Southern African Large Telescope

Title: **Gain calculation for the RSS CCD**

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ABSTRACT

In this report I present results of my study for the absolute gain calculations for the RSS CCD mosaic. The RSS CCD mosaic has some specific (the effect of smearing of charge) that make calculations of its gain values more tricky since the auto-correlation variance has to be calculated instead of the normal variance. I suggest the simple method to calculate its gains in the classical way. Using calculations based on this suggested method I show that calculated gains look reasonable and calculated gain ratios between different CCD amplifiers agree well with that numbers I have found previously using my method for the calculations of the relative gain corrections.

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1 Introduction

The RSS CCD mosaic consists of six different CCD amplifiers. There are some known problems of work with data taken with this mosaic. Some of these problems were fixed and never happen again, where others exist up to now. One of the very important is the problem of gain determination since of non-linearity of gain measurements in case gain calculations are done in the standard way.

In this report I present my view on this problem and suggest the simple way for the gain calculations for RSS CCD mosaic.

2 The general method

For each CCD the parameter gain defines the conversion coefficient between amount of counts of ADU (ADU = Analog-to-Digital Unit), that were counted by the **readout amplifier**, to the total amount of photons (electrons) that appears in the each cell of the Charge Coupled Device (CCD). To define this parameter the photon transfer curve (PTC) is used most widely since it is simple to use and does not require complicated or specialized equipment. This method only requires the taking of progressive increasing time series of two flats at constant illumination. For that reason this method is widely used at telescopes to check the health of CCDs. Many of other parameters of CCDs are determined using this gain parameter: read-out noise (RON), dark current (DC), quantum efficiency (QE), and full well.

Lets look on the PTC method in more details. If someone obtains two bias frames (BIAS_1, BIAS_2) and set of pairs of flats $(\mathrm{FLAT}_1, \mathrm{FLAT}_2)_j$, where j reflects the fact, that flats were obtained with progressive increasing time series at the constant illumination, and each pair of flats for the constant j was obtained with the same exposure time.

After that, following parameters could be calculated using bias frames:

$$BIAS_{diff} = BIAS_1 - BIAS_2 \tag{1}$$
$$VAR_{BIAS}(ADU^2) = Variance(BIAS_{diff})/2 \tag{2}$$
$$BIAS_{level}(ADU) = Median(BIAS_1 + BIAS_2)/2 \tag{3}$$

where $BIAS_{diff}$ is an image, VAR_{BIAS} is a number and $BIAS_{level}$ is a number.

After that, for each pair of flats with the same j following parameters could be calculated:

$$FLAT^j_{diff} = FLAT_1 - FLAT_2 \tag{4}$$
$$VAR_{FLAT}(ADU^2)^j = Variance(FLAT_{diff})/2 \tag{5}$$
$$FLAT^j_{level} = Median(FLAT_1 + FLAT_2)/2 \tag{6}$$
$$COUNTS(ADU)^j = FLAT_{level} - BIAS_{level} \tag{7}$$
$$VAR_{signal}(ADU^2)^j = VAR_{FLAT} - VAR_{BIAS} \tag{8}$$

where $FLAT_{diff}$ is an image, VAR_{FLAT} is a number and $FLAT_{level}$ is a number.

Finally, we can say that:

$$GAIN(e/ADU)^j = \frac{COUNTS(ADU)^j}{VAR_{signal}(ADU^2)^j} \tag{9}$$

where $GAIN$ is measured in e/ADU and shows **how many electrons are in the one ADU count**.

Since, there are j measurements for j pairs of flats, the normal way is to plot all found VAR^j_{total} versus all $COUNTS^j$ and fit all these points with linear polynomial function (y = A + Bx), where, finally, $GAIN = B \pm \delta B$. So, this method is called PTC (the Photon Transfer Curve). From the general idea of this method both $COUNTS(ADU)^j$ and $VAR_{total}(ADU^2)^j$ are growing linearly and $GAIN$ can be easily found.

Lets look on the real RSS data. Such PTC for the Amplifier#1 from RSS mosaic is shown in Figure 1. As we can see from this figure the final function is NOT linear and PTC method has a problem. It was shown with the spatial autocorrelation analysis that the mechanism behind of the non-linearity was due to the correlation, a sharing of charge, between pixels and this effect increases with the increase of the signal level. In other words, in case of CCDs, that have such "sharing of charge" ("smearing of charge") effect, **the REAL** variance is:

$$VAR_{real} = VAR_{ac}(ADU^2) \tag{10}$$

where VAR_{ac} is the auto-correlation variance.

3 Suggestion from Alexei

The calculation of the auto-correlation variance is the real solution in case of CCDs with smearing of charge. Unfortunately, it has one more additional parameter as the auto-variance scale – the size of pixel-area, where CCD is "sharing of charge".

I do not want to say that it is not-possible, but it is an additional trick. So, the my idea is more simple and it is shown in Figure 2. Lets plot diagram $GAIN(e/ADU)$ versus all $COUNTS$. In the ideal case of CCD without smearing of charge, all $GAIN(e/ADU)^j$ will show very stable level, that is shown as green line with some scatter of points around of it because of statistical errors. In case of our real CCD, our calculated variance started to be systematically more far off the true value with increase of the flux that is shown with the blue line that fit obtained black points. Fortunately, both of these lines ARE CROSSING at **COUNTS=0** that reflects the fact **that in case of the flux=0 value, the auto-correlation variance is equal to the normal variance** because there is no any signal to smear it. With other words: one needs to fit these black points with linear function (y = A + Bx) and finally will determine the correct gain value as $GAIN = A \pm \delta A$.

This problem, from my personal point of view, is very equal to the well-known scientific problem of the primordial helium abundance determination: we do not know the level of the primordial helium $(He/H)_0$, but could suggest that amount of modern helium in HII regions of different galaxies is proportional to the amount of other elements in these HII regions that are not hydrogen and helium. In case we can measure abundances of oxygen (O/H) and

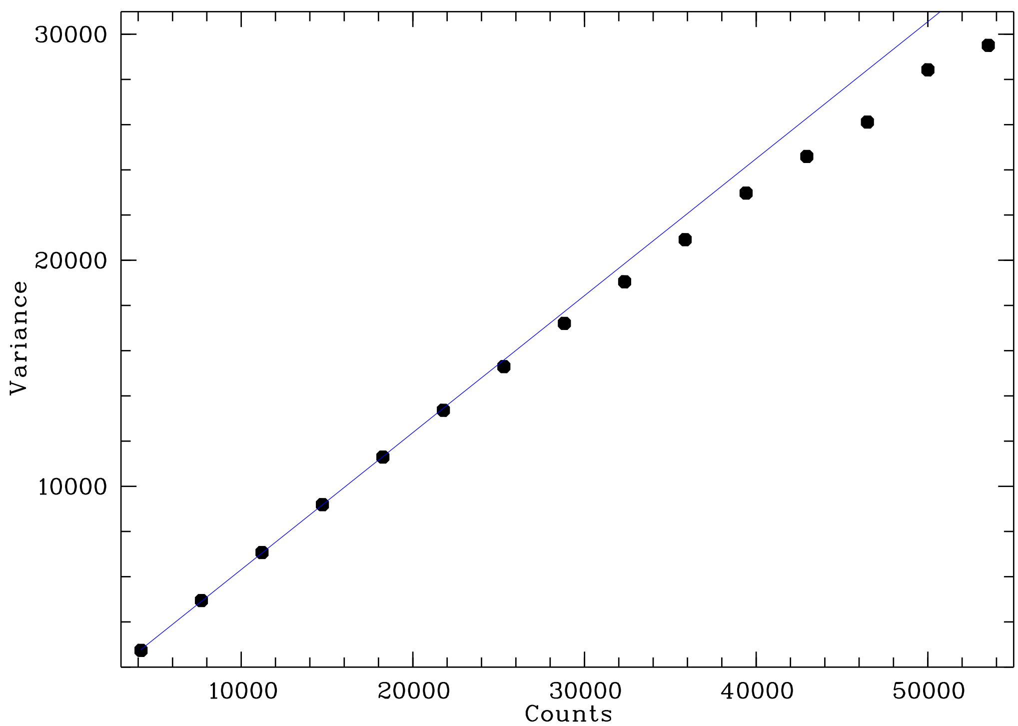

Figure 1: The PTC diagram for the Amplifier#1 from the RSS CCD mosaic. Measured numbers for count and variance are shown with black dots and linear fit is shown to all points as well.

helium (He/H) for many different galaxies, the extrapolation of the diagram He/H versus O/H will give us amount of the primordial helium abundance $(He/H)_0$ in time when amount of oxygen O/H=0.

4 The implementation

As the result of such hard theoretical work and to put down my stress after it, I have created Shell+MIDAS program to calculate gains for the RSS mosaic. Program is aimed to calculate gain and read-out noise for each amplifier of the RSS mosaic, for all modes with suggestion that input set of data consist of two BIAS frames for each mode and progressive increasing time series of two flats at the constant illumination. Since determination of RON and gain depend on the CCD statistic, program divides CCD into some amount of equal parts (10 parts by default) and determine gain and RON and each of these parts. So, the final gain, RON and their errors are based on the statistics of these independent determinations.

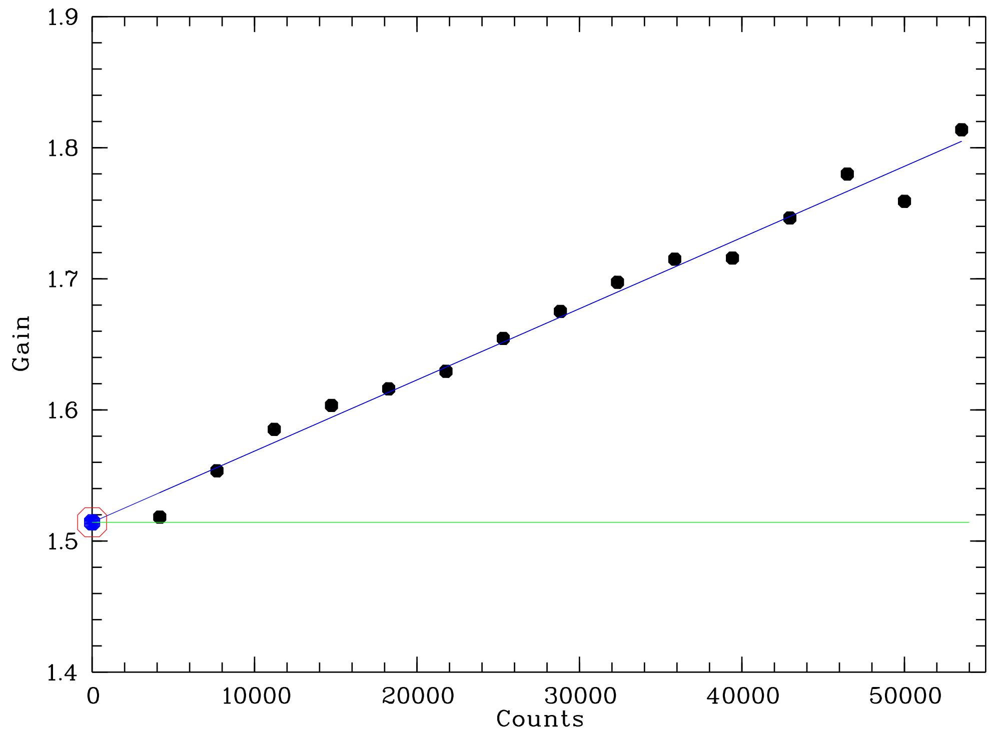

Figure 2: The PTC diagram for the Amplifier#1 from RSS mosaic. Measured numbers for count and variance are shown with black dots and linear fit is shown.

The total time of the work for one set of data is 2 minutes at my laptop that means we are able to check gains for the RSS CCD mosaic practically in the real-time mode, where gain calibration data could be checked at the telescope immediately after they will be taken.

For example, the result of such gain calculations that are based on the calibrations taken on 2019.06.28 are shown in Table 1 altogether with currently used gains and RONs. Here, I would like to point out, that currently used gains and RONs are based on the result of work previous software and my programs to determine the relative corrections for all gain values RELATIVELY of the amplifier #3. For that reason, we do not know the total errors for the currently used gains and RONs since it is based on the total error for the amplifier #3 (unknown) and the error of the calculated correction coefficient (known). I have added columns (4) and (7) to Table 1, where I present ratio between gain of the amplifier #3 to the gains of other amplifiers in the same mode. It is possible to see that these ratios well agree within cited errors.

Table 1: Gains for the RSS CCD amplifiers based on the calibrations taken on 2019.06.28

Amplifier Number (1)	Current gains (2)	Current RON (3)	Ratio (4)	New found gains (5)	New found RON (6)	Ratio (7)
		SLOW *** FAINT				
#1	1.604	2.48	0.94	1.51±0.01	2.25±0.01	0.96±0.01
#2	1.675	2.61	0.98	1.56±0.01	2.30±0.01	0.99±0.01
#3	1.710	2.58	1.00	1.58±0.01	2.29±0.01	1.00±0.00
#4	1.638	2.51	0.96	1.51±0.01	2.20±0.01	0.95±0.01
#5	1.546	2.57	0.90	1.44±0.01	2.17±0.02	0.91±0.01
#6	1.490	2.42	0.87	1.39±0.01	2.11±0.01	0.88±0.01
		SLOW *** BRIGHT				
#1	3.594	3.77	0.93	3.13±0.01	3.78±0.02	0.96±0.01
#2	3.751	3.84	0.97	3.24±0.01	3.86±0.02	0.99±0.01
#3	3.880	3.90	1.00	3.25±0.01	3.88±0.01	1.00±0.00
#4	3.722	3.61	0.96	3.13±0.01	3.73±0.01	0.96±0.01
#5	3.543	3.80	0.91	3.02±0.01	3.66±0.01	0.93±0.01
#6	3.418	3.48	0.88	2.93±0.01	3.51±0.01	0.90±0.01
		FAST *** FAINT				
#1	3.430	4.36	0.93	2.59±0.01	3.70±0.01	0.96±0.01
#2	3.590	4.60	0.97	2.68±0.01	3.84±0.01	0.99±0.01
#3	3.710	4.56	1.00	2.69±0.01	3.84±0.01	1.00±0.00
#4	3.542	4.28	0.96	2.59±0.01	3.73±0.02	0.96±0.01
#5	3.361	4.47	0.91	2.49±0.01	3.64±0.01	0.93±0.01
#6	3.255	4.25	0.88	2.40±0.01	3.49±0.01	0.89±0.01
		FAST *** BRIGHT				
#1	11.582	14.63	0.98	9.19±0.02	12.36±0.03	1.01±0.01
#2	11.216	13.84	0.95	8.76±0.18	11.74±0.22	0.96±0.02
#3	11.810	15.03	1.00	9.12±0.04	12.20±0.07	1.00±0.00
#4	11.933	9.55	1.01	9.29±0.03	12.45±0.10	1.02±0.01
#5	9.959	13.31	0.84	8.13±0.02	11.06±0.05	0.89±0.01
#6	9.761	9.83	0.83	8.00±0.04	10.90±0.20	0.88±0.01

5 Conclusions

I see some conclusions as the result of this work:

1. The RSS CCD mosaic has some specific that make calculations of its gain values more tricky since the auto-correlation variance has to be calculated instead of the normal variance. Fortunately, from my personal point of view, it is possibly to calculate its gains in the classical way.

2. I have described the method, wrote program to calculate gains based on the calibrations taken for the RSS CCD mosaic and calculated gains based on the described method. All found numbers look reasonable and gains ratios agree with that numbers I have found previously using my method for the calculations of relative gain corrections.

3. The gain calculation procedure is so fast, that could be done at SALT immediately after calibration data will be taken.