CCD CHARGE TRANSFER EFFICIENCY (CTE) DERIVED FROM SIGNAL VARIANCE IN FLAT FIELD IMAGES

The CVF method

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Abstract: This paper describes a novel technique for estimating the CTE of a CCD. It is based on the change in variance with CCD row or column in simple flat field images, and uses the fact that imperfect charge transfer during readout has a smoothing effect on the final image. The data used to test the procedure are acquired with the ESO test bench, in the context of characterizing the OmegaCAM CCDs. For nine CCDs results from the CTE measurements by e2v and with the variance based technique developed in this paper were compared. Results are promising. This technique, still under development, proved reliable and can be used for simple and efficient CTE measurements.

Key words: Charge-Coupled-Device characterization, Charge Transfer Efficiency.

1. INTRODUCTION

During the tests of the OmegaCAM[1] CCDs (Christen 2002), flat images have been acquired using the ESO test bench (Amico 1996) to check out the chips cosmetics. This paper will describe how to use these data to measure also the charge transfer efficiency. This parameter, reported in units of percent, characterizes the efficiency to transfer correctly charges from one

[1] OmegaCAM is a one square degree wide field imager which will be mounted on the VST telescope in Paranal, Chile, (Kuijken 2004 & Iwert 2005, Scientific Detector Workshop 2005, “The OmegaCAM 16k x 16k CCD Detector System for the ESO VLT”)

pixel to its neighbor. It will be extracted from the study of the variance of the signal measured in them.

After a description of the Change in Variance in Flat field (CVF) method in Section 2, the first results will be presented in Section 3. The preliminary conclusions are in section 4.

2. CHANGE IN VARIANCE IN FLAT FIELD (CVF) METHOD

Instead of studying the loss of signal like in the EPER method (Janesick 2001), the loss of variance across flat field images will be analyzed. During the transfer of charges, flat field images will be smoothed due to the charge loss. The signal in the flat field remains constant during the transfer but the variance from one line (column) to the other will decrease as soon as the CCD is read. See below the effect of an imperfect transfer on the variance:

$$\sigma_e^2(i) = a^{2i}N_e + \binom{i}{1}^2 a^{2i-2}b^2N_e + \cdots + \binom{i}{i-1}^2 a^2b^{2i-2}N_e \qquad (1)$$

$$\sigma_e^2(i) = a^{2i}N_e + O(b^2) \qquad (2)$$

$\sigma_e^2(i)$: Variance of the signal in e$^-$ of the line i
N_e : Number of electrons
a : Charge Transfer Efficiency, CTE
b : Charge Transfer Inefficiency, CTI, $(b = 1 - a)$
$O(b^2)$: Residual, $O(b^2) << a^{2i}N_e$

By using the CTI $b = 1 - a$, and considering that $b << 1$, the term $(1-b)^{2i}$ becomes $1 - 2ib + O(b^2)$ and Eq. (2) can be written as follows:

$$\sigma_e^2(i) = N_e - 2ibN_e + O(b^2) \qquad (3)$$

Equation (3) can be expressed in Analog Digital Unit (ADU) instead of electrons. The signal and the variance, measured in electrons, are related to the signal and variance respectively in ADU by:

$$N_e = gN_a \text{ and } \sigma_e = g\sigma_a \qquad (4)$$

g : Gain in electrons per ADU
N_a : Number of ADU
σ_a : rms noise in ADU

Equation (3) becomes:

$$\sigma_a^2(i) = \sigma_{a0}^2 - 2b\sigma_{a0}^2 i + O(b^2) \tag{5}$$

σ_{a0} : rms noise in ADU before any charge shift

The Eq. (5) shows a linear dependence between the variance of the signal in line (column) i and the line number i. To estimate this equation, we will use the best fit line of the set of points $(i, \sigma_a^2(i))$.

To measure the variance of each line, two flats (same level) and two biases are taken. The bias images are subtracted from the flats and these two new images are divided, one by the other. The result is multiplied by the mean of one of the images. The final result will give an image (R) with fixed pattern noise (Photon Response Non Uniformity, PRNU) flat fielded out. The total noise (in pixel units, ADU) in this image R will be composed of photon noise and read out noise essentially. To measure the photon noise, the read out noise[2] is subtracted from the total noise.

To create the plot variance of lines (columns) versus lines (columns), we measure the variance for each line (column) of R. This value is divided by 2 to have the variance of one line and the point $(i, \sigma_a^2(i))$ is plotted, see Figure 1 for example. During the calculation of the variance, bad pixels are eliminating by using the sigma clipping method.

The best fit line will give us:

$$\sigma_a^2(i) = \mu - \nu\, i \tag{6}$$

μ : y-axis intercept (in ADU^2)
ν : slope of the line

The constant term μ will give us the variance of the signal before being

2 This parameter is measured by subtracting two bias images. The variance of the pixels in the difference image is equal to two times the read out noise squared. The variance from this image can be directly subtracted from the variance measured in the image R to have only two times the photon noise squared in ADU.

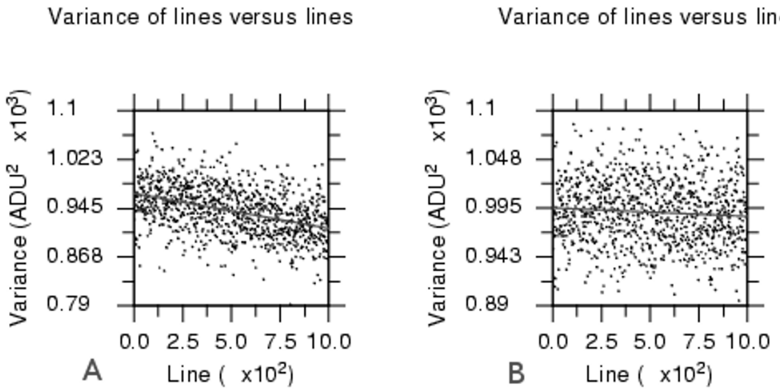

Figure 1. Image A and B show the plot $\left(i, \sigma_a^2(i)\right)$ at different CTEs with the best fit line in red. In A, the CTE is 0.999970 and in B, 0.999996. These plots have been done with simulated data. The dimensions of the images are 1k x 1k. The number of electrons in the images is 1000 plus a Poisson noise. The CTE is applied after. Similar pattern are observed with real data. In the x-axis, the line count increases away from the readout register.

affected by the charge transfer inefficiency and the slope, ν , divided by 2μ , the charge transfer inefficiency. The charge transfer efficiency, a, is then:

$$a = 1 - \frac{\nu}{2\mu} \qquad (7)$$

3. RESULTS

3.1 Simulated Data

The CVF method has been tested on simulated data. Two images (1k x 1k) with a mean intensity of 1000 e^- and a photon noise of $\sqrt{1000}$ have been created. For each set of images different CTEs have been applied (see column one and four of the Table I). The procedure, based on the study of the variance and developed section 2 is used to extract the horizontal and vertical CTE.

The first tests with these simulated data show, Table 1, that the CVF method approximates extremely well the CTEs. The measurements are in accordance with the original values of the CTE.

Table I. CTE measured with the CVF method applied to simulated data.

CTE	CVF		CTE	CVF	
H & V CTE	H-CTE	V-CTE	H & V CTE	H-CTE	V-CTE
	0.9999.. ± 0.000001		0.999992	92	92
1.	1.	99	0.999990	90	90
0.999998	98	98	0.999985	85	85
0.999996	95	95	0.999980	80	81
0.999994	93	94	0.999970	71	71

The first and fourth columns are the theoretical CTE in the simulated data. Columns two, three, five and six are the horizontal and vertical CTE measured with the CVF method.

3.2 Real Data

The CVF method has been tested on the data of 9 different CCDs. For each CCD two bias and two flat field images have been recorded. For 5 CCDs, these data are acquired using a read out speed of 225kpix/s and a gain set at ~0.55e^-/ADU. For 4 CCDs, the data are taken with the same read out speed and a gain at ~2.5e^-/ADU. The operating temperature is -120 degrees.

The CTE from the e2v data sheet are included in our table of results for comparison. E2v uses the ^{55}Fe method (Janesick 2001). The working temperature is -100 degrees Celsius and the read out speed, 250kpix/s.

The results, reported in Table IIA and Table IIB are encouraging. Almost all the measurements carried out with the CVF method are consistent with the measurements from e2v.

These results should not hide the difference observed for the devices 02111-01-02 and 02111-05-02. For these two CCDs, the CVF method is not in accordance with the e2v results. This difference may due to traps. In flat fields, the traps are full and do not catch charges during the transfer which is not the case with images taken with the ^{55}Fe setup. In that case the traps catch more charges and reduce the CTE.

4. CONCLUSION

This paper has described an interesting alternative technique to estimate the Charge Transfer Efficiency of a CCD.
This method is based on the study of the change in variance with CCD row or column in simple flat field images, and uses the fact that imperfect charge transfer during readout has a smoothing effect on the final image.

The data used to test the CVF method are simulated data (an ideal 1k x 1k CCD with only charge transfer inefficiency) and real data from the OmegaCAM CCDs. The results are very promising. The measurements done

Table II. Horizontal and Vertical CTE measured with the CVF and ^{55}Fe method.

CCD	H-CTE		V-CTE	
	CVF	^{55}Fe	CVF	^{55}Fe
A	0.9999.. ± 0.000001			
09253-13-01	99	99	98	98
00152-16-01	98	98	98	98
00152-13-02	98	97	98	97
00152-05-01	96	97	99	98
00152-12-02	98	99	97	97
B				
02111-01-02	97	93	99	99
02111-05-02	98	95	98	99
02111-13-01	97	97	98	98
02263-20-02	95	96	99	98

In the part A, the data are taken with a read out speed of 225kpix/s and with a gain set at ~0.55 e^-/ADU. In the part B, the read out speed is the same but the gain is set at ~2.55e^-/ADU.

with simulated data are in accordance with the theoretical CTE. We observe the same results with almost all the measurements achieved with real data. In that case the CVF method is compared with the measurements done with a ^{55}Fe set up. On top of that, this method overcomes the use of a dangerous radioactive material, such as ^{55}Fe, that needs special tooling and entrance windows to perform the measurements.

This technique is still at its preliminary development however, convinced by these first results, the procedure will be intensively tested and improved.

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