FORS IOT Secondary Standards Working Group – Report I:

FORS1 BIAS & Flatfield properties

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1 Introduction

This is the first of the two reports that will be delivered by the FISSWG. This report describes in detail the properties of the test data and the reduction steps taken in generating the master BIAS frame and master flatfields.

2 Data

The primary data set investigated included 160 BIAS frames, in total 8 B and 9 R twilight flatfields, and 13 B and 20 R standard star fields. All of the B flatfields were taken during the evening twilight. Two of the R flatfields were taken during the evening twilight and 7 during the morning twilight.

Of the standard star images, in B, we had 4 images without offsets with different rotation angles (180,90,0,-90), and 8 offset positions, in total 13 images of the field. All exposuretimes in B are 5 seconds.

In R band, we have 4 images without offsets with the same rotation angles as in B band and 4 offset positions with 2 to 3 images per position. For all positions there are 2 and 1 second exposures. The offset pattern used for B and R bands is given in Fig. 1.

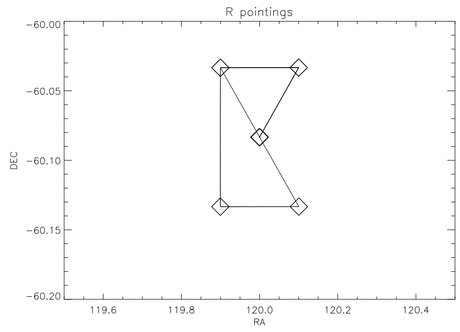

Figure 1: Pointing patterns for B and R band images.

3 BIASes

The FORS1 CCD (Tektronix TK2048EB4-1) is read out using four amplifiers and thus dividing the image into four quadrants. The quadrants are called A, B, C and D starting from lower left corner and counting anticlockwise. In order to study the stability and structure of the BIAS frames, a mean along columns (Y) was taken for plotting the profiles A–B and D–C and a mean along rows (X) was taken for plotting the profiles A–D and B–C. For crossprofile plots, the bottom and the top 100 rows and the left- and rightmost 16 columns, i.e. the overscan areas, were not used for calculating the mean values. In both cases sigma clipping with cut level at $\sigma = 4.5$ was used in order to remove cosmic events.

Fig. 2 illustrates that there are significant slopes in both directions in most of the quadrants; both horizontal and vertical in A and D and only horizontal in B and C. The BIAS levels do not settle to a constant value even close to the centre (i.e. even after reading out for a long time). Neither do the count levels come down to the level of the overscan areas. Also what can be seen is that the BIAS level ramps up in the first 100 rows in vertical plots and then turns downward not quite reaching the overscan level either.

The reason for the difference between overscan count level and the BIAS frame image area count level might be a (un)documented feature of FORS1 CCD/FIERA, but information on this could not be found from the instrument web pages. According to the quality-control department this offset and the slopes (ramping up/down) are common.

The slopes of the ramping up/down are on the level of 1 ADU over 1000 pixels (Fig. 3). For most quadrants the slopes are stable, but quadrant B shows some wiggling in the profile which varies with time, but the amplitude of the wiggling is below one ADU.

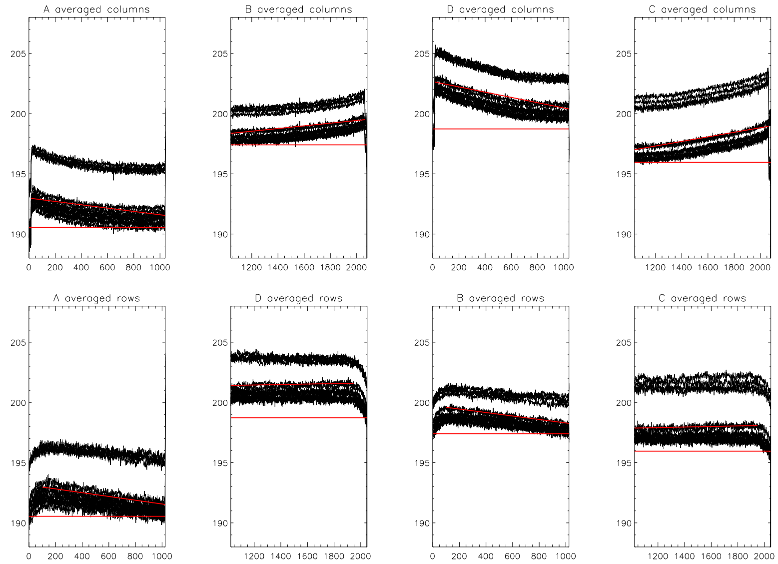

Figure 2: Crossprofiles averaged along columns (top) and rows (bottom).

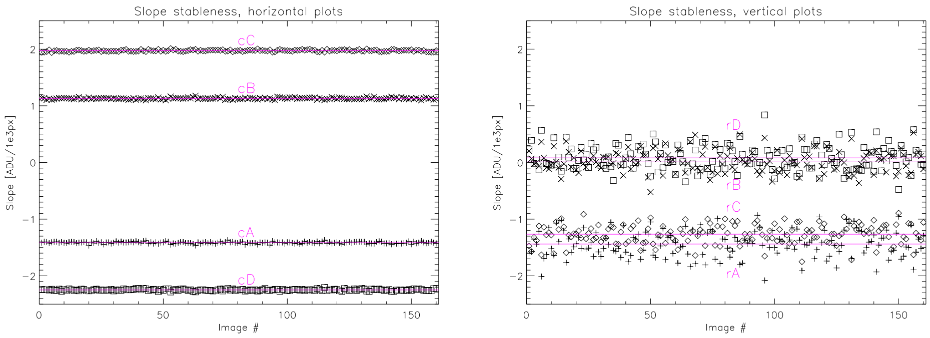

Figure 3: Slope coefficients for crossprofiles along columns (left) and along rows (right). Plot symbols for different quadrants are "+"=A, "X"=B, "◇"=C and "□"=D. Y-axis units are ADUs per 1000 pixels.

4 Procedure for BIAS subtraction

We investigated different methods for BIAS subtraction, and it was decided to proceed with 2-D BIAS subtraction in order to take the slopes into account. This was done by treating individual quadrants separately, and by creating a synthetic master BIAS by expanding the profiles in both horizontal and vertical directions. Procedure for BIAS subtraction is to first subtract the median of the overscan of the quadrant from the image to be processed and then subtract the synthetic BIAS frame.

The goodness of the synthetic BIAS frame was investigated by subtracting it from all of the individual BIAS frames. In the worst case the residuals from the subtraction are ± 0.27 ADUs. A crossprofile plot of one of the subtracted images is presented in Fig. 4.

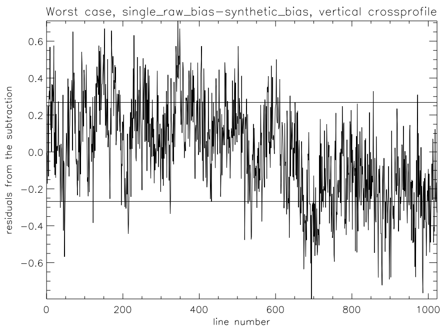

Figure 4: Worst case residuals of subtracting synthetic BIAS from individual BIAS frames, solid lines are plotted at 1σ rms.

The overscan areas were also inspected thoroughly. In case of FORS1 CCD, the overscan areas are not real pixels and, therefore, do not have exactly the same properties as the rest of the frame. The BIAS frames are normally obtained using templates consisting of 5 individual BIAS frame readouts. The overall overscan level changes linearly with time by 2-3 ADUs from the first frame of the template to the last (see Fig. 5). This might be an effect of temperature in the control electronics. In the 155 BIAS frames taken before the night this pattern was clearly seen inside each 5 frame template run. However, the offset between the overscan count level and the BIAS frame count level stays constant within the errors of the measurements.

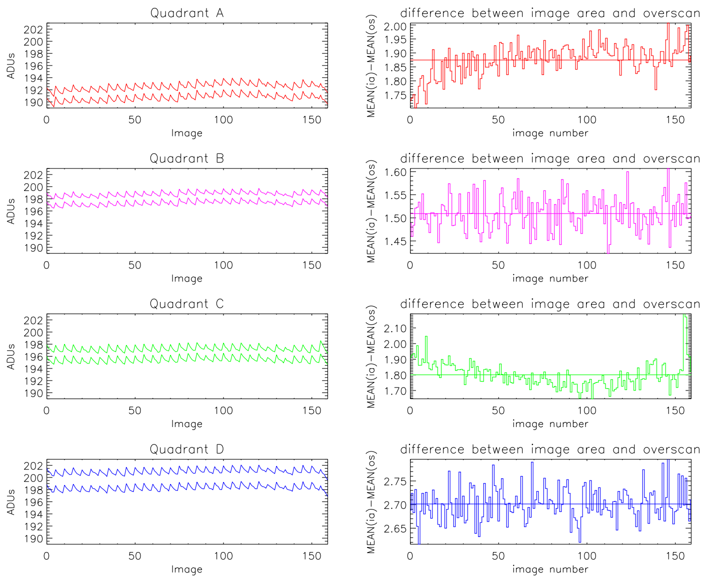

Figure 5: Count levels of the overscan areas of all of the frames (left) and the differences between the overscan and image area (right).

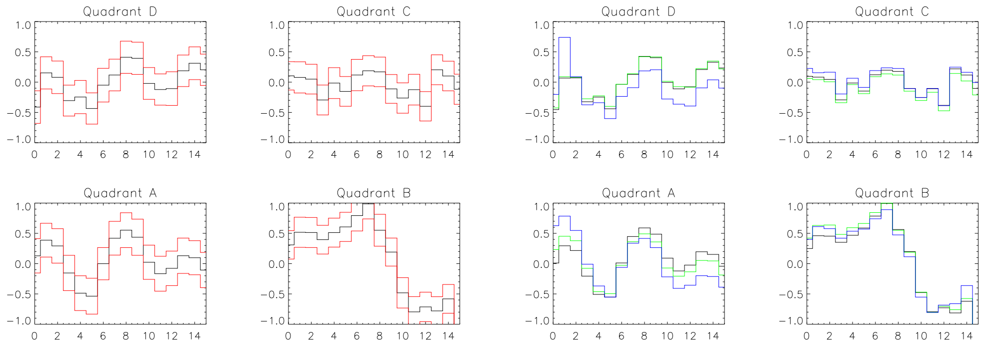

Figure 6: Overscan area profiles for each quadrant, left: combined for all 237 images (black line) with measured rms (red lines) right: separately for BIASes (black), flatfields (green) and standard star images (blue)

The crossprofile along the columns in the overscan areas has a distinct persistent pattern in each quadrant (see Fig. 6). This pattern is stable at least in timescales of days, and has a peak-to-peak amplitude of ~ 2 ADUs. The shape of the pattern has no dependence on the intensity level of the rest of the frame, but the overall count level has (see Fig. 7). This change is on

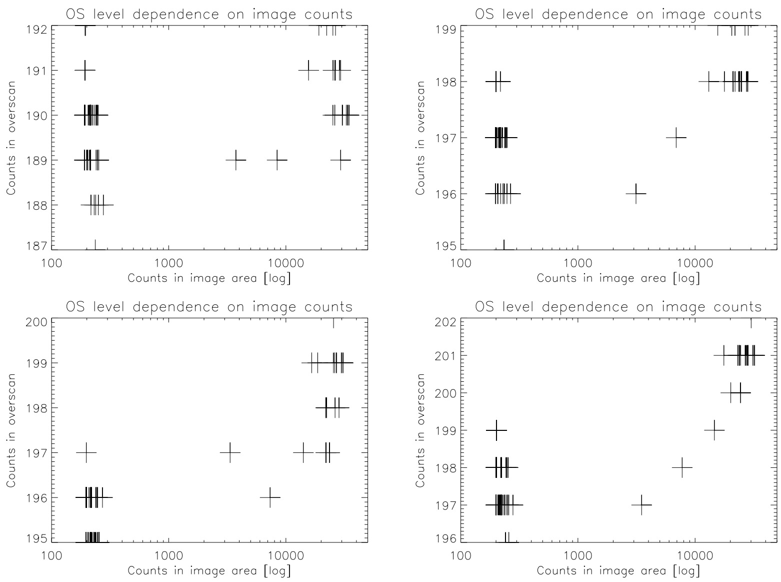

Figure 7: Differences in ADU levels between image area and overscan area in the BIAS frames.

the same level as inside BIAS frame template runs, and, therefore, does not cause extra concern. A wider overscan area might allow the CCD controller to settle, but it might also follow the pattern of the BIAS frame image area and not settle.

5 Bad Pixels

A bad pixel mask was generated for each individual flatfield frame by comparing each pixel value to its immediate surroundings and flagging out deviating high and low pixels. The results were combined, and if a pixel was found to deviate in all flat field images, it was marked as a bad pixel in the mask image.

The bad pixel mask was then used when combining the flatfields into a master flatfields for each filter. The masked pixels were not used in calculating the median in combining the flatfields. After median combining the individual quadrants, the master flatfield was "glued" back together, and normalised to 1.0 using statistics from the entire image area and all of the quadrants in order to retain the information of the different sensitivities of the individual CCD amplifiers of the different quadrants.

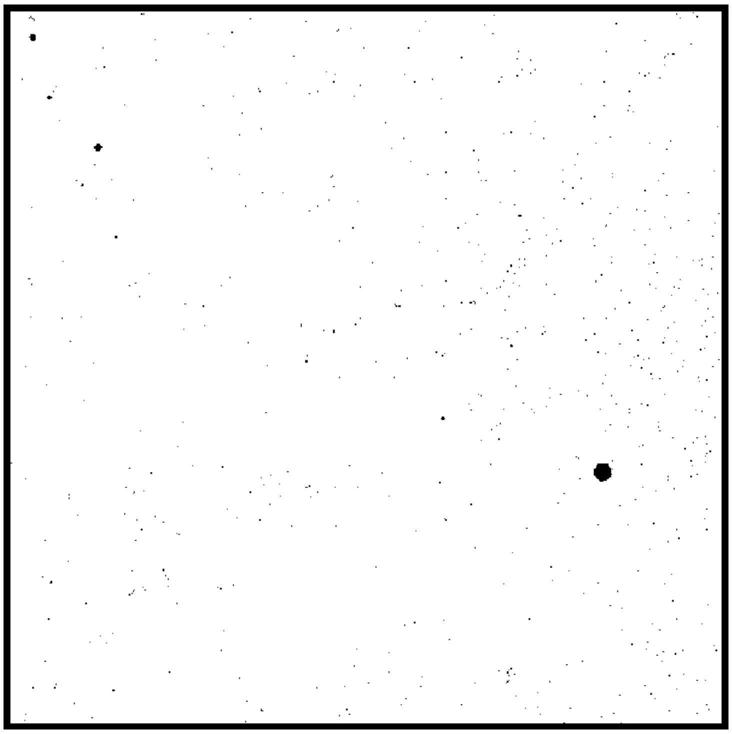

Figure 8: Bad pixel mask generated from B-band flatfields. Most notable feature is the "big black hole" in the B-quadrant. Black border added for clarity.

6 Flatfields

In the dataset obtained for this project, we had Bessel B and R band standard star data and, therefore, the efforts were concentrated on the respective twilight sky flatfield images. There was a concern that the overscan level would show different characteristics (ramping up or down) depending on the intensity level of the image area, but no indication of this was found. Only the mean count levels of the overscan areas increased in those flatfield frames which had high number of counts in the image area (see section 4 and Fig. 7).

The columns 17 and 2063 (i.e. the very first real physical pixels to be read out) were found to have significantly higher count levels than the rest of the image, and the top most row (2048, the very first row read out with amplifiers C and D) was found to have significantly lower count level in all flatfields. Experiment with dividing the first observed B flat with the last observed B flat resulted in a clear disagreement on the shape of the crossprofile on a level of 0.4% over the entire image area, peak-to-peak. For the R band the disagreement was 0.8%. These crossprofiles are presented in Fig. 9 and color-emphasised, smoothed R-band master twilight sky flatfield is shown in Fig. 11.

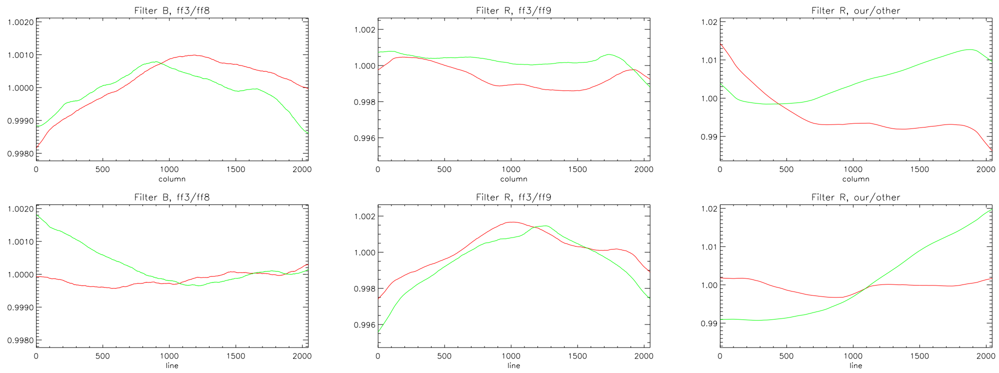

Figure 9: Crossprofiles of flatfields taken in the beginning of the evening twilight divided by last flatfields of the same twilight. From left to right: B band and R band of our dataset and R band flat of our set divided by R band flat from other dataset, taken 7 months later. Red and green line show the different two quadrants in both directions. In top plots red is A–B cut and in bottom plots A–D, similarly green line is D–C and B–C. The profiles have been boxcar smoothed using 201 pixel wide box, truncating box size at the edges.

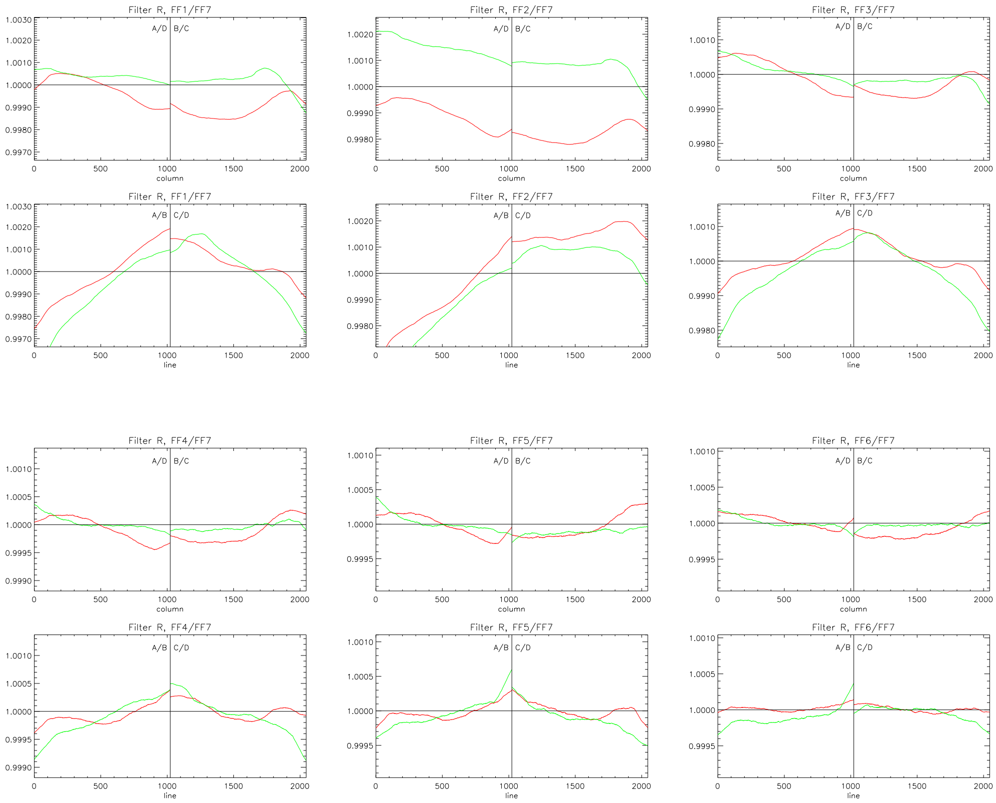

Figure 10: Crossprofiles of individual R band flatfields taken in the beginning of the morning twilight divided by the last morning twilight flatfield. Red and green line show the different two quadrants in both directions. In top plots red is A–B cut and in bottom plots A–D, similarly green line is D–C and B–C. The profiles have been boxcar smoothed using 201 pixel wide box, truncating box size at the edges.

In Technical Memo "Measure of the stability of the SKYFLATs in FORS1", it was found that the change in pixel to pixel variations is below 0.5% and does not vary much over 7 months time period, which includes this data set. Also found, was that the large scale structure in the flatfields varies significantly during the 7 months period. This we tested independently with the flatfields from this data set and with flatfields from another set of data taken for investigation by Wolfram et al. (see Fig. 9, right most pair). We found that there is a disagreement in the shapes of flatfield frames with peak-to-peak difference of 3%, which is significantly larger than that found inside same night Fig. 10.

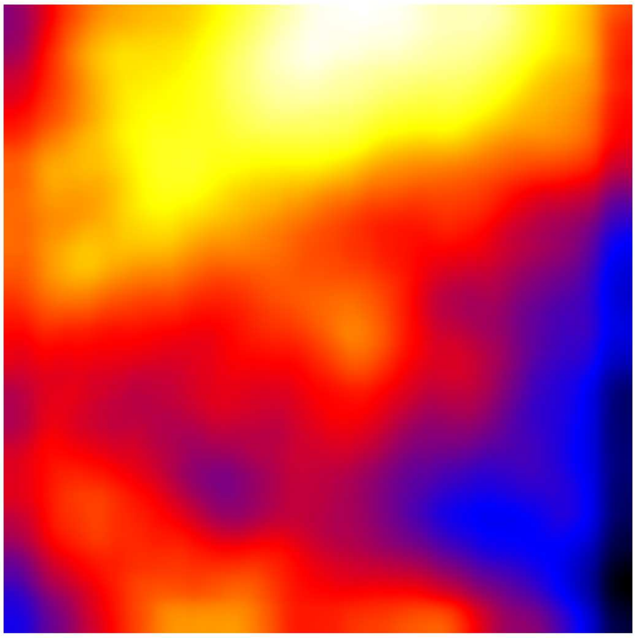

Figure 11: R-band twilight sky master flatfield frame, individual quadrants were first scaled to same mean and then the frame was smoothed with median filtering.

7 Conclusions

Outstanding conclusion is, that increasing the number of BIAS frames does not improve the photometry noticeably. Increasing the number of flatfield frames did not improve it either, mostly due to big variations from one flatfield to the other resulting in a systematic error of the order of 1% accross the field of view, peak-to-peak.

We experimented on the dataset using the methods presented in this report and comparing the resulting photometry with the same dataset reduced with the FORS1 pipeline, and found that there was no significant improvement over the currently used pipeline.