WFC3 Instrument Science Report 2008-50

WFC3 TV3 Testing: IR Gain Results

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December 16, 2008

ABSTRACT

Over the course of Thermal Vacuum 3 (TV3) testing during the spring of 2008, we used flat field data to calculate the gain of the IR4 (FPA165) flight detector. At the nominal flight gain setting of 2.5 e^-/ADU, we measure gain values between 2.31 – 2.41 e^-/ADU, after accounting for inter-pixel capacitance (IPC). This corresponds to 2.66 – 2.77 e^-/ADU before the IPC correction.

Introduction

As was done in TV1 and TV2 testing, the goal of this study was to calculate the effective gain of the WFC3-IR channel. All data were collected at the nominal gain setting of 2.5 e^-/ADU. By measuring basic statistics of the signals across the detector, and accounting for several unexpected behaviors, we were able to calculate the gain in each quadrant of the detector.

Data

IR channel gain data were collected using the Science Mission Specification (SMS) IR02S01. The detector was illuminated using the optical stimulus' tungsten lamp, through the F125W broadband filter. One run of the SMS produced 20 ramps. Each ramp was composed of 14 reads, following the RAPID timing pattern. This resulted in a total exposure time of 38.1 seconds for the final read in each ramp. The SMS was run twice during TV3, in order to characterize the gain using both sets of electronics in the instrument.

Gain Setting (e^-/ADU)	Day of Year	Sample Sequence	Number of Ramps	Reads per Ramp	CASTLE Lamp	Filter	MEB
2.5	71	RAPID	20	14	Tungsten	F125W	1
2.5	92	RAPID	20	14	Tungsten	F125W	2

Table 1: IR channel gain data collected during TV3 testing.

Analysis

Method

Prior to the gain calculation, several data reduction steps were applied to each of the ramps. The mean value of all vertical inboard reference pixels was used to remove the bias signal in each read of each ramp. Pixel-to-pixel variations in the zero level of a ramp were then removed by subtracting a median RAPID dark current ramp derived from TV3 dark current observations, read-for-read, from each of the gain data ramps. This method was used rather than the more standard step of subtracting the zeroth read from all subsequent reads of a ramp. The reasoning behind this strategy involves the non-linearity correction, which was performed after this zero level correction. The non-linearity correction relates the measured signal to that which would be measured on a linear detector. However, subtracting the zeroth read from the gain ramp would remove any signal that accumulated prior to the readout of the zeroth frame, resulting in an inaccurate non-linearity correction. By subtracting a dark current ramp, we were able to remove the pixel-to-pixel variation in the zero level and perform the dark current correction, while preserving all measured signal. Finally, non-linearity effects were removed on a pixel-by-pixel basis, using a third order polynomial calculated from the TV3 nonlinearity observations (Hilbert 2008b).

As was done in TV1 and TV2 testing, we used the mean-variance method to calculate the gain in these data. This method uses two ramps to calculate gain values, and is described in detail in Baggett (2005) and Hilbert (2005). First, we create a summed ramp by adding together, read-by-read, two of the original ramps. We also create a differenced ramp by subtracting the same two original ramps. In this case, the original ramps were composed of 14 reads, leading to summed and differenced ramps of the same size. Mean and variance values were calculated separately for each quadrant of each read, using the method described below.

Beginning with the summed ramp, we calculated a histogram of the data values in each quadrant of each read. The peak value of a best-fit Gaussian to each histogram was recorded as the "mean" value for that read. To calculate variance values, the same recipe was used on the difference ramp, where the width of the Gaussian was recorded. Examples are shown in Figure 1. As the input ramps were composed of 14 reads each, we ended up with 14 mean-variance pairs in each quadrant. Using these pairs, we produced plots similar to Figure 2. The inverse of the slope of a line fit to the mean-variance pairs gave a measure of the gain.

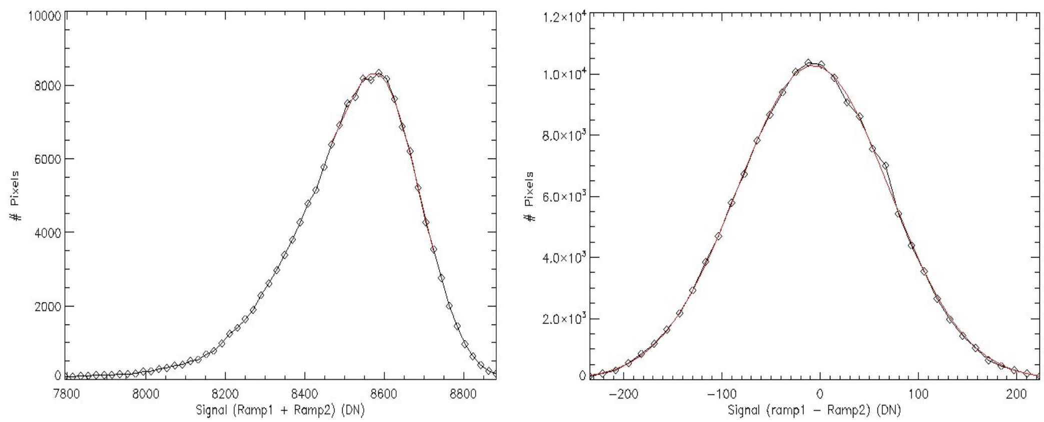

Figure 1: Histograms and Gaussian fits of a single read of a summed (left) and differenced (right) ramp. The peak of summed histograms gave the "mean" signal values for the gain calculation, while the square of the width of the differenced histograms gave the variance values.

Non-Linearity Effects

As mentioned above, the calculations of gain values were found to be highly sensitive to any non-linearity effects present in the data. For a given pair of ramps, slopes of the mean-variance plots could vary by 20-30% between corrected and uncorrected (or poorly corrected) data. Figure 2 shows an example. In the uncorrected case, as the signal level increases and pixels begin to go non-linear, they under-measure the true signal. This depresses both the mean signal and variance, leading to a lower slope when compared to the corrected data. Any attempt to make a linear fit to the uncorrected data would clearly result in an inaccurate measure of the gain.

The corrected data showed a more linear behavior across the range of measured signals. However, from Figure 2, it is obvious that the non-linearity correction is far from perfect. The relation between mean signal and variance is still not linear at high signal levels. In order to avoid non-linearity effects as much as possible, we restricted line-fitting for the purposes of gain calculation to mean signal levels below 26,500 ADU. As seen in Figure 2, at these signal levels, the magnitude of the non-linearity correction is small, and the resulting mean-variance values are linear.

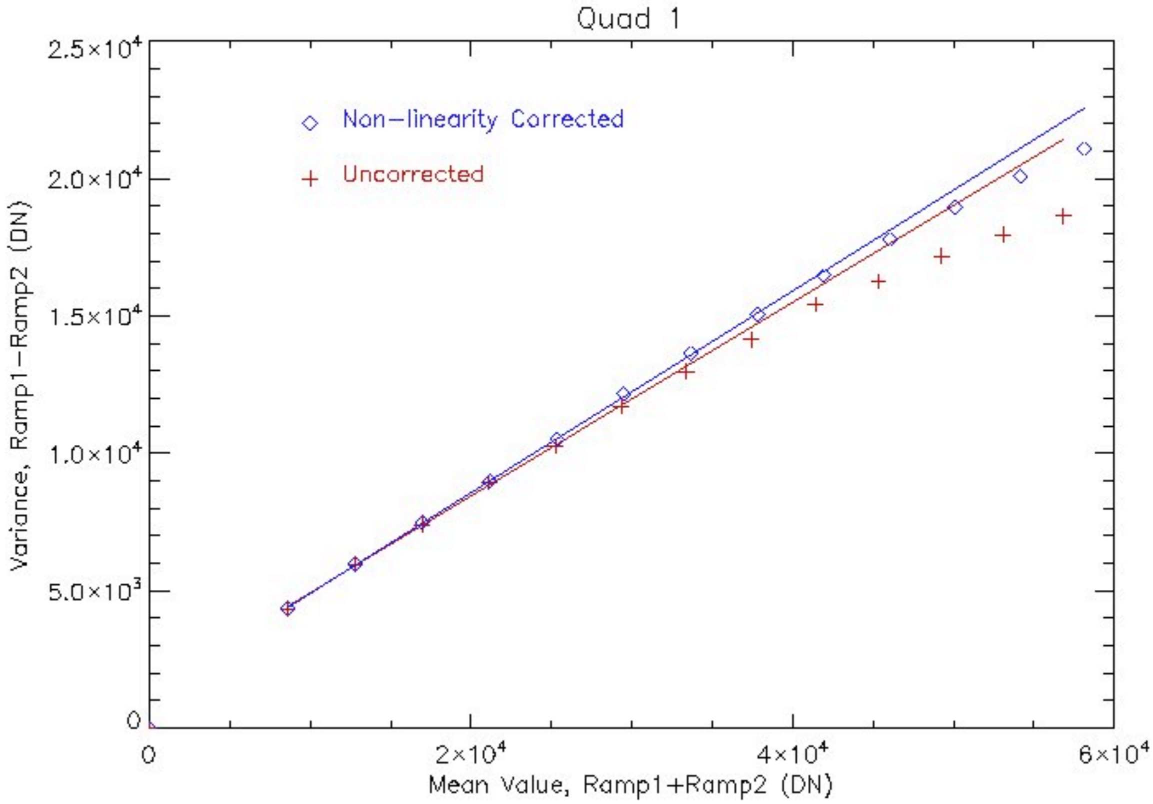

Figure 2: Mean versus variance plot for one quadrant of one pair of ramps. The gain is the inverse of the best-fit linear slope. The red pluses show mean and variance values for a ramp without the non-linearity correction applied, while the blue diamonds show the signal values after non-linearity correction. The red and blue lines show the best-fit line to the first 5 points of the uncorrected and corrected ramps, respectively.

"First Ramp" Versus "Second Ramp" Differences

For both iterations of the gain SMS in TV3, data ramps were collected in pairs. Each pair of ramps was dumped from the instrument buffer to a local computer before collecting the next pair. Similar to the variance differences described above, we also found that the variances were generally different when comparing the first versus the second ramps within a data dump. In cases where we calculated mean and variance values from the pair of ramps within a single data dump, we found variance values which were elevated by up to 5% (meaning gain values were depressed by up to 5%), compared to the case where we used the first ramp from two separate data dumps.

In order to avoid this effect, we only calculated gain values by pairing up initial ramps from data dumps (henceforth referred to as "first ramps") with one another, as well as by pairing the second ramps from data dumps ("second ramps") with one another. Results from the "first ramps" and "second ramps" were kept separate, as there were also differences in mean and variance signals between them. These differences, detailed below, were also observed during TV2 testing with a different IR detector (Hilbert, 2007). Figures 3 and 4 show differences between the "first ramp" and "second ramp" pairs. In Figure 3, we have plotted the fractional difference in the measured mean signal between 5 "first ramp" and "second ramp" pairs. Each color in the plot represents the difference between one "first ramp" and "second ramp" pair, and the five points in each color correspond to the five reads up the ramp that had signal below the line-fitting cutoff of 26,500 ADU. For example, the 5 black diamonds represent the fractional signal differences between the first two "first ramps" and the first two "second ramps". In quadrant 1, we see that in the first read, the mean signal from the "second ramps" is approximately 1% lower than that of the "first ramps". For subsequent reads, this difference decreased to 0.7%, and then 0.6%. Overall we see that for quadrants 1 and 4, the "second ramps" always exhibit 0.4% - 1.0% less signal than the "first ramps". For quadrants 2 and 3 the magnitude of the difference is higher; up to 2%. However the sign of the difference is not always negative (i.e. the "second ramps" do not always show less signal than the "first ramps").

More telling is Figure 4, which is identical to Figure 3, but displays the fractional differences in the measured variances. In all four quadrants, the black points are elevated significantly from the others, and show a positive slope as the read number increases. This shows that by the end of the ramp, the variance measured from the initial "first ramps" (in other words, the first and third ramps of the dataset) is higher than that measured for the initial "second ramps" (the second and fourth ramps of the dataset), by 3% - 8%. These elevated variance values come from abnormal behavior in the very first ramp of the dataset. Any ramp pair created using the first ramp of the dataset exhibited elevated variance values. When using these higher variances to calculate gain values, plots such as Figure 2 displayed elevated slopes, and therefore depressed gains.

Immediately prior to the collection of these gain data during TV3 testing UVIS-channel tests were conducted, with the IR detector cooled and in autoflush mode. This suggests that persistence from previous tests should not be present in the first ramp of each dataset. The fact that the mean signals in the ramp pair involving the first ramp (black diamonds in Figure 3) behave similarly to those from the other ramp pairs also suggests that persistence is not the culprit. Other investigations into IR channel TV3 data have revealed systematic differences in the reset bias level amongst the ramps in a given dataset (H. Bushouse, private communication). This may be a related effect. Given this observed behavior, we did not use the initial "first ramp" pair in gain analysis.

Ignoring the black points in Figures 3 and 4, we found that the behavior of all other ramp pairs were consistent with one another. It does appear that there is a small difference between mean signal and variance values calculated from "first ramps" and "second ramps". The variance plots in Figure 4 are consistently less than zero, indicating a smaller variance in the "second ramps" as compared to the first. Due to these differences, we have kept "first ramps" and "second ramps" separate throughout the gain analysis, in an effort to quantify any gain differences between them.

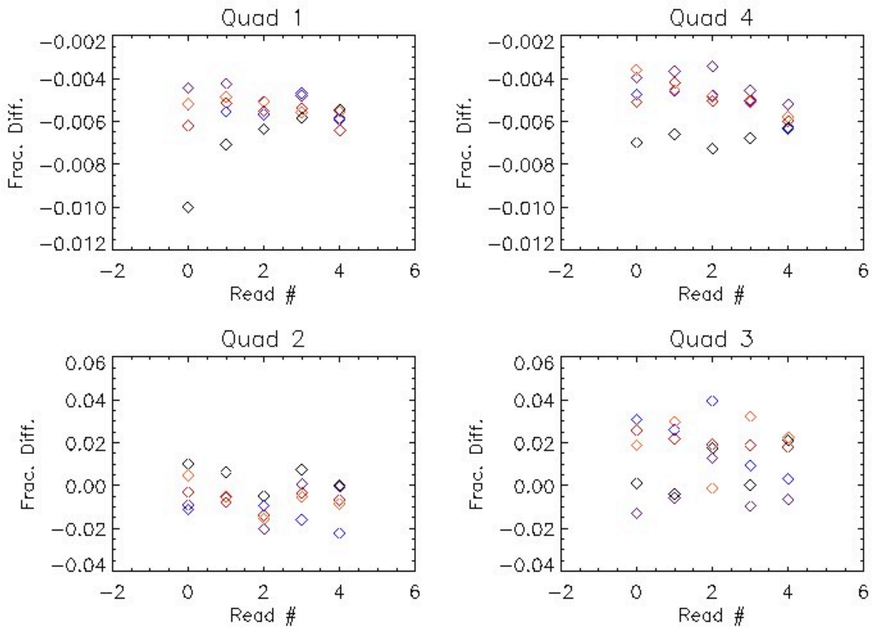

Figure 3: Fractional difference in the mean signals of "first ramp" pairs vs "second ramp" pairs. Each color represents the difference between one "first ramp" and "second ramp" pair, and the five points of each color correspond to the five reads up the ramp that had signal below the line-fitting cutoff value of 26,500 ADU. These signal differences were then normalized by the "first ramp" signal.

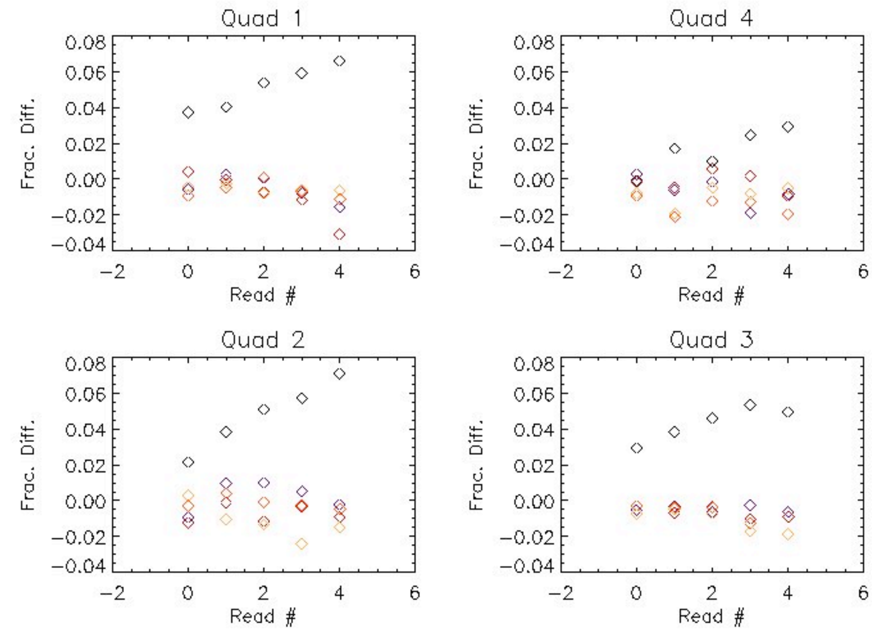

Figure 4: Same as Figure 3, but for the fractional difference in the calculated variances. Note the elevated black points, resulting from inconsistent behavior in the very first ramp of the dataset.

Electronics Side 1 Versus Side 2

The gain data SMS was run twice during TV3 testing, with one run performed using each of the two sets of WFC3 electronics. We also kept the results from the two electronics sides separate, in order to search for any side-dependencies in the gain value.

For each of the two datasets listed in Table 1 we created 8 ramp pairs, 4 of which were composed of the "first ramps", and 4 from the "second ramps", avoiding the first pair of ramps, for reasons discussed in the previous section. We performed the analysis described above on each pair of ramps, producing a measure of the gain in each quadrant of the detector. We ignored the outer ~100 pixels around the edge of the detector, as this avoided any effects due to certain features on the detector ("wagon wheel", "death star" etc). Some of these features are visible in Figure 1 of WFC3 ISR 2008-30 (Hilbert 2008a).

Figures 5 and 6 show the calculated gain values for each pair of ramps. There appears to be no systematic difference between the gain values from "first ramp" pairs and "second ramp" pairs. The scatter in each dataset's points also dominates any differences between MEB1 and MEB2 gain values. For each electronics side/quadrant/"first/second ramp" combination, we calculated a final gain value by taking the mean of the 4 values calculated from the ramp pairs. These values are listed in Table 1, along with the standard deviation of each set of 4 points as uncertainties.

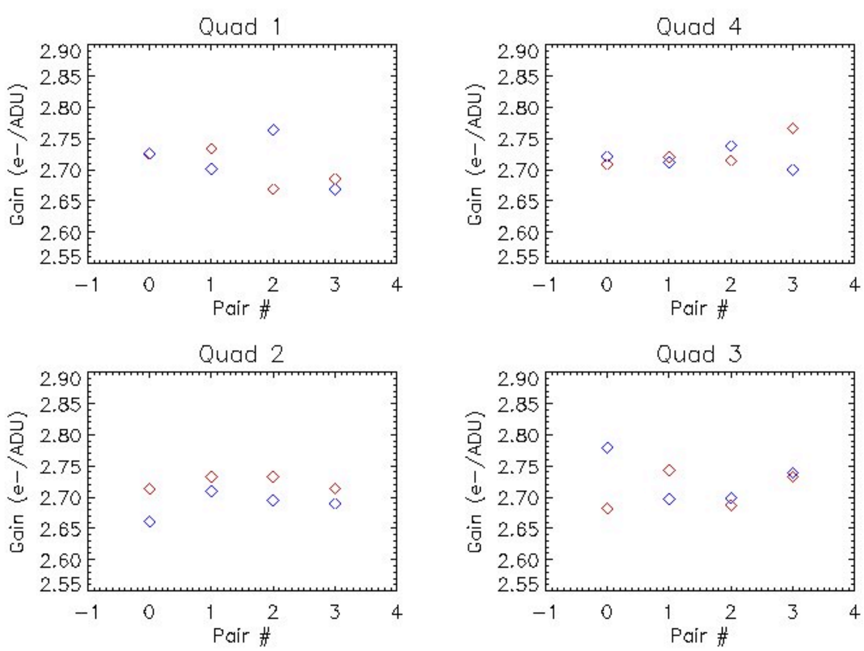

Figure 5: Gain values calculated from data taken with MEB1. Red diamonds show values for the "first ramps" of each data dump, while blue diamonds represent the "second ramps" of each data dump.

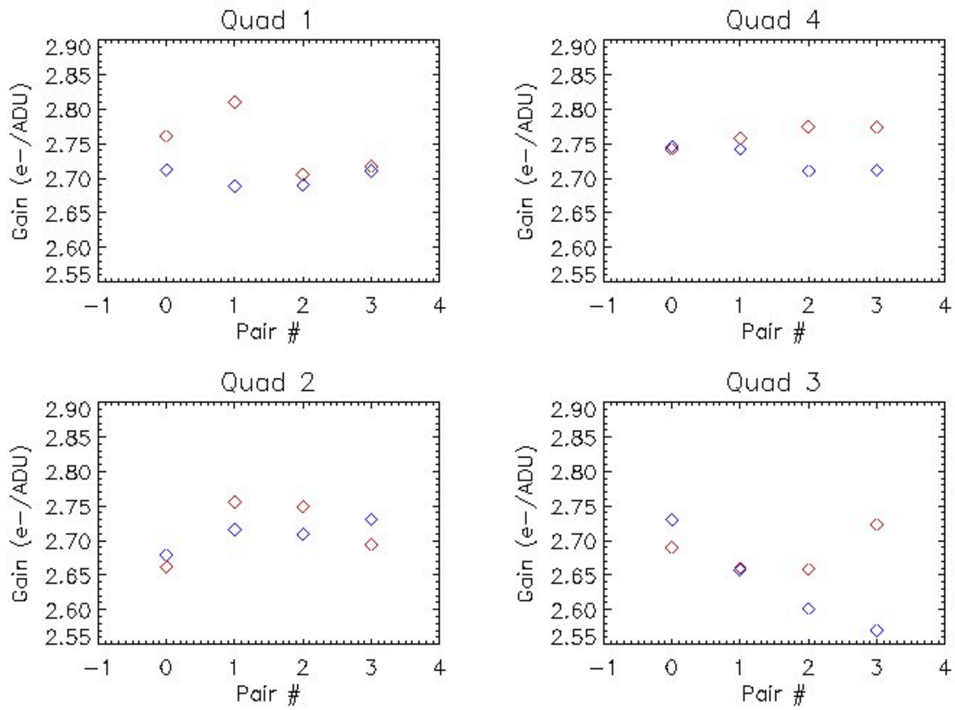

Figure 6: Same as Figure 3, except for data taken with MEB2.

Conclusions

Final gain values are listed in Table 2, along with the standard deviation of each set of 4 points as uncertainties. For all MEB1 and MEB2 "first ramps" and "second ramps", the mean gain values are identical to within the uncertainties. This implies that the behavior which made it impossible to create a ramp pair from the two ramps within a given data dump, affected the measured signals in a consistent way across the detector, such that the relationship between mean signals and variances was unchanged.

All calculations and plots to this point do not include the effects of inter-pixel capacitance. This effect, caused by capacitive coupling between pixels, artificially decreases the photon shot noise seen by an individual pixel. A decrease in the variance will translate into a decrease in the slope of Figure 1, resulting in an artificial increase in the gain. Our best estimates conclude that IPC effects can be removed by scaling measured signal down by a factor of 0.87 (T. Brown, private communication). Tables 2 and 3 show the final gain results for WFC3-IR from TV3 testing before and after IPC correction.

Prior to IPC Correction				
	Quadrant 1	**Quadrant 2**	**Quadrant 3**	**Quadrant 4**
Commanded Gain: 2.5				
MEB 1 (first ramps)	2.73 +/- 0.03	2.73 +/- 0.01	2.73 +/- 0.03	2.72 +/- 0.01
MEB 1 (second ramps)	2.73 +/- 0.04	2.70 +/- 0.02	2.74 +/- 0.04	2.72 +/- 0.02
MEB 2 (first ramps)	2.76 +/- 0.06	2.75 +/- 0.05	2.69 +/- 0.04	2.77 +/- 0.02
MEB 2 (second ramps)	2.71 +/- 0.01	2.72 +/- 0.02	2.66 +/- 0.08	2.74 +/- 0.02

Table 2: Calculated gain values for WFC3-IR in units of e$^-$/ADU.

Including IPC Correction				
	Quadrant 1	**Quadrant 2**	**Quadrant 3**	**Quadrant 4**
Commanded Gain: 2.5				
MEB 1 (first ramps)	2.38 +/- 0.03	2.38 +/- 0.01	2.38 +/- 0.03	2.37 +/- 0.01
MEB 1 (second ramps)	2.38 +/- 0.03	2.35 +/- 0.02	2.38 +/- 0.03	2.37 +/- 0.02
MEB 2 (first ramps)	2.40 +/- 0.05	2.39 +/- 0.04	2.34 +/- 0.03	2.41 +/- 0.02
MEB 2 (second ramps)	2.34 +/- 0.01	2.37 +/- 0.02	2.31 +/- 0.07	2.38 +/- 0.02

Table 3: Gain values from Table 1, scaled down by a factor of 0.87 to account for the IPC correction.

References

Baggett, S., 2005, WFC3 ISR 2005-08, "WFC3 Thermal Vac Testing: UVIS Gain Results"

Hilbert, B., 2008a, WFC3 ISR 2008-30, "WFC3 TV3 Testing: IR Channel Dark Current"

Hilbert, B., 2008b, WFC3 ISR 2008-39, “WFC3 TV3 Testing: IR Channel Nonlinearity Correction,” in preparation.

Hilbert, B., 2007, WFC3 ISR 2007-28, “WFC3 TV2 Testing: IR Gain Results”

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Hilbert, B., 2004, WFC3 ISR 2004-10, “Basic IDL Data Reduction Algorithm for WFC3 IR and UVIS Channel”