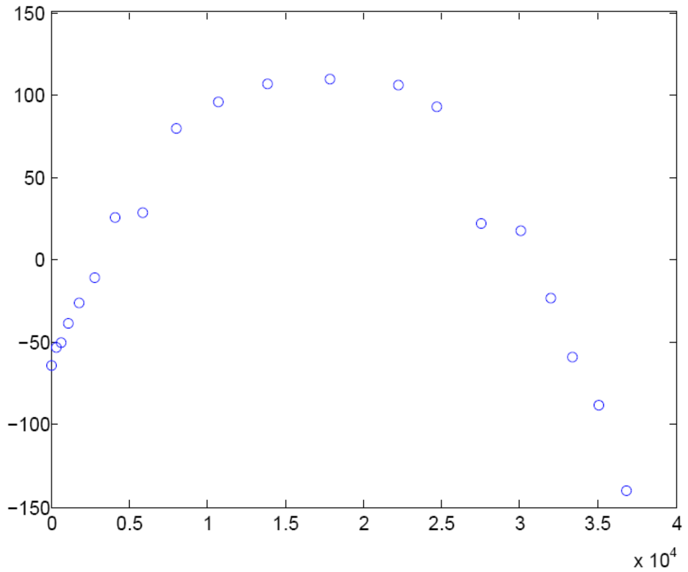


Figure 14. Deviation of data points from linear fit.

Experiment 6 (Conventional gain)

Following parameters were set before recording:

Exposure: 50ms

Delay between exposures: in sequence

Vertical shift speed: 3.3us

Vertical clock voltage: +4

Readout Rate: 1MHz

Pre Amplification Gain: 1x

Conventional output

Baseline clamp (stabilize the baseline of image)

Temperature: -85°C

Averaging box: 250×250

Number of frames: 10

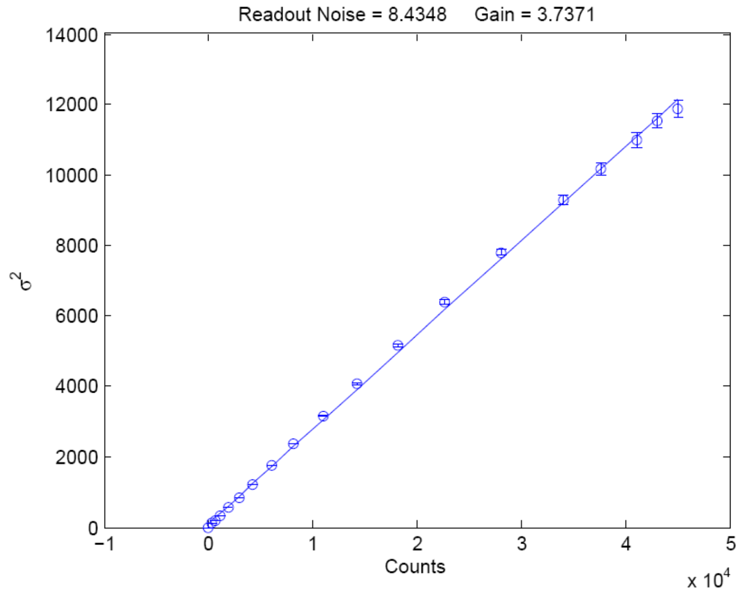


Figure 15. Gain measurement for Gain 1x and conventional output, the vertical error bar calculated from Eq(1)

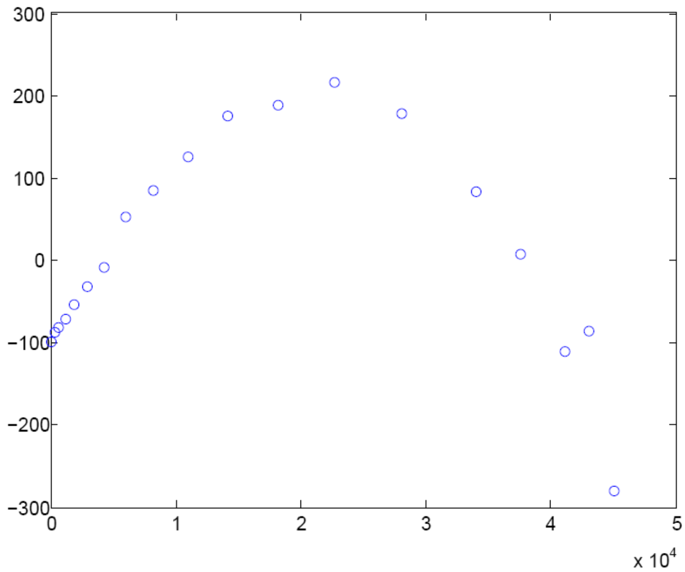


Figure 16. Deviation of data points from linear fit.

Experiment 7 (EM gain)

Following parameters were set before recording:

Exposure: 0.28485s

Delay between exposures: in sequence

Vertical shift speed: 1.7us

Vertical clock voltage: normal

Pre Amplification Gain: 1x

EM Readout Rate: 1MHz

EM Gain: 5

EM output

Baseline clamp (stabilize the baseline of image)

Temperature: -85^{o}C

Averaging box: 250×250

Number of frames: 10

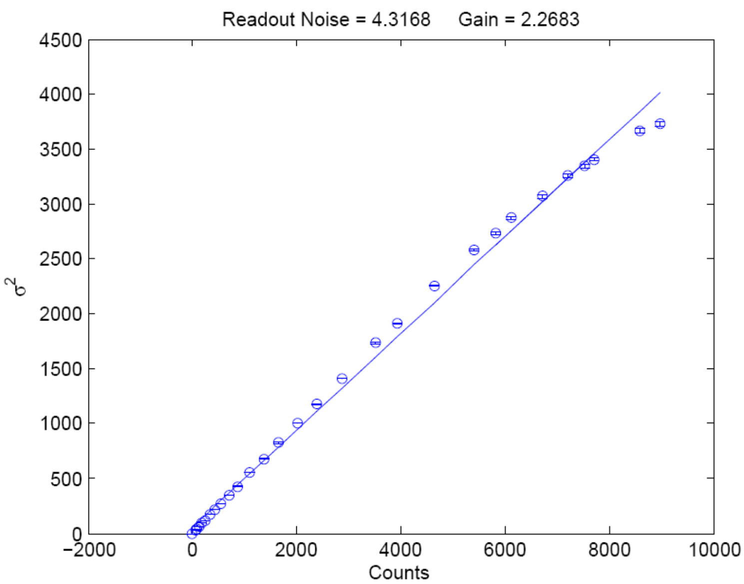


Figure 17. Gain measurement for EM Gain 5 and conventional output, the vertical error bar calculated from Eq(1)

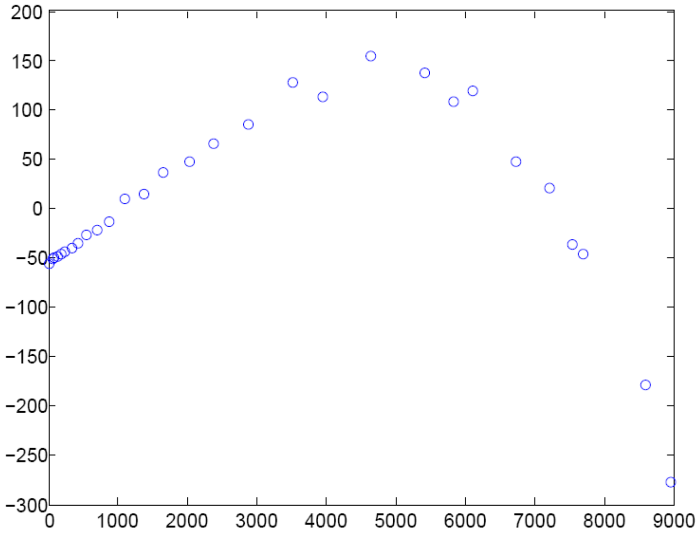


Figure 18. Deviation of data points from linear fit.

Experiment 8 (EM gain)

Following parameters were set before recording:

Exposure: 50ms

Delay between exposures: in sequence

Vertical shift speed: 1.7us

Vertical clock voltage: normal

Pre Amplification Gain: 1x

EM Readout Rate: 1MHz

EM Gain: 100

EM output

Baseline clamp (stabilize the baseline of image)

Temperature: -85^{o}C

Averaging box: 250×250

Number of frames: 10

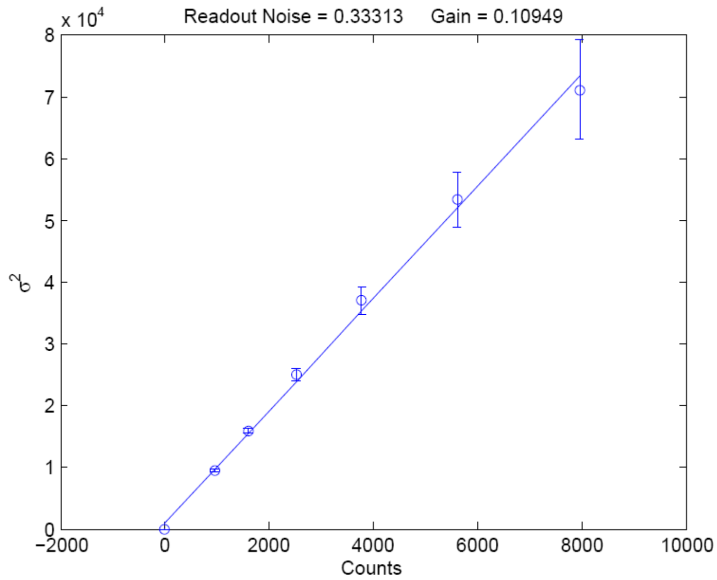


Figure 19. Gain measurement for EM Gain 100 and conventional output, the vertical error bar calculated from Eq(1)

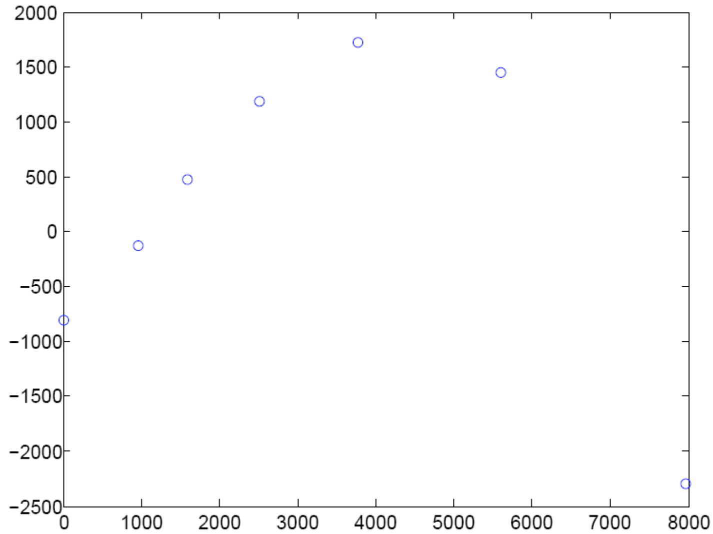


Figure 20. Deviation of data points from linear fit.

Experiment 9 (EM gain)

Following parameters were set before recording:

Exposure: 50ms

Delay between exposures: in sequence

Vertical shift speed: 1.7us

Vertical clock voltage: normal

Pre Amplification Gain: 1x

EM Readout Rate: 1MHz

EM Gain: 300

EM output

Baseline clamp (stabilize the baseline of image)

Temperature: -85°C

Averaging box: 250×250

Number of frames: 10

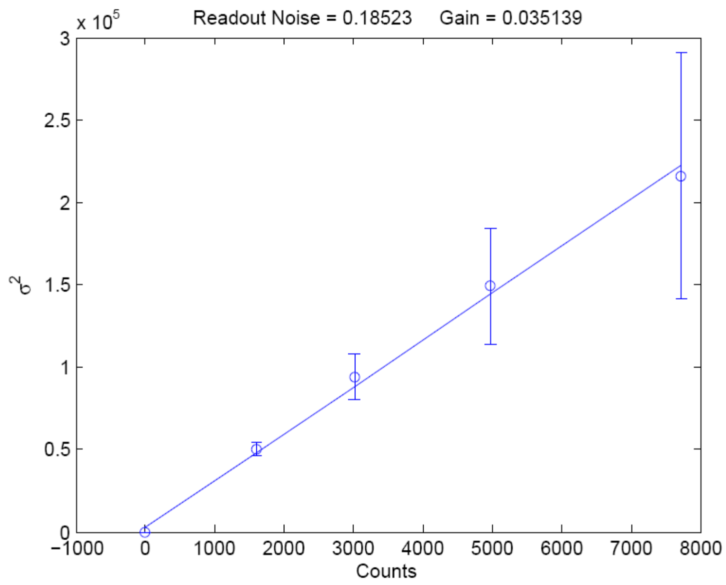


Figure 21. Gain measurement for EM Gain 300 and conventional output, the vertical error bar calculated from Eq(1)

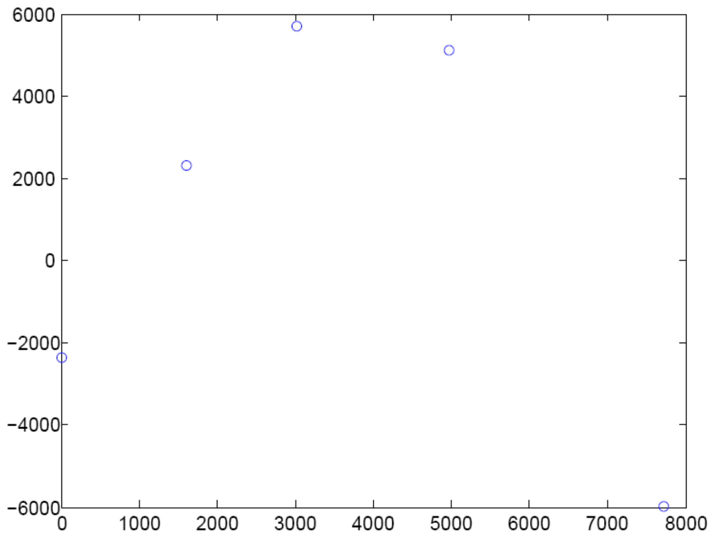


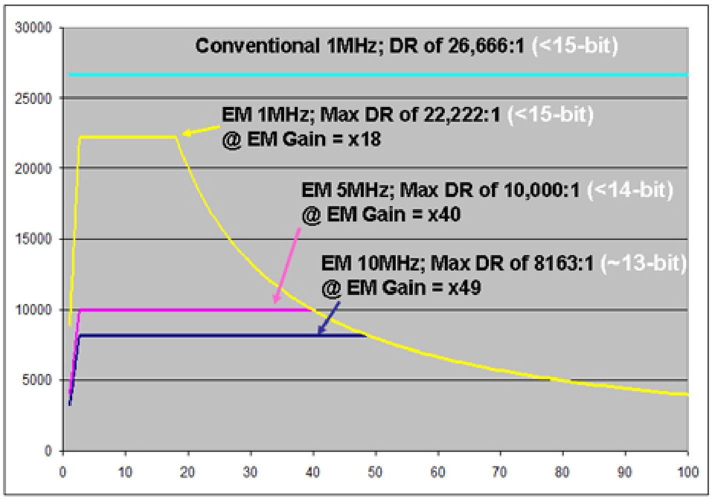
Figure 22. Deviation of data points from linear fit.

3. Discussion

Table 1 shows the summary of results. As it is expected, the nonlinearity is higher at EM mode. The nonlinearity decreases at higher gain, because of smaller the dynamic range of the CCD, Figure 23. Two other parameters, Vertical Shift Speed (VSS) and Vertical Clock Voltage (VCV) also affect the linearity response of camera. It is appear that at larger VCV and lower VSS the camera has lower nonlinearity. Higher VCV means higher voltage to push the electrons row by row and therefore larger efficiency. Small VSS means lower Clock Induced Charge (CIC) also called spurious charge. By increasing VSS, the probability of creation of spurious charge or non-photon derived electrons is increased, which, generate random high value pixels above the read noise.

Table 1. Summary of results

Experiment	Exposure	VSS	VCV	Gain	A/D Factor	Readout Noise	Nonlinearity
1	285ms	1.7µs	+1	1x	3.7	8.0	1.4%
5	50ms	1.7µs	+4	1x	3.7	8.0	1.1%
6	50ms	3.3µs	+4	1x	3.7	8.4	1.6%
2	285ms	1.7µs	Normal	1x	3.7	8.5	1.3%
3	285ms	1.7µs	Normal	2.5x	1.45	6.6	0.6%
4	285ms	1.7µs	Normal	5.1x	0.64	6.2	0.2%
7	285ms	1.7µs	Normal	5 EM	2.3	4.3	4.3%
8	50ms	1.7µs	Normal	100 EM	0.11	0.3	2.1%
9	50ms	1.7µs	Normal	300 EM	0.035	0.2	2.7%



The above plot shows Dynamic Range vs EMCCD Gain for iXon^{EM}+ DU-897. Shown for EM amplifier @ 10, 5 and 1MHz readout speed and for Conventional amplifier at 1MHz readout speed. Well capacities used in DR calculation are characteristic of the CCD97 512x512 back-illuminated L3 sensor from E2V. Dynamic range only exceeds 14-bits max @ 1MHz, through either amplifier.

Figure 23. Dynamic range for different CCD gain factor (Andor camera website)