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The reference pixels on the WFC3 IR detectors

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Abstract

1. Introduction

The Infrared (IR) channel of the Wide Field Camera (WFC3) is constrained by a focal plane temperature of 150K. This rather high value has required the development of a new type of IR detector. The Rockwell Science Center WFC3-IR FPA is a 1024x1024 hybrid HgCdTe device MBE grown on a ZnCdTe substrate, doped to provide cutoff wavelength at ~1.7µm. The detector array is indium bumped to a multiplexer (MUX). The Hawaii-1R MUX is also a new type of device largely based on the Hawaii-2 design and on the recent advances for the NGST project. Among the new features of the Hawaii-1R, a set of reference pixels that may be used to reduce the effects of thermal or electrical drifts in the detector, in the off-chip electronics, or both.

In this document we discuss the performance of the reference pixels, as measured on one of the engineering parts provided by Rockwell to the WFC3 project. The data presented here were collected at the Detector Characterization Laboratory (DCL) of the NASA Goddard Space Flight Center (Greenbelt, MD).

2. Detector architecture

From the point of view of the signal processing, the detector architecture is governed by the MUX design. The Hawaii-1R MUX is structured with four independent quadrants, each quadrant having 1 or 8 output channels. WFC3 uses 1 output channel per quadrant. The optically active area is 1014x1014 pixels; the outer 5 rows and columns of the MUX contain the reference pixels, so there are 507x507 photoactive pixels per quadrant. The four quadrants are mirror images of each other; otherwise they are electrically identical. On each quadrant, the readout starts from the outermost corner with the fast axis (X axis) reading in toward the central columns of the MUX. The slow clock (Y axis) is read toward the central rows (Figure 1). Therefore, at the beginning of the readout, the 5 horizontal lines of reference pixels are sequentially read, whereas the last pixel to be read is the innermost pixel of the quadrant, one of the 4 central pixels of the MUX.

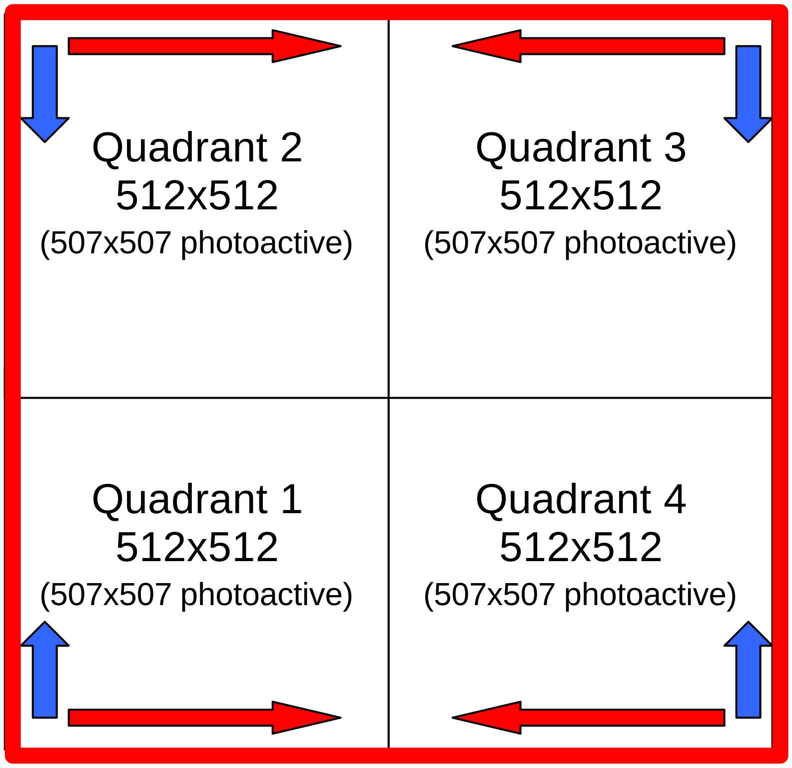


Figure 1: readout architecture. Red arrow: fast clock; Blue arrow: slow clock. The red frame represent the position of the reference pixels.

Reference pixels are built by inserting a capacitor between the input transistor gate and the substrate bias DSUB, to approximately mimic the detector capacitance. Apart from that, the detector interface circuit is in general the same as for the photoactive pixels. The HgCdTe diodes are deactivated in correspondence of the reference pixels, so there is no photo-generated current. The indium bumps are still present to preserve the optimal mechanical coupling between the two parts of the hybrid device. There are two types of reference pixels.

1) Inboard reference pixels;
2) Outboard reference pixels.

The inboard reference pixels are located on the four innermost rows and columns. They are "inboard" in the sense that their reference capacitors are contained within each pixel (unit cell). The DSUB bias is routed to the capacitance through the detector layer and the indium bumps. The outboard reference pixels are located on the outermost rows and columns. The capacitors in this case are place outside the unit cell, at the edge of the MUX. The DSUB bias is taken in this case directly from the MUX. The inboard reference pixels have the same capacitance of 40fF. The outboard reference pixels have 4 different values distributed sequentially increasing along the row and column directions. The capacitance values are 8fF, 16fF, 32fF, and 64fF to span the signal range. Figure 2 illustrates how the two types of reference pixels are distributed on the array.

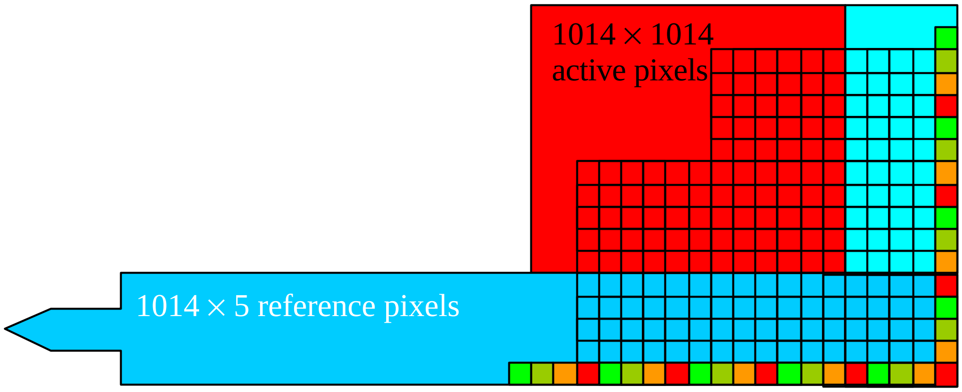


Figure 2. Schematic layout of the reference pixels at the corner of quadrant 4 in Figure 1. The red box represents the active pixels. The light blue area represents the reference pixels. The outer rows and column contain the outboard reference pixels, with a 4x periodicity in the value of their capacitances.

3. Results

3.1 Outboard reference pixels

The data discussed in this document have been obtained at DCL the 25th July 2001 on the engineering array FPA#15. The array was read in Fowler sampling mode, with 6 read immediately after the reset and 6 read at the end of the integration. Figure 3 shows a quadrant of the array in one of the reset reads. In particular, this is the 4th read of the file JL25_flt1500_150k_90sr30.fits. The naming convention of the file contain the month and day (JL25), the wavelength of the illuminating radiation (1500nm), the detector temperature (150K), the integration time (90s) and, in the case of repeated exposures, the serial order (repeat=30). The frame is represented with a histogram equalization table to enhance the low dynamic range of the signal. The vertical bands are probably due to residual noise associated to the 8 unused output lines.

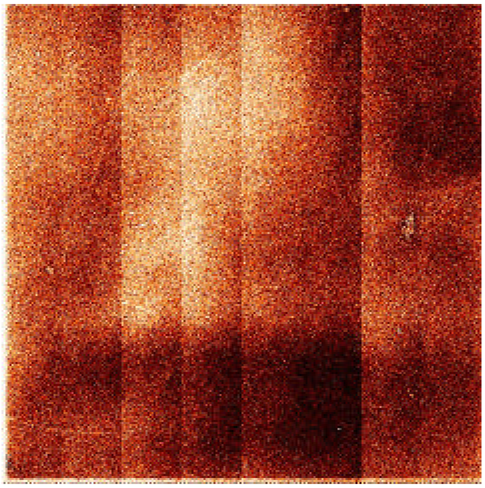


Figure 3. Reset read of Quadrant 1 of FPA#15 (see text). Median counts: –16,275

Figure 4 shows the signal generated by the outboard reference pixels. The four lines correspond to the four different capacitances, as labeled. There is a clear offset between the average values, increasing with the capacitance (lower counts indicate higher signal with the DCL electronics). Among each family of capacitances, the scatter is very large, ~3000 counts peak-to-peak. This is due to the intrinsic limitations of the Outboard design. For comparison, the signal level of the active pixels is ~16,000 counts. It is clear that the range of capacitances implemented on the reference pixels matches the low range of the signal.

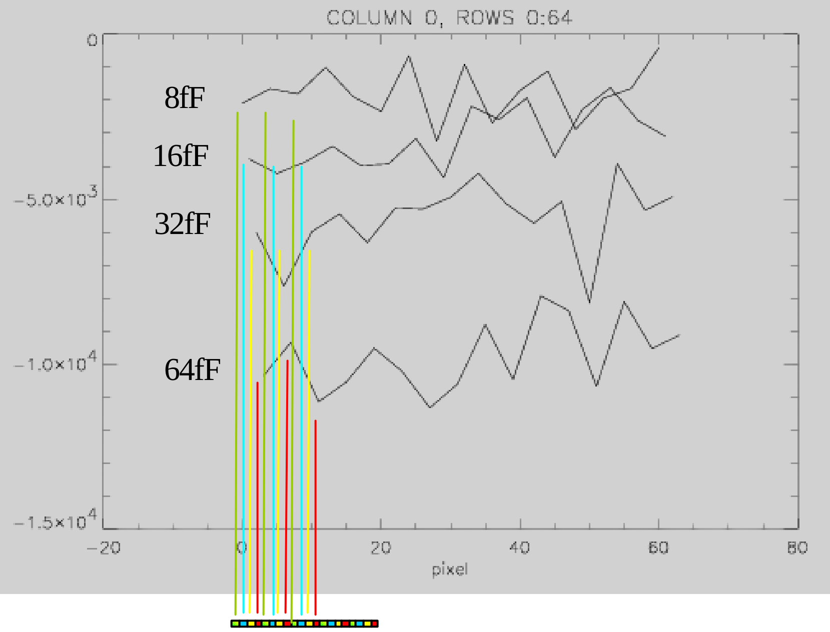


Figure 4. Sequence of the first 64 outboard reference pixels

The corresponding distribution of values for the entire quadrant is plotted as a histogram in Figure 5. Despite the large scattering, the averages are nicely consistent. In Figure 6 we plot the average counts, indicates by the arrows in Figure 5, against the design capacitances. A linear fit allows to obtain 130counts/fF as conversion factor.

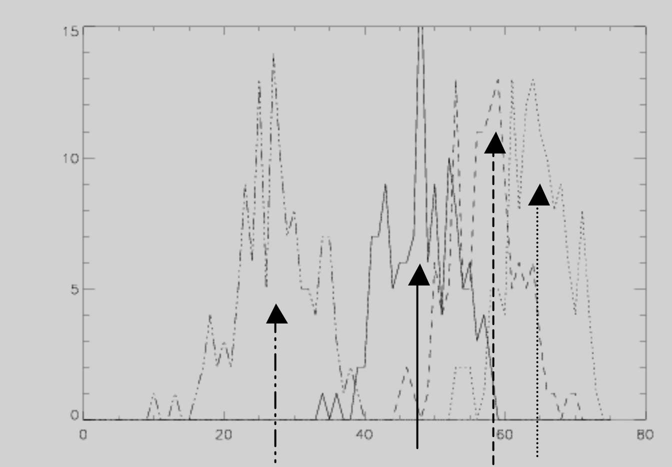


Figure 5: distribution of the Outboard reference pixels.

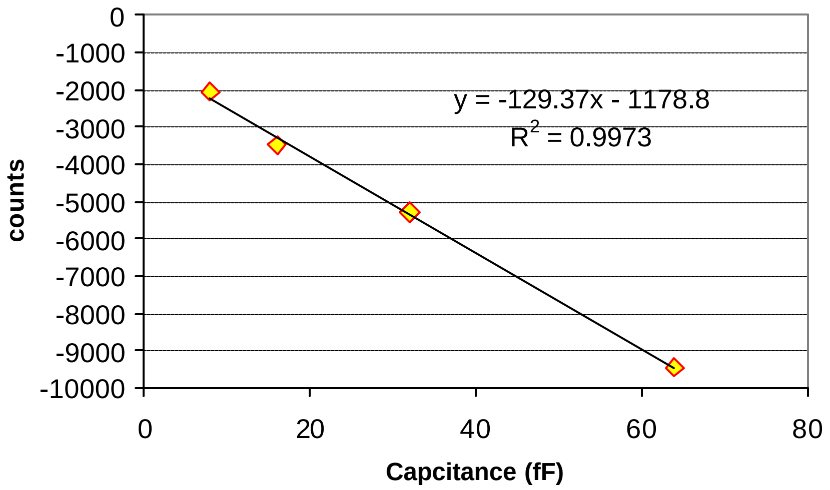


Figure 6. Linearity relation between the mean counts of the Outboard reference pixels and the capacitance.

The amount of noise in the Outboard reference pixels can be evaluated by considering another read of the same reset. The correlated reads eliminate the differences between different capacitances and the kTC noise. Both frames reproduce with high accuracy the same pattern with an uncertainty due to the readout noise. Figure 7 shows the differences of the 5th-4th reset read for the four families of Outboard reference pixels. There is a small drift between the two reads, indicated by the negative offset. The standard deviation is in the range 5-7 counts for the four channels, corresponding to a readout noise of ~10electrons, assuming a 1.75e/adu gain.

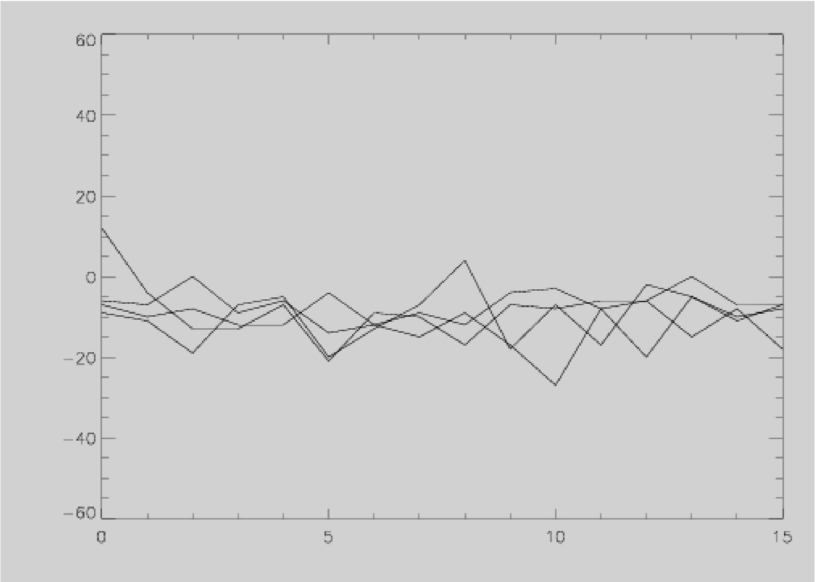


Figure 7. Differences between the Outboard reference pixels, as measured in two successive read of the same reset. The 16 values correspond to the first 64 pixels of the row.

In Figure 8 we show the same quadrant after 90s integration with light on. The image, reset subtracted, shows a small amount of cosmetic defects, including a cluster of bad pixels and scratches on the detector surface. The reference pixels are now clearly evident as a red edge on two sides of the quadrant. They are expected to have ~0 counts, whereas the active pixels are at ~32,600 counts.

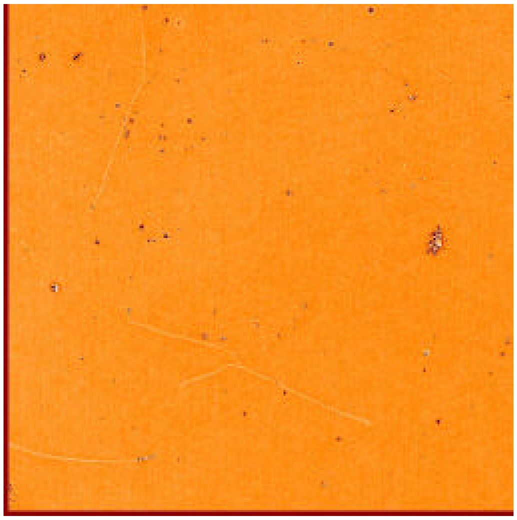


Figure 8. First quadrant; 4th read (frame 9/12); IT=90s @ 1.5micron; Median counts 32,612.

The fact that in the "light-on – reset" frames the reference pixels do not have values ~0 has been a surprise. Figure 9 is the analogous of Figure 7 for the signal-reset frame. Three out of four pixels behave properly in the first read, providing differences close to zero. The other pixels show a clear offset, increasing with the capacitance. The average values are presented in Table 1. In general, the reference pixels provide lower counts after the illumination of the array.

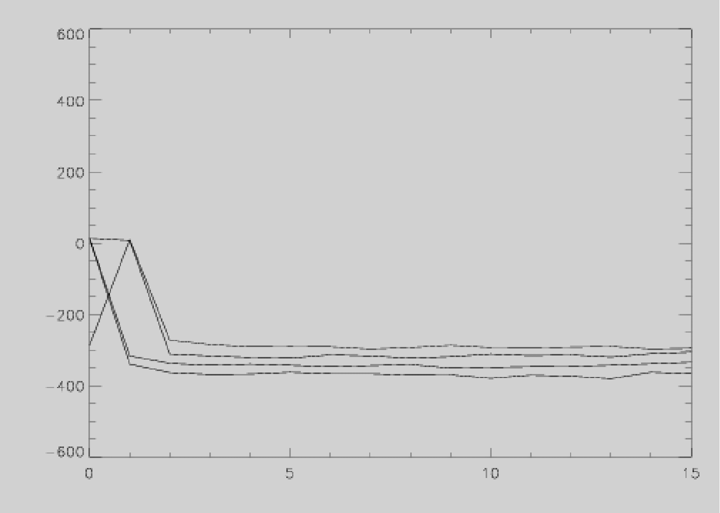


Figure 9. Difference between the Outboard reference pixels before and after the illumination of the array.

Table 1.

Capacitance	Signal – reset counts
8fF	–290.6±6.1
16fF	–316.1±4.8
32fF	–343.3±4.5
64fF	–369.6±5.7

The values presented in Table 1 can be fitted by a linear relation. This is shown in Figure 10. The drift is -1.3×C(fF), at 32,600 counts.

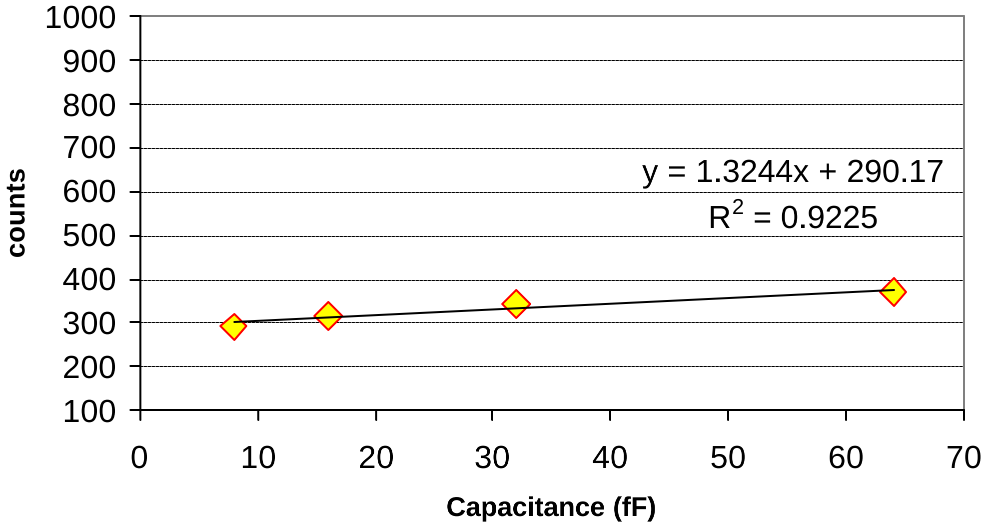


Figure 10. Drift of the reference signal at 32,600 counts, for different values of the capacitance.

Let us compare now the vertical Outboard reference pixels with the horizontal Outboard reference pixels. Figure 11 refers to the same quadrant 1 image used in Figure 3, and compares the DC levels of the first 64 pixels from the corner. There is a ~10,000 counts offset between the vertical and horizontal Outboard reference pixels.

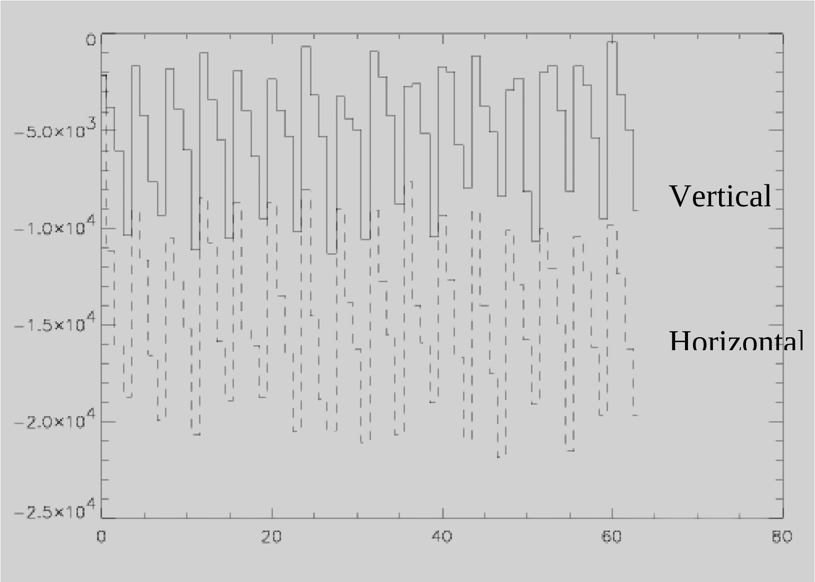


Figure 11. Comparison of the vertical and horizontal reference pixels. Solid line: Outboard vertical reference pixels; dashed line: Outboard horizontal reference pixels.

Like the vertical reference pixels, the horizontal reference pixels appear to be sensitive to the detector illumination. Figure 12 shows the pixels counts of the first 32 pixels before and after illumination. The data refer to the same pair of frames used to produce Figure 8.

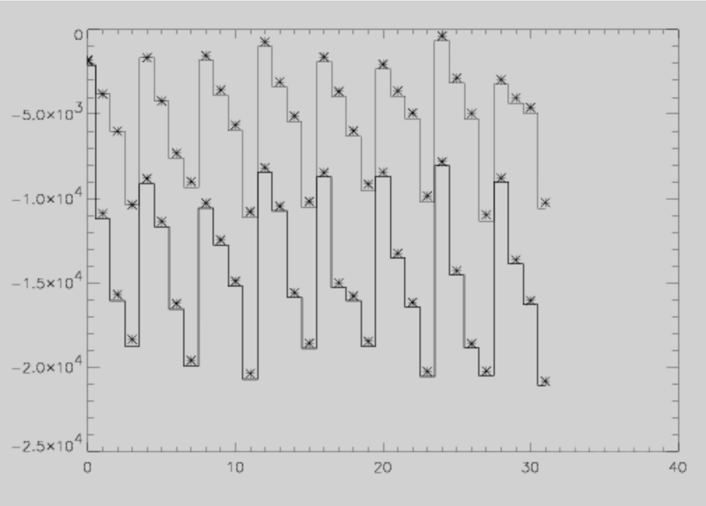
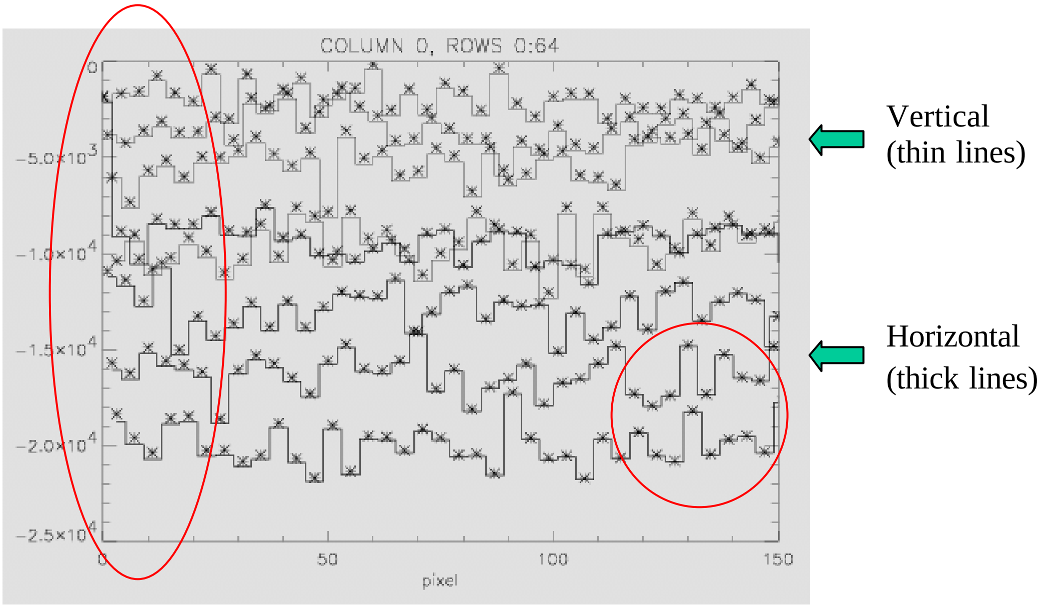


Figure 12. Pixel counts before and after illumination. Solid line: Outboard reference pixels, reset read. Crosses: Outboard reference pixels, signal read.

The Outboard horizontal reference pixels, however, show a transient behavior. Their light sensitivity appears to drop along the line. This is directly illustrated in Figure 13, which shows the

8 families of Outboard reference pixels, 4 vertical and 4 horizontal, for the entire quadrant 1, before and after illumination. The first pixels, both vertical and horizontal, show light sensitivity (red ellipse on the left of the figure). The last pixels, however, are light sensitive only if they are vertical, whereas if they are horizontal they provide the same signal of the pre-illumination frame (red circle at the bottom-right of the figure).

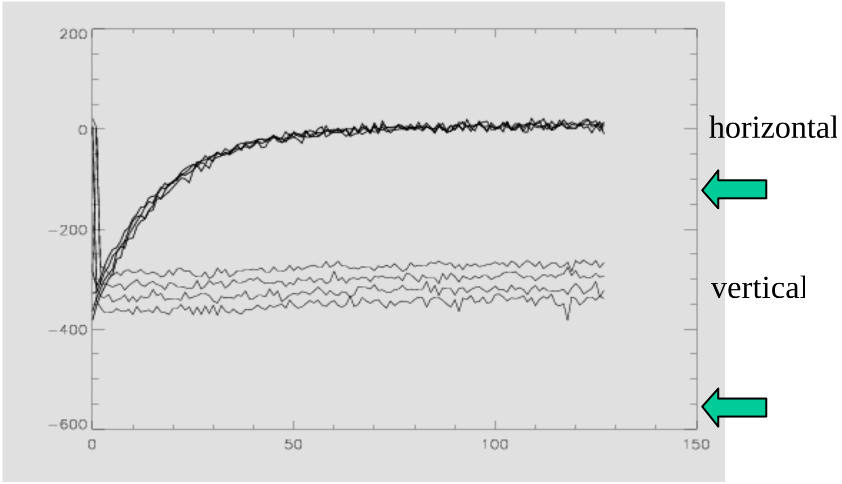


Vertical
(thin lines)

Horizontal
(thick lines)

Figure 13. Comparison of pre- and post-illumination data for the Outboard reference pixels. Solid lines: reset read. Crosses: signal read.

This behavior is more clearly illustrated in Figure 14, where the differences between light-on and light-off are plotted. The light response of the horizontal reference pixels shows a rapid decay, reaching values close to zero approximately halfway through the row. Note also that during the decay these pixels do not show differences between capacitances.



horizontal

vertical

Figure 14. Same as Figure 13, with the differences plotted.

It is interesting at this point to look some more in detail to the behavior of the first reference pixels, at the corner of each quadrant. In Figure 15 we show the corner of Quadrant 1 in a light-on minus reset frame. There are five different zones: the active pixels, the horizontal and vertical inboard reference pixels and the horizontal and vertical Outboard reference pixels. In principle, horizontal and vertical pixels should provide the same values, so one would expect to see 3 zones only. In fact, the situation is more complex. At the bottom of the image, the first line is composed by the Outboard reference pixels. On top of them we have the inboard reference pixels. The first anomaly is that the Outboard pixels (on the leftmost column) in rows 2 - 6 behave like inboard reference pixels (orange color). We can expect the horizontal Outboard and inboard reference pixels to behave differently, but the vertical Outboard pixels should not be associated to the inboard reference pixels. The second anomaly is that the vertical inboard reference pixels are different from the horizontal ones, but only starting from column 7. The horizontal inboard reference pixels have some sort of "strong character": they assimilate the response of the vertical reference pixels, both Outboard and inboard, until the first row of active pixels is addressed. Reference pixels addressed after the exposure to the light behave (almost) normally.

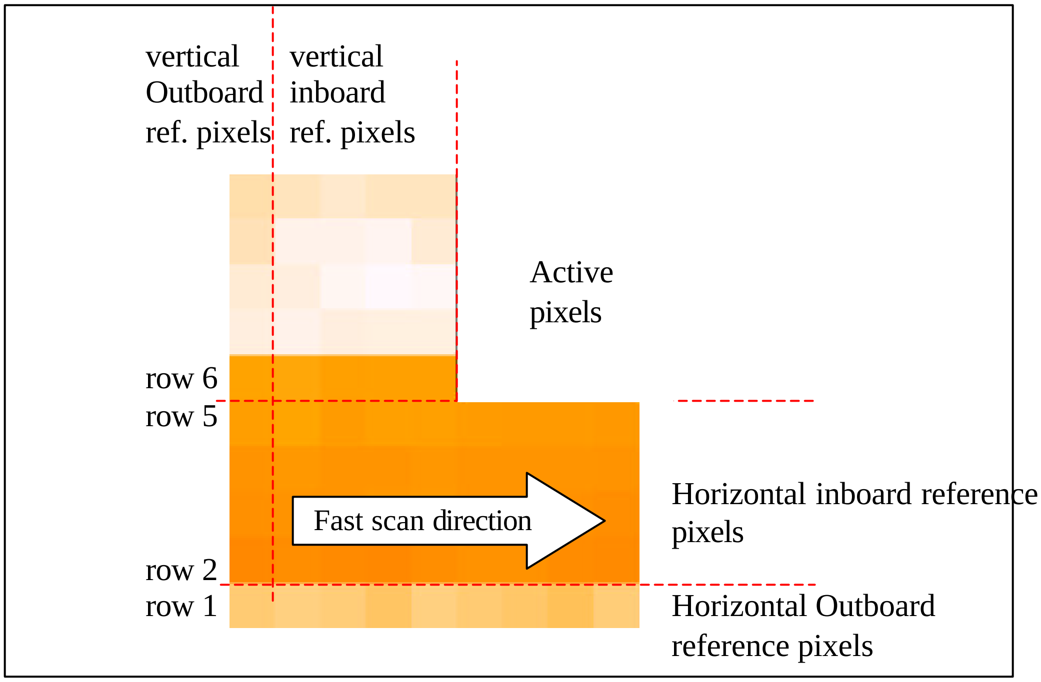


Figure 15. Enlarged view of the reference pixels at the corner of the array.

3.2 Inboard reference pixels

Like the Outboard reference pixels, the vertical inboard reference pixels show light sensitivity. The offset generated by the light exposure is similar to the offset measure on the 64fF capacitances. The horizontal reference pixels behave properly: they don't show evidence for light sensitivity, like the vertical inboard reference pixels, and are nicely stable at around 0 counts in the subtracted frames, at the contrary of the Outboard horizontal reference pixels.

A summary of the reference pixels performance is presented in Figure 16. In a subtracted frame, one would expect to find zero values. Only the inboard horizontal reference pixels (4x507 pixels per quadrant) behave as expected.

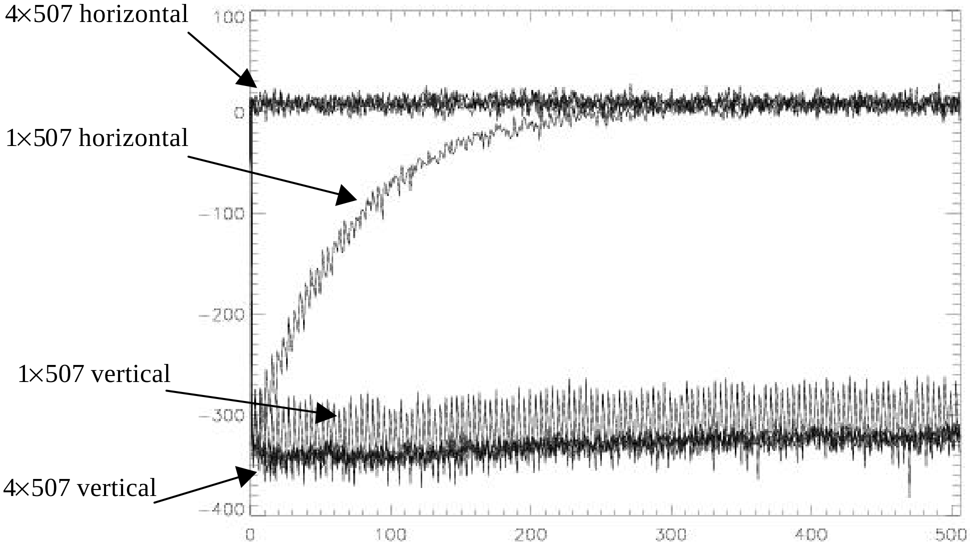


Figure 16. Summary of the reference pixels behavior.

4. Curing the light sensitivity

The WFC3 team at DCL has been able to correct for the light sensitivity of the vertical reference pixels by modifying the clocking pattern. On the assumption that the light sensitivity is related to some sort of memory in the readout circuitry, a delay time has been added at the beginning of each row. Figure 17 shows the results obtained on FPA#25 with moderate flux levels. With no delay The difference before and after lilght exposure is ~40 counts. This reduces to ~0 counts when a delay of 3ms is inserted at the beginning of each row. The price to pay for this correction is an increase of the minimum integration time by 512x3ms=1,536ms. The total readout time moves therefore from ~2.1s to ~4.1 s total at the ~90KHz nominal readout rate of WFC3.

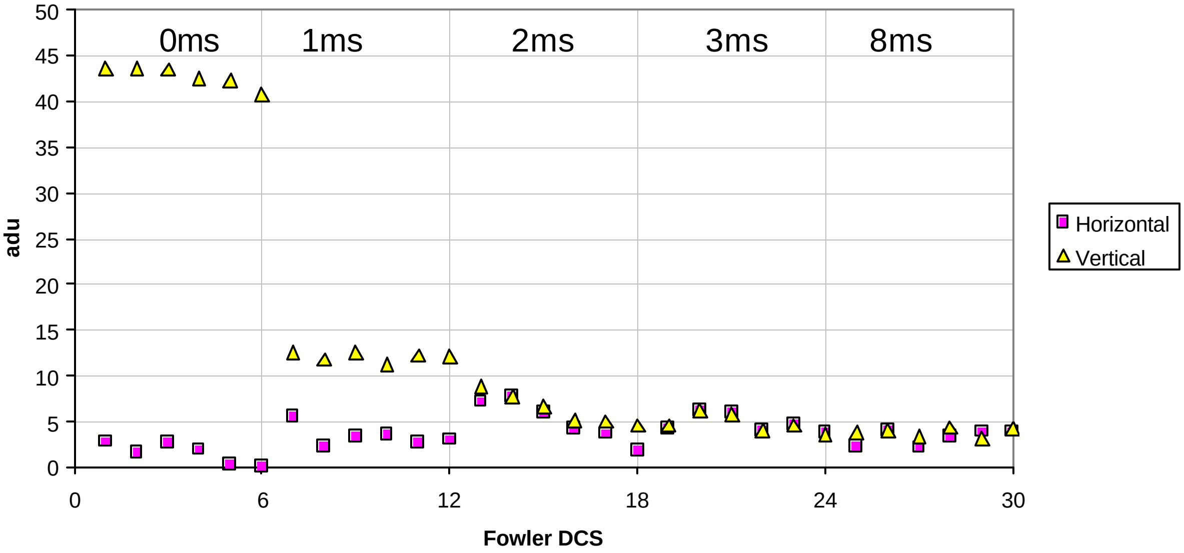


Figure 17. Variation of the inboard reference pixel response to the light vs. the delay time at the beginning of each row. The 6 values per each integration time refer to the 6 Fowler pairs "signal – reset".

5. Use of the reference pixels

In several cases, reference pixels provide a noticeable improvement of the detector stability. Figure 18, obtained for FPA#25, illustrates how a dark current measure may improve when reference pixels are used. The first 6 points on the left side of the plot represent the average counts in 6 Fowler "Signal-Reset" pairs, for quadrant 1. It may be noticed that the first two reads present spurious values, whereas the remaining four are much more stable and in mutual agreement. The rest of the plot shows the same values once the different type of reference pixels have been subtracted. It is clear that the 1st and 2nd read cannot be adjusted to match the values of the following reads. The other 4, however, become more uniform, and in particular the vertical reference pixels consistently provide the best correction.

The inboard vertical reference pixels seem to provide the best correction also to the drifts occurring on long time scales. Figure 19 compares the average values obtained on the horizontal and vertical inboard reference pixels for a 60hr long test session performed on FPA#31. Using the sample-up-the-ramp mode, 20 dark exposures, each 3 hr long, were taken. For each exposure, 17 read were obtained at evenly spaced intervals of ~10minutes. After an initial rapid settling, there is a general monotonic trend which seems to be tracked with higher accuracy by the vertical reference pixels.

Whereas the horizontal reference pixels are read at the beginning of the frame, the vertical reference pixels are read at the beginning of each row and therefore provide a much better sampling of the high frequency variations during the read. It must be noted, however, that during this experiment the active pixels experienced for the first 30hrs a very large drift, currently under investigation. This drift is not reflected in the reference pixels, that therefore cannot be used to correct it.

6. Conclusion

The WFC3-IR detector have been equipped with reference pixels built with different technologies. We have illustrated how the various type of reference pixels perform. The vertical reference pixels show “light sensitivity”. This can be cured by adding a delay time ~3ms at the beginning of each row. In this way, the vertical onbard reference pixels seem to provide the better correction for the signal drifts both on short (ms) and long (hr) times scales. On the other hand, the reference pixels cannot compensate for the major drifts encountered at the beginning of the Fowler reads (1st and 2nd reads), or during the dark current exposures obtained after power cycle in FPA#31 and #33.

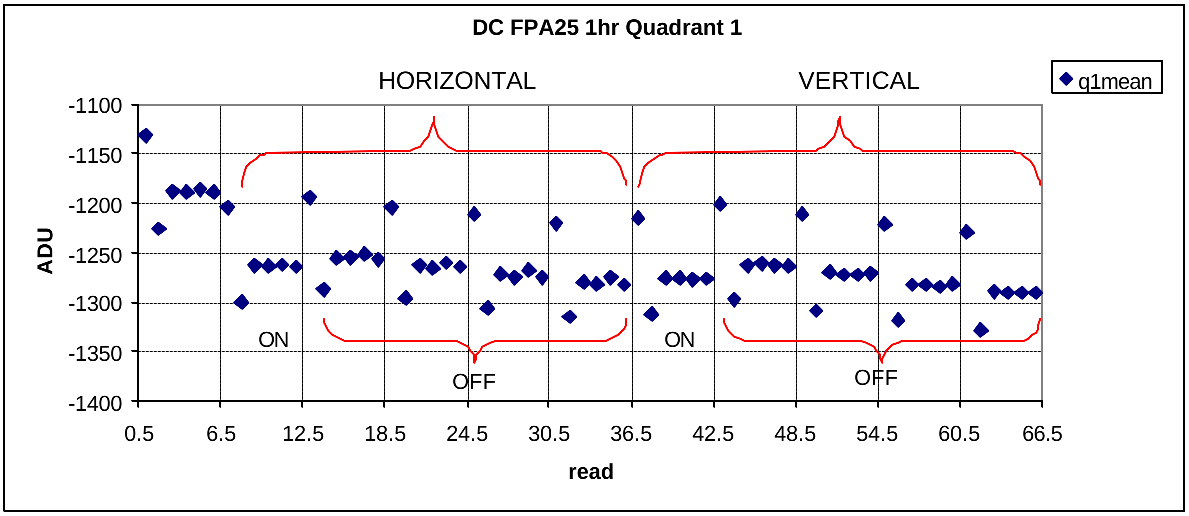


Figure 18. Effect of the application of the reference pixels on a dark current exposure taken in Fowler sampling mode (6+6 read).

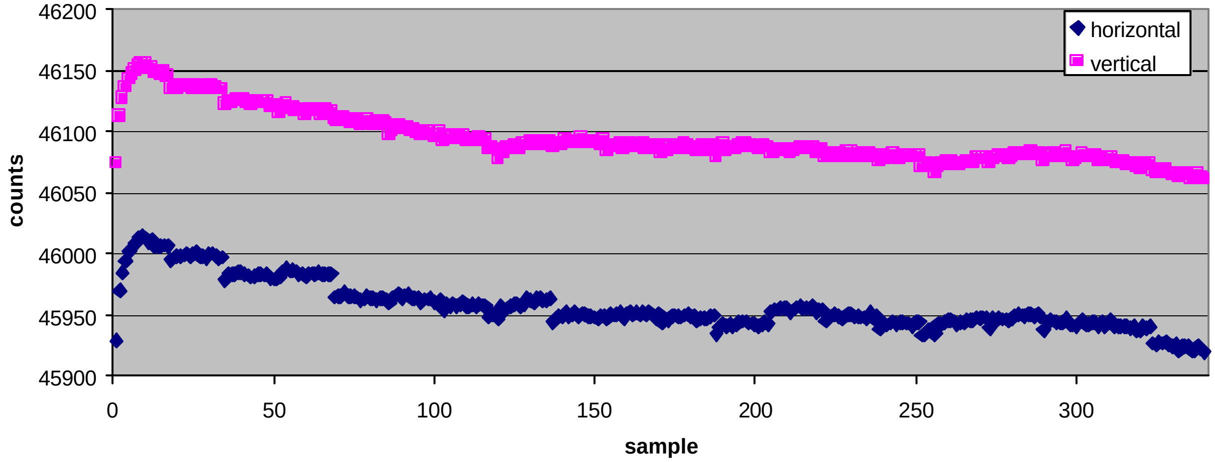


Figure 19. The inboard reference pixels in a 60 hr long dark current experiment. Data were taken on FPA#31 in sample-up-the-ramp mode.