Charge Transfer Efficiency (CTE) based on the variance of the signal in Flat Field Images and Gain Correction

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Abstract

This poster 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 a 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 taken with the ESO ODT test bench facilities, in the context of characterizing the OmegaCAM CCDs. For nine CCDs results from the CTE measurements by e2v, by ESO (EPER method), and with the variance based technique developed in this poster were compared. Results are promising. This technique is still under development. If it proves reliable, this technique can be used for simple and efficient CTE measurements of CCDs, also outside the laboratory.

Charge Transfer Efficiency, Definition.

After collecting the light during the integration period, the charges collected by each pixel have to be transfered to the output well to be quantified. During the transfer, charges are lost due to the imperfection of the process. Defects in the silicon can remove fraction of charges from the transfered packet. The CTE is the parameter, reported in units of percents, that characterize the efficiency to transfer correctly charges from one pixel to its neighbor. An example of the effect of the Charge Transfer Inefficiency (CTI = 1 - CTE) can be found Figure 1.

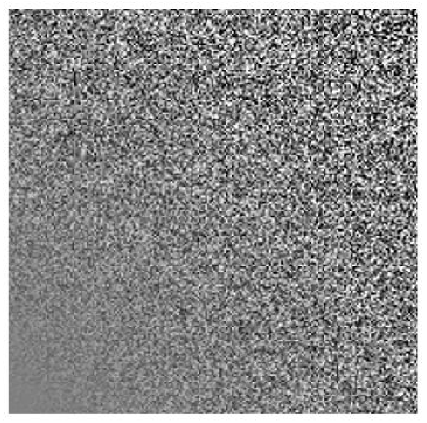

Figure 1 (right): Effect of the CTI. A simulated flat field image (1k x 1k) has been created, duplicated and modified with a CTE equal to 0.999970. What we see is the subtraction of the modified image from the original one(cuts of the image in ADU, [-3,3] around the level 0). The output is on the bottom left.

Extended Pixel Edge Response (EPER) Method

To characterize the OmegaCAM CCDs, the EPER technique has been used. To use this method, flat fields with overscan region are necessary. The charges lost due to the non perfect charge transfer process will be collected in the overscans and the majority of them in the first line and first column. The mean intensity in the last sensitive line (column), I_n , and the mean intensity in the first line (column) of the overscan region, I_{n+1} , are measured. Knowing the number of transfer necessary to read the complete image (n) we can measure the Charge Transfer Efficiency with equation (1):

$$a = 1 - \frac{I_{n+1}}{nI_n} \qquad (1)$$

Change in Variance in Flat Field (CVF) Method

Instead of studying the loss of signal like in the previous method, we will analyze the loss of variance across flat field images.

Principle: During the transfer of charges, flat field images will be smoothed due to the charge lost. The signal, N_e, in the flat field will stay constant during the transfer (conservation of charges) but the variance, σ_e^2, from one line (column) to the other will decrease as soon as the ccd is read. For each pixel in the line (column) i, the effect of an imperfect transfer of charge affects the variance as follows (a and b are the charge transfer efficiency and inefficiency):

$$\begin{aligned} \sigma_e^2(i) &= a^{2i}N_e + \binom{i}{1}^2 a^{2i-2}b^2N_e + \ldots + \binom{i}{i-1}^2 a^2b^{2i-2}N_e \qquad (2) \\ &= a^{2i}N_e + o(b^2) \qquad (3) \end{aligned}$$

By using the CTI b = 1 - a, and as we have 2i>0 and b<1, $(1-b)^{2i}$ can be decomposed according to the binomial series. Eq (3) becomes:

$$\sigma_e^2(i) = N_e - 2ibN_e + o(b^2) \qquad (4)$$

With $N_e = g\,N_a$ and $\sigma_e = g\,\sigma_a$, we can express Eq. (4) in Analogic Digital Unit (ADU)

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

To estimate the linear equation (5), we will use the best fit line of the set of points (i, σ^2(i)).

$$\sigma_a^2(i) = \mu - \nu i \qquad (6)$$

The constant term μ will give us the variance of the signal before being affected by the CTI and the slope ν divided by 2μ will give us the CTI.

$$\mu = \sigma_{a0}^2 \qquad (7)$$

$$b = \frac{\nu}{2\mu} \qquad (7b)$$

The CTE a is then:

$$a = 1 - \frac{\nu}{2\mu} \qquad (8)$$

Conclusion: To measure the CTE, the variance of each line (column) in ADU^2 has to be plotted versus the line (column) number. Then, a best fit line is calculated and equation (8) applied (In Figure 2, examples of such plot are shown).

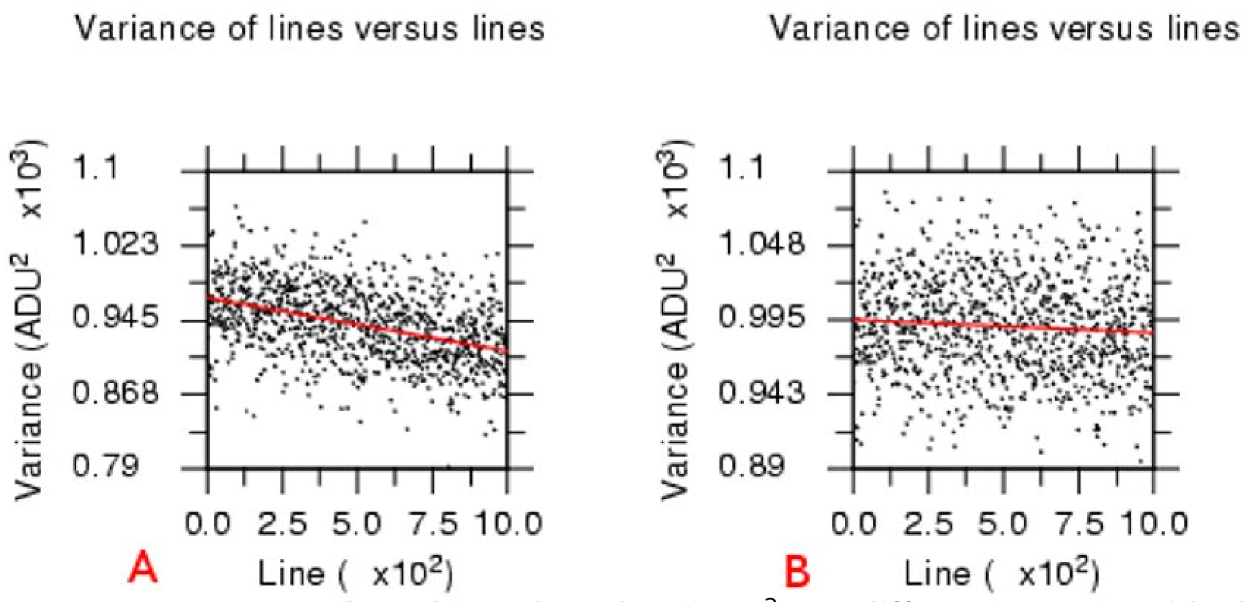

Figure 2: Image A and B show the plot (i, σ_a^2) at different CTEs with the best fit line in red (μ, ν). In A, the CTE is 0.999970, in B, 0.999996. These plots have been done with simulated data. The dimensions of the images are 1k x 1k. The number of electrons per pixel in the original images is 1000 plus a Poisson photon noise. The CTI is applied after. Similar patterns are observed for real data. (x-axis, the line count increases away from the readout register.)

Results from 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 square root of 1000 have been done. For each image different CTEs have been applied (See column one of the Table (1) for the different CTEs). The measurements are in columns 2 and 3 in the Table 1.

CTE	CVF	
H & V CTE	H-CTE	V-CTE
0.9999.. ± 0.000001		
1.	1.0	99
98	98	98
96	95	95
94	93	94
92	92	92
90	90	90
85	85	85
80	80	81
70	71	71

Table 1 (right): CTE measured with the CVF method applied on simulated data. The first column is the theoretical CTE in the simulated data. Column two and three are the horizontal and vertical CTE measured with the CVF method

Results from real data

The CVF method has been tested on the data from 9 different E2V 44-82 CCDs. For each CCD two bias and two flat field images have been taken. For 5 CCDs the flats taken with mode 1 (225kpix/s High Gain) will be used, and, for 4 CCDs, the flat taken with the mode 2 (225kpix/s Low Gain).

All the measurements realized with the EPER method has been done with images taken at the speed of 50kpix/s and a high gain.

The CTE from the e2v Data sheet will be also included in Table 2 and 3 for comparison. e2v uses the Fe55 method. The working temperature in their case is -100 degree Celsius and the read out speed, 250kpix/s.

CCD	H-CTE			C-CTE		
	CVF	EPER	E2V	CVF	EPER	E2V
			0.9999..			
ColumbaII	97	97	93	99	99	99
MicroscopiumII	98	97	95	98	99	99
MuscaAustralisII	97	98	97	98	99	98
Telescopium	95	90	96	99	99	98

Table 2: Horizontal and Vertical CTE measured with the CVF, EPER and Fe55 method. In the first column the CCDs used (nickname from constellations). The gain is ~2.5 e$^-$/ADU.

CCD	H-CTE			V-CTE		
	CVF	EPER	E2V	CVF	EPER	E2V
			0.9999..			
Chameleon	99	97	99	98	99	98
Dorado	98	99	98	98	99	98
Fornax	98	99	97	98	99	97
Grus	96	98	97	99	99	98
Mensa	98	98	99	97	99	97

Table 3: The gain for this group was set to ~0.55 e$^-$/ADU

Impact of the Charge Transfer Inefficiency on the Gain.

The Table 4 shows the measurement of the gain (in the simulated data) based on the photon transfer method as a function of the CTE. It shows also the gain corrected by equation (11). The theoretical gain is 1e$^-$/ADU. It is interesting to see that after correction the gain is very close to the gain measured in the images which are not affected by the charge transfer inefficiency (first line of Table 4).

The gain measured with images affected by the charge transfer inefficiency can be corrected by the following equation:

$$g_0 = g_m\,(1 - b_h n_h - b_v n_v) \qquad (11)$$

Where:

g_0, g_m : Gain of the CCD CTI corrected and gain measured.

b_h, b_v : Horizontal and vertical charge transfer inefficiency.

n_h, n_v : Number of lines and columns of the sensitive area.

CTE	Gain		
H & V CTE	Gain measured	Gain corrected	$g_{err\%}$
1.	1.00272	1.00262	
0.9999..			
98	1.00647	1.00244	0.37
96	1.01078	1.00067	0.80
94	1.01483	1.00164	1.19
92	1.01888	1.00258	1.59
90	1.02294	1.00248	1.98
85	1.03312	1.00213	2.94
80	1.04335	1.00266	3.89
70	1.06396	1.00225	5.76

Table 4: Impact of the CTI on the gain (column two) and correction of the gain after using the equation (11) (column three). To correct the gain the measured CTI is used not the theoretical value.

Conclusion

The results are promising. Almost all the measurements done with the CVF method are in accordance with the measurements done with a Fe55 set up. This technique is still at its preliminary development but convinced by these first results, the procedure will be intensively tested and improved (Map of cosmetic defects and their suppression in the calculation. For the moment only a sigma clipping method is used to remove the suspicious pixels. Development of the theory in 2d + development of a protocol of measurement and data reduction). The second step will be to compare directly the measurement from the CVF method to the measurement done with the ESO Fe55 setup. If all the tests are passed successfully, this method will enter in the standard ESO/ODT test procedure for CCDs.

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