How to Scientifically Determine CCD Gain and Offset Settings

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Many people have quarrelled with the values for the CCD gain and offset. The following method should help you determine the optimum settings for the gain and offset values to maximize the pixel full well capacity of the CCD. In this example nebulosity is used to determine the gain and offset settings for a QHY9M camera.

1. Determine Full Well Saturation Condition.

We need to determine what value the CCD reports when the pixel well depth is completely full. First we need a light source. Any light source will do. The brightness is not that important but at the same time we do not want it to be too bright or too dim. The brightness only determines how long it takes to fill the pixel wells. Too bright will fill it too quickly and too dim will take a longer time to complete the process. In this example a 60W bulb illuminated the room where the test was conducted. The CCD cover was removed and the CCD was pointed towards the ceiling but not directly at the light source. The following is now performed.

- Set the camera gain and offset to standard minimum values for your driver. In this example gain=0 and offset =100 were used. These were the driver defaults.
- Set the binning to the desired bin setting to evaluate. In this case binning = 1x1.
- Set the exposure duration for a doubling sequence (0.02, 0.04, 0.08, 0.16, 0.32, 0.64, 1.28.... seconds)
- Capture or preview the image at each of the time intervals, with shutter open.
- Record the entire image mean pixel value Nebulosity displays this value in the pixel stats display window. Be sure you are looking at the entire image mean and not a sample point mean.
- Repeat the process with the increasing time interval until the mean pixel value tops out. Chances are this value will not be 65535. The top out value indicates the pixel wells are completely full.
- Determine the minimum length of time it takes to fill the pixel well from you results. In the following example 0.64 seconds reaches pixel well saturation.

Gain		0
Offset		100
Bin	1x1	
Exposure	Mean	
	0.02	8873
	0.04	19438
	0.08	24760
	0.16	37585
	0.32	58804
	0.64	59144
	1.28	59139
	2.56	59131
	5.12	56136

2. Determine The Gain Value For 65535 At Full Well Saturation

We have just detmined the lighting and exposure condition to reach full well saturation. We know need to determine a gain value so the full well saturation occurs at the maximum bit depth. For a 16 bit A/D sample the maximum value is at 65535. The following sequence is now applied.

- Set the exposure duration to the minimum full well saturation time that was just determined. In this example 0.64 seconds.
- Capture images from the camera with the same light source as the previous step. This time the gain will be increased slightly with each image, rather than time. In this example the QHY9 driver gain are increased in numerical steps of 2. The QHY driver also reports the gain as a percentage to the user.
- Record the entire image mean pixel value.
- Repeat the process until the mean pixel value is saturated at 65535. Now pay attention to the minimum and maximum entire image pixel value. Some times the mean value may not reach 65535 because of cold pixels. If the minimum value reaches 65535 , record that as the mean value.
- Determine the Gain value at which 65535 is just reached or the value just before it is reached. In this example a gain of 14 (which is 22%) was determined.

Gain	2(3%)	4(6%)	6(9%)	8(12%)	10(15%)	12(19%)	14(22%)	16(25%)	18(28%)
0.64sec mean	55942	57429	58334	60679	62377	64242	65535	65535	65535

3. Determine An Offset Value For The Full Well Gain

Now using the previously determined gain we need to determine the offset value. The goal is that any image that we take should have a minimum mean pixel value above 0 units. So in this process we will take bias images with increases in the offset value and record the results. The following steps are performed.

- Install the lens cover on the camera and if available set the shutter to closed.
- Set the camera exposure duration to the minimum possible exposure time. In this example 0.001 seconds was used.
- If you have cooling regulation turn it off for the first pass. Lower temperature set points will be used in subsequent passes.
- Capture images from the camera. This time the offset will be increased slightly with each image. In this example the QHY9 driver gain are increased in numerical steps of 2.
- Record the entire image minimum, mean and maximum pixel value.
- Repeat the process until the mean pixel value is above 1000.

.001sec -closed

Gain 14(22%) Temp 24C

Offset	100	102	104	106	108	110	112	114
min	0	0	0	0	160	431	727	981
mean	0	0	0	29	284	549	838	1092
max	0	0	111	369	658	889	1194	1482

- Repeat the same process with decreased TEC temperature values, if available.

Gain 14(22%)	Temp 0C							
Offset	100	102	104	106	108	110	112	114
min	0	0	0	0	123	389	684	980
mean	0	0	0	0	245	508	795	1050
max	0	0	0	0	792	1143	908	1362

Gain 14(22%)	Temp -15C							
Offset	100	102	104	106	108	110	112	114
min	0	0	0	0	125	385	685	937
mean	0	0	0	0	252	497	805	1059
max	0	0	0	0	404	1085	1169	1316

- Determine an offset value where the lowest temperature will reasonably report a value between 500-1000 for all temperatures. In this example an offset of 112 was chosen.

4. Re-assess The Effect Of The Offset Value On The Gain Value.

Gain and offset adjustments directly impact each other. For best optimization we need to go back and re-assess the effect which offset value change has had on the gain value. Using the offset value, that was just determined, run the gain assessment sequence, again.

- Set the exposure duration to the minimum full well saturation time that was previously used. In this example 0.64 seconds.
- Set the offset value to the value that was just determined.
- Capture images from the camera with the same light source as the previous step. This time the gain will be increased slightly with each image, rather than time. In this example the QHY9 driver gain are increased in numerical steps of 2 and they report the percentage of gain to the user.
- Record the entire image mean pixel value.
- Repeat the process until the mean pixel value is saturated at 65535. Now pay attention to the minimum and maximum entire image pixel value. Some times the mean value may not reach 65535 because of cold pixels. If the minimum value reaches 65535 , record that as the mean value.

Lights 0.64sec									
Off=112	2(3%)	4(6%)	6(9%)	8(12%)	10(15%)	12(19%)	14(22%)	16(25%)	18(28%)
0.64sec- mean	61644	63284	65016	65479	65535	65535	65535	65535	65535

- Determine the Gain value at which entire image mean pixel value of 65535 is just reached or the value just before it is reached. In this example a gain of 8 (which is 12%) was determined.
- Now we will play a little bit of math and optimization. A gain of 8 (12%) is just when the full well depth is totally full. When the saturation limit is approached, the linearity response of the analog-digital converter tapers off on the upper end. Our goal is to reduce the effect of the non-linear portion at saturation. Ti fix this we will increase the gain slightly more than this point. This will help to optimize the pixel values are more in the linear response. So in this case we will increase the gain by 5%. Basically this can be thought as that 65535ADU will be reached when 95% of the full well capacity is

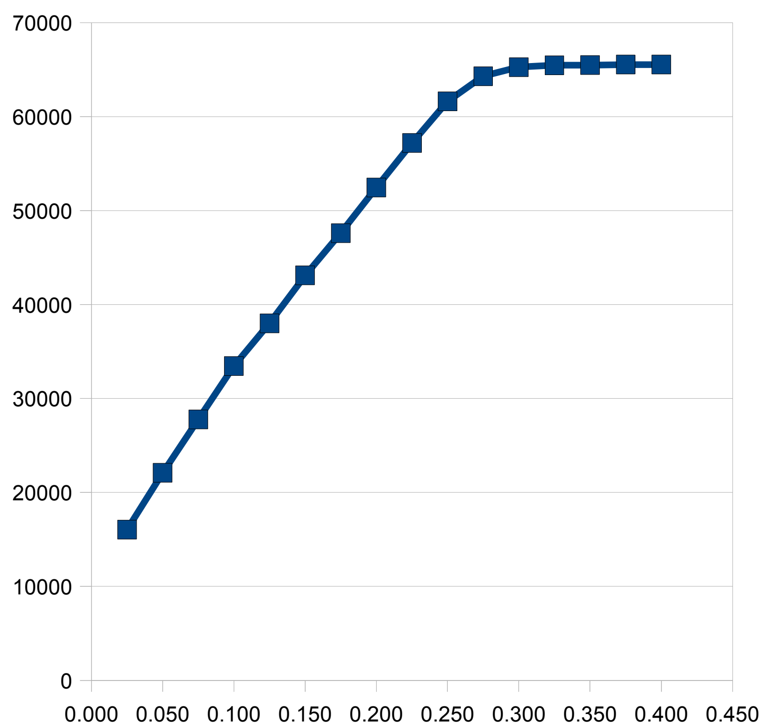
reached. We will not wait for the last non-linear 5% response. So in this example we will now say the optimum gain value is 12% + 5% = 17% or gain = 11

- If one was really concerned the offset check could be redone to determine how much change was done to offset. The selection of 500-1000 ADU should protect us from this.
- So now the optimum values for this camera are gain = 11 and offset =112.

5. As A Final Step, Complete A Photon Response Plot Of CCD.

- Set the camera gain and offset values to the optimum values that were just determined. In this example gain=11(17%) and offset =112 were used.
- Install the camera cover and set the shutter closed for the first exposure. We will validate the offset response with these settings.
- Set the first image duration for the shortest exposure possible. In this example 0.001sec.
- Capture and record the entire image mean pixel value. It should be above 400 ADU.
- Remove the camera cover and open the shutter to expose the camera to the same light source in step 1. Set the exposure duration for steps of 0.025 seconds or some step size that will be reasonable for 10 - 20 steps to reach full saturation at 65535.
- Capture or preview the image at each of the time intervals and record the entire image mean pixel value.

Gain		11(17%)
Offset		112
Bin	1x1	
Exposure	Mean	
0.001		689
0.025		16040
0.050		22085
0.075		27769
0.100		33461
0.125		38000
0.150		43105
0.175		47600
0.200		52455
0.225		57190
0.250		61616
0.275		64299
0.300		65271
0.325		65465
0.350		65483
0.375		65535
0.400		65535
0.425		65535
0.450		



- We can see the roll into saturation occurs very nice and is not prolonged over an extended range because of the 5% gain increase. Also the drop in gain still leaves the minimum exposure of 0.001 second well above 0 ADU.

6. Repeat the same process for all binned settings for your camera. In some cases gain might reduced to minimum value and offset is only thing that still has range to affect. The end result is full pixel values will be reported for approximately 95% full well capacity, thus maximizing the camera's capability. Higher gains could be use, but this will only result in compression of the CCD dynamic range. For this test QHY9M CCD camera, the optimum gain and offset settings have been determined as the following:

	Optimum	
Binning	Gain	Offset
1x1	11 (17%)	112
2x2	0	110
3x3	0	102
4x4	0	100

Footnote: The process may seem like a detailed process. In actual fact is is very easy and the test example only took 2 hours to complete all in the warmth of the indoors for all operating modes. Good luck and happy imaging. The following are some nebulosity scripts that can help complete the process even faster.

For Step 1 test saturation.txt

```
setTimelapse 3000
SetShutter 0
SetOffset 100
SetGain 0
Setduration 20
Capture 1
Setduration 40
Capture 1
Setduration 80
Capture 1
Setduration 160
Capture 1
Setduration 320
Capture 1
Setduration 640
Capture 1
Setduration 1280
Capture 1
Setduration 2560
Capture 1
```

For Step 2 test Gain.txt

```
setTimelapse 3000
SetShutter 0
SetGain 2
Capture 1
SetGain 4
Capture 1
SetGain 6
Capture 1
SetGain 8
Capture 1
SetGain 10
Capture 1
SetGain 12
Capture 1
SetGain 14
Capture 1
SetGain 16
Capture 1
SetGain 18
Capture 1
```

For Step3 Offset run.txt

```
setTimelapse 4000
SetShutter 1
PromptOK Install CCD cover
SetOffset 100
Capture 1
SetOffset 102
Capture 1
SetOffset 104
Capture 1
SetOffset 106
Capture 1
SetOffset 108
Capture 1
SetOffset 110
Capture 1
SetOffset 112
Capture 1
SetOffset 114
Capture 1
```

For Step 6 Photon final.txt

```
setTimelapse 3000
PromptOK Install CCD cover
SetShutter 1
Setduration 1
Capture 1
PromptOK Remove CCD cover
SetShutter 0
Setduration 25
Capture 1
Setduration 50
Capture 1
Setduration 75
Capture 1
Setduration 100
Capture 1
Setduration 125
Capture 1
Setduration 150
Capture 1
Setduration 175
Capture 1
Setduration 200
Capture 1
Setduration 225
Capture 1
Setduration 250
Capture 1
Setduration 275
Capture 1
Setduration 300
Capture 1
Setduration 325
Capture 1
Setduration 350
Capture 1
Setduration 375
Capture 1
Setduration 400
Capture 1
Setduration 425
Capture 1
Setduration 450
Capture 1
```