Fast Conversion Factor (Gain) Measurement of a CCD Using Images With Vertical Gradient

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Abstract

This poster describes a fast technique for estimating the Conversion Factor of a CCD. It is based on the adjustment of the standard photon transfer curve technique to 2 TDI (Time Delay Integration) images. A similar technique based on one TDI image will also be presented. The data used to test the procedure are taken with the ESO ODT test bench facilities, in the context of characterizing the OmegaCAM CCDs. No modifications to the test bench are needed to use this technique. For seven CCDs, results from the standard photon transfer method, and with the two techniques developed in this paper were compared. Results are very good. This technique is still under development, and possible future improvements will be discussed. If it proves reliable, this technique can be used for simple and efficient gain measurements of CCDs.

Introduction

Contrary to a standard image which is read out entirely after some period of light collection, a TDI acquisition consists of collecting light and reading out continuously the image on a detector one row of pixels at a time from the bottom of a detector chip (where the output register is located). Under a constant illumination (shutter fully open), this reading mode will create an image (see Figure 1) with a typical response shown Figure 2.

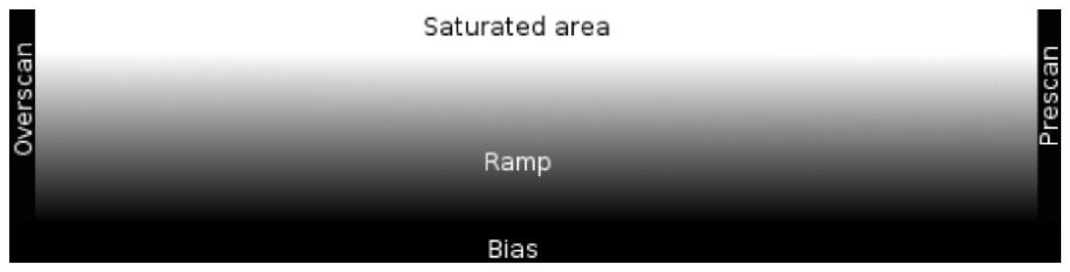

Figure 1: Example of a TDI image taken with the ESO test bench. Here is a 2148x512 pixels size image. A legend has been added. The area where is the ramp, is also called in this paper sensitive area.

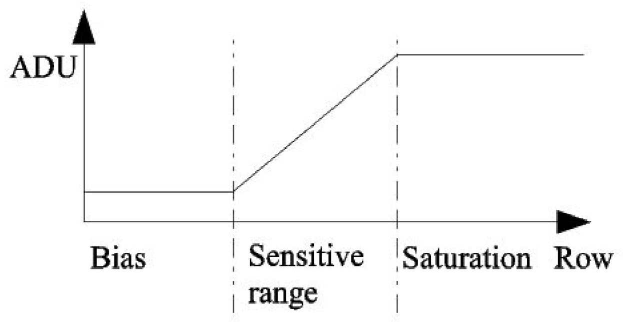

Figure 2: Typical response of a TDI image.

The sensitive area of such images, flat fielded by a normalized flat-field, is also used to measure the linearity and residual non linearity (Cyril Cavadore & al 1999) in the ESO CCD test procedure.

Photon Transfer Curve From TDI Images, Gain

The principle and the mathematical tools are the same as in the standard photon transfer curve technique. The variance of the signal will be plotted versus the mean signal. To extract these parameters the following manipulations have to be done.

Method 1: Extraction of the signal and the variance from Two TDI images

To measure the mean signal, two TDI images are averaged. In the sensitive area, the mean of each row is measured and the bias subtracted.
To measure the variance we subtract one TDI image from the other (See Figure 3). From each row of the sensitive area the variance, σ^2_{pv}, is measured ($\sigma^2_{pv} = \sigma^2/2$ The variance is divided by two to obtain the variance of the line in a single frame).

Method 2: Extraction of the signal and the variance from One TDI image

In the sensitive area, the mean of each row is measured and the bias subtracted. This procedure gives us the averaged signal for each line.
To have an estimate of the variance, for each line of the ramp, we subtract to each pixel the pixel on its right. This step is done to "simulate" the subtraction of two images like in method 1. Then variance of each line is measured. This value is divided by two to obtain the variance for a single line.

Comment: In normal circumstance, in a flat field for example, such technique will not give you the shot noise but the shot noise plus the pixel to pixel non uniformity variation.
Here, in the case of a TDI image, the quantity of electron in a pixel is the sum of all the elementary flux it received during its complete transfer until the output register. Except in the first few lines read out, the pixel intensity in the output image is thus barely affected by the pixel to pixel non uniformity.

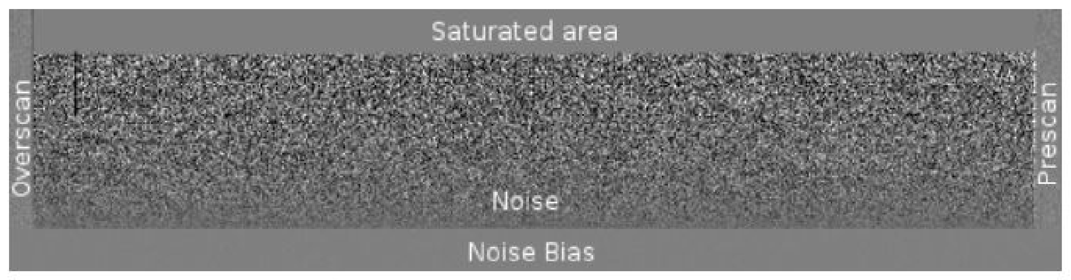

Figure 3: Example of noise pattern after subtraction of two images. Similar patterns are observed with same characteristics when we apply the pixel to pixel subtraction (Method two).

Photon Transfer Curve

We have now from each row the signal, $\bar{S}_{pv}$, and the variance σ^2_{pv}. The plot of the ($\bar{S}_{pv}$, σ^2_{pv}) pairs will give us the photon transfer curve. The slope of the linear fit is the inverse of the conversion factor and from the y-axis intercept we can calculate the readout noise but it is better to measure this parameter from bias frames.

$$\sigma^2_{pv} = \frac{1}{g}\bar{S}_{pv} + \frac{1}{g^2}\sigma^2_{ron} \qquad (1)$$

Results, comparison

To test method one and two, sets of data from seven 44-82 e2v CCDs are used. The data from Five CCDs (ColumbaII, Lepus, MicroscopiumII, Musca AustralisII and Reticulum)[a] tested with a low gain mode (~2.5 e- / ADU) and the data from two CCDs (Carina and Canis Major)[a] tested with a high gain mode (~0.5 e- / ADU) are taken.

Method one and two will be compared to the standard technique used in the OmegaCAM test procedure to measure the gain.

This technique is based on the photon transfer method (or variance method). Two flat field (F1 and F2) and two bias exposures (B1 and B2) are taken and equation (2) applied. From the image I, 100 sub-windows are selected. In each sub-window i, the mean signal, $\bar{S}_i$, and its variance, σ^2_i , are measured. The gain is calculated using equation (3) and the gain's error is the standard deviation of the 100 conversion factors measured.

$$I = \frac{F_1 - B_1}{F_2 - B_2} M\left(F_2 - B_2\right) \quad (2) \qquad g_i = \frac{2\bar{S}_i}{\sigma^2_i} \quad (3)$$

For each CCD and for both methods, the photon transfer curve is plotted (see an example of the curve Figure 4) and the conversion factor calculated. The results are in Table 1 and 2.

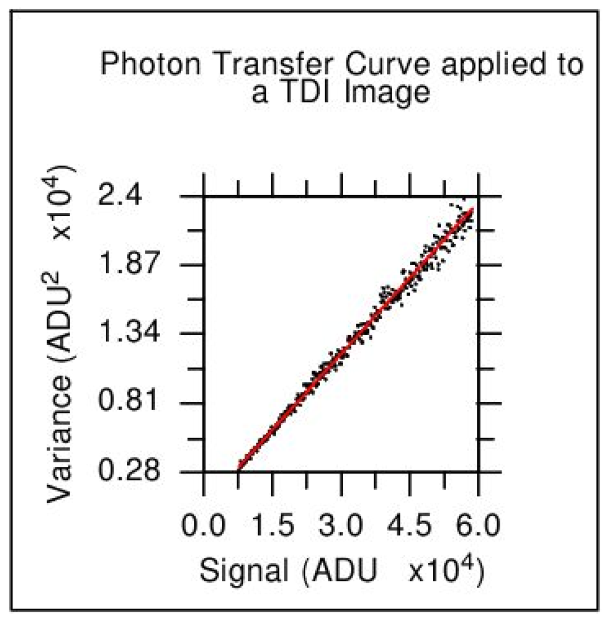

Figure 4: Example of a photon transfer curve realized with two TDI images. Similar pattern is observed with the technique based on one TDI image.

CCD nickname	Gain*		
	From one TDI Image	From two TDI Images	Standard technique
Reticulum	2.60 ± 0.01	2.58 ± 0.01	2.59 ± 0.02
ColumbaII	2.51 ± 0.01	2.50 ± 0.01	2.52 ± 0.02
Lepus	2.64 ± 0.01	2.62 ± 0.01	2.58 ± 0.01
MicroscopiumII	2.50 ± 0.01	2.50 ± 0.01	2.51 ± 0.01
Musca AustralisII	2.62 ± 0.01	2.60 ± 0.01	2.62 ± 0.01

$^*e^-/ADU$.

Table 1: Results obtain from the different methods. In column one we have the gain measured with one TDI image, column two the grain from two TDI images and column three the gain measured with the photon transfer technique. The low gain mode of FIERA has been used (~2.5 e- / ADU).

CCD nickname	Gain*	
	From one TDI Image	Standard technique
Carina	0.522 ± 0.001	0.522 ± 0.002
Canis Major	0.543 ± 0.001	0.541 ± 0.002

$^*e^-/ADU$.

Table 2: Test of the photon transfer curve on one TDI image (column one) and compared to the standard photon transfer technique (column two). The images were taken with the high gain mode of FIERA (~0.55 e- / ADU).

In the method 2 we assume that the total noise is not affected by the noise from the pixel-to-pixel non uniformity. In reality, it is. Particularly at the beginning of the ramp. The noise from Photon Response Non Uniformity (PRNU), even if it is smoothed, still exists and affects the total noise. Figure 5 shows the ratio, variance from one image divided by the variance from two images versus row number. The cloud of points is not scattered around the horizontal line (y=1) but around (y=1.0173 – 4.1e-3 N_{row}). The variance from one image is slightly higher than it should be and will bias the conversion factor measurement.

Precautions have to be taken if method 2 is used. To reduce the systematic error, the points measured at the beginning of the ramp are not taken into account to estimate the best fit in Fig 4.

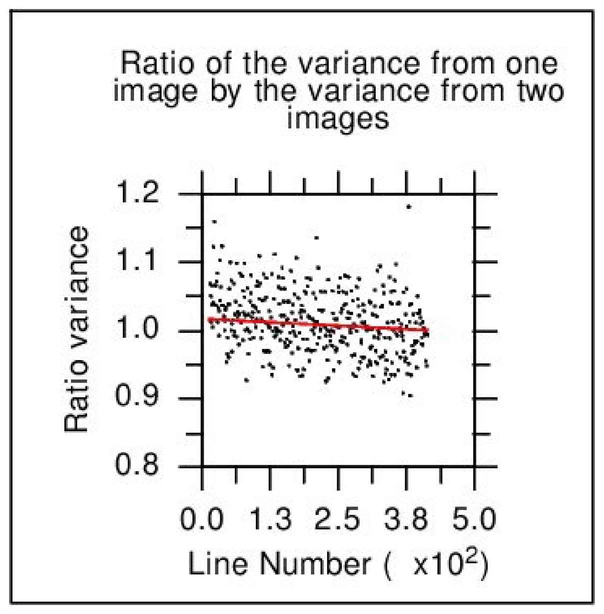

Figure 5: To compare method 1 and 2, the ratio of the variance from one image by the variance from two images are performed for each line (in x-axis, 0 corresponds to the bottom line of the sensitive area (Fig. 1).

Conclusion

This poster describes a fast and efficient technique to estimate the Conversion Factor (Gain) of the CCD. It is based on the photon transfer curve adjusted to TDI images (one or two). It has been tested on data taken at ESO Garching by the Optical Detector Team (ODT) team to characterize the OmegaCAM CCDs. The TDI images are taken during the ESO CCD test procedure to measure the linearity of the chips. The preliminary results to measure the gain with these data are very promising. They are in agreement with the standard gain measurement method.

This technique have the advantage to use the ESO test bench without any modification, provides more points for the photon transfer curve (here in our test about 400 points per plot) and is very quick. Only one or two TDI images and a set of flat field are necessary to measure the Linearity, Residual non Linearity and the Conversion Factor.

Due to the fact that the gain measurement with this method is faster than the standard one, it is appropriate to use it during the tuning of CCDs (voltage adjustment). Complementary work will be done to improve the measurements (cosmetic defects extraction, automatic detection of the sensitive area, weighted least square method instead of the standard one, automatic detection of the non linearity regime). To validate the final technique and to know its limits, comparison has to be done with Fe55 and standard photon transfer curve method.

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4: Thales, France.

a: All 88 CCDs of the OmegaCAM project were assigned a constellation as a nickname

James R. Janesick, "Scientific Charge-Coupled Devices" SPIE Press monograph, Bellingham Washingthon 2001, (Chapter 2.2.10.2 "Shutterless Photon Transfer").
Cyril Cavadore & al, "New Test Bench" ESO Internal Document.
Steve B. Howell, "Handbook of CCD Astronomy", Cambridge University Press.