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WFC3 TV2 Testing: UVIS Shutter Stability and Accuracy

B. Hilbert
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Abstract

Images taken during WFC3's Thermal Vacuum 2 (TV2) testing have been used to characterize the performance of the UVIS channel shutter. Images with exposure times ranging from 0.5 to 30 seconds have been used to examine shutter shading, accuracy, and repeatability. Fits to ratio images reveal no shutter shading effects down to the 0.77% level, corresponding to an exposure time difference across the image of no more than 0.004 sec (CEI Spec is 0.01 sec). Measured exposure times are within 2.4% of commanded values in all cases except the 0.5 second images. Similar to results from TV1, these data show the UVIS shutter fails to meet the CEI Spec for shutter repeatability in 5 of the 9 commanded exposure times.

Introduction

The shutter in WFC3's UVIS channel is composed of a circular disk with alternating open and opaque quadrants, such that a 90° rotation changes the shutter from an open to a closed position, and a 180° rotation will take the shutter from the closed position on side "A" to the closed position on side "B". The goal of this study was to characterize the behavior of the shutter, focusing on how closely and repeatably the shutter performs relative to expectations. First, we looked for shutter shading effects. If the shutter were to have a non-linear velocity, certain parts of the CCDs would have longer integration times than others, resulting in large scale brightness variations across images. Next, we examined the accuracy of the shutter. For a given image, we measured the exact amount of time that the shutter was open, and compared this to the commanded exposure time. Finally, we looked at the variations in measured exposure times for sets of images with identical commanded exposure times.

Data Reduction

Data for this test were taken following the instructions described by SMS UV08S01B. As with the version of the test performed during Thermal Vacuum I testing, the data consisted of full frame, 3x3 binned images with exposure times from 0.5 to 30 seconds. Flat field illumination was provided by the Xenon lamp in the CASTLE. The F438W filter was used in order to avoid the fringing issues observed during the TV1 version of this test (Hilbert 2004b). In order to obtain good signal-to-noise on all images, the ND1 neutral density filter was used for observations equal to or longer than 4 seconds, in order to avoid saturation. Several 4-second images were also taken without the ND1 filter, in order to calibrate the throughput of the ND1 filter. This will be discussed further below. Details of all observations are listed in Table 1.

Exposure Time (sec)	***Number of Images***	***ND Filter***
0.5	16	None
0.7	16	None
0.8	16	None
1.0	4	None
1.2	4	None
1.4	4	None
2.0	4	None
4.0	8	None
4.0	4	ND1
8.0	4	ND1
30.0	4	ND1
0.0	2	None

Table 1 List of images obtained for the UVIS Shutter Shading study.

Prior to any data analysis, all images were run through the IDL data reduction pipeline (Hilbert 2004a). Row-by-row bias level corrections were made by subtracting overscan values. A median bias image was created from the two bias images taken during the test. This image was subtracted from all other images in order to perform the overall bias correction. Finally, images were converted to units of electrons by applying gain values, calculated for each amp from TV2 data and supplied by Sylvia Baggett (private communication). For amps A through D, these gain values were 1.57, 1.54, 1.63, and 1.59 e^-/ADU, respectively.

Before any analysis could be performed, we had to account for the neutral density filter used in the longer integrations. The exact factor by which the ND1 filter reduced the throughput was unknown, and had to be calculated from the data. We used the 4-second files for this purpose. We created a mean image from the 8 4-second images taken without the ND1 filter, and a separate mean image from the 4 4-second files where the ND1 filter was in place. Assuming that the output of the illuminating lamp was steady over the duration of the 4-second images, the mean of the ratio of these two images gave a measure of the reduction in throughput from the ND1 filter. For this dataset, we calculated a throughput reduction of a factor of 9.518 +/- 0.0002 for ND1. We then applied this factor to all images taken with the ND1 filter in place, in order to have a consistent set of images for analysis.

With the effects of bias levels and filter throughputs taken into account, we performed the final step in preparation for subsequent analyses by creating a mean image for each exposure time.

Analysis

Shutter Shading

In order to search for any shutter shading effects, we created a ratio image of the mean 30-second exposure to the mean 0.5-second exposure. By dividing these two images any detector dependent effects, such as spatial sensitivity differences, should be removed. Any shutter shading effects would remain in the ratio image, due to the fact that a variable exposure time across the detector will have a proportionally larger effect on the 0.5-second image compared to the 30-second image.

Figure 1 shows the ratio image with a log stretch. In order to quantify any large spatial variations in the signal, we fit both a plane and a quadratic surface to the ratio image. Results are summarized in Table 2. In the worst case, the quadratic fit returned a signal variation of 0.77% across the detector, which translates into a difference in exposure time of 0.004 seconds across the detector, assuming all of the variation is in the 0.5-second image. This is a factor of 2.5 lower than the CEI Spec of 0.01 seconds.

Fit	***% Signal Variation***	***Corresponding Exposure Time Variation (sec)***
quadratic surface	0.77	0.004
planar surface	0.57	0.003

Table 2 Shutter shading examination. Measured exposure time variations are all well below the CEI Spec of 0.01 seconds.

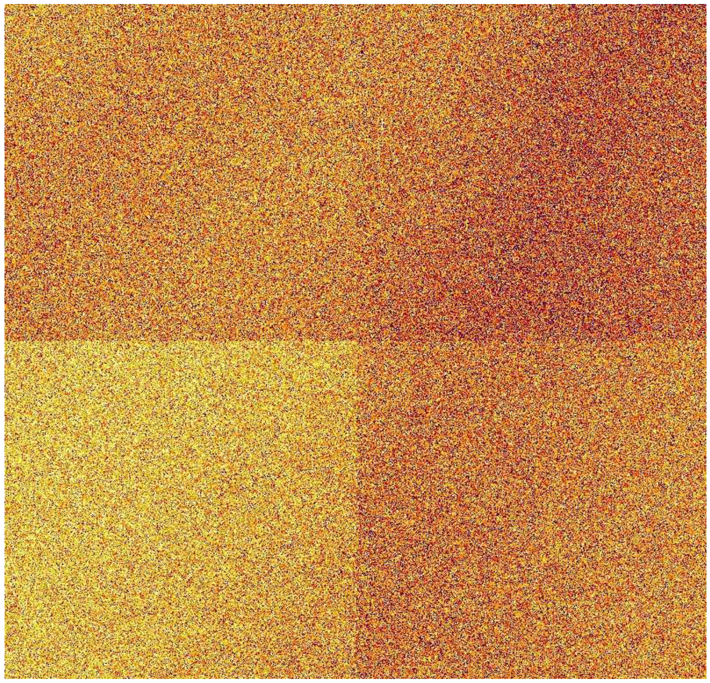

Illustration 1 Log-stretched shutter shading image. No shutter shading is seen down to the 0.77% level.

Shutter Accuracy

The data were also used to characterize the accuracy of the UVIS shutter, by comparing measured exposure times to commanded exposure times. There is no formal CEI Specification on the accuracy of the UVIS shutter, but it is important to quantify how close to expectations the shutter is performing. In order to calculate actual exposure times, signal rates of shorter integration time images were compared to the signal rates of the 30-second images. Again, we use the assumption that for the 30-second images, errors due to the difference between the measured and commanded exposure time are small compared to other sources of error.

For each commanded exposure time n, we created a countrate ratio image, R_n, following Equation 1, where *mean image*$_n$ is the mean image associated with exposure time n. The mean of each R_n image was calculated, giving the fractional countrate measured in shorter images versus the countrate of the 30-second image. Multiplying this fractional countrate by the commanded exposure time gave the measured exposure time for each mean image. Results are given in Table 3.

$$R_n = (\text{mean image}_n / n) \;/\; (\text{mean image}_{30} / 30) \qquad (1)$$

Commanded Exposure Time (sec)	*Mean Fractional Countrate relative to 30-sec Image*	*Error on Mean Fractional Countrate*	*Measured Exposure Time (sec)*	*Meausred Exposure Time from TV1 (sec)*
0.5	0.944434	$3x10^{-6}$	0.472217	0.497800
0.7	0.985878	$3x10^{-6}$	0.690115	0.686700
0.8	0.994800	$3x10^{-6}$	0.795840	0.792600
1.0	0.989752	$4x10^{-6}$	0.989752	0.989500
1.2	0.995395	$4x10^{-6}$	1.194470	1.183500
1.4	0.994282	$4x10^{-6}$	1.391990	1.389200
2.0	0.995148	$3x10^{-6}$	1.990300	1.977700
4.0	0.996572	$3x10^{-6}$	3.986290	3.969100
8.0	0.999590	$4x10^{-6}$	7.996720	NA

Table 3 Countrate differences between shorter integrations and 30-second integrations, along with measured vs. commanded exposure times.

The measured exposure times from TV2 testing are all closer to the commanded exposure times than those measured in TV1, except for the 0.5-second case. Figure 2 illustrates the differences between TV1 and TV2 measurements.

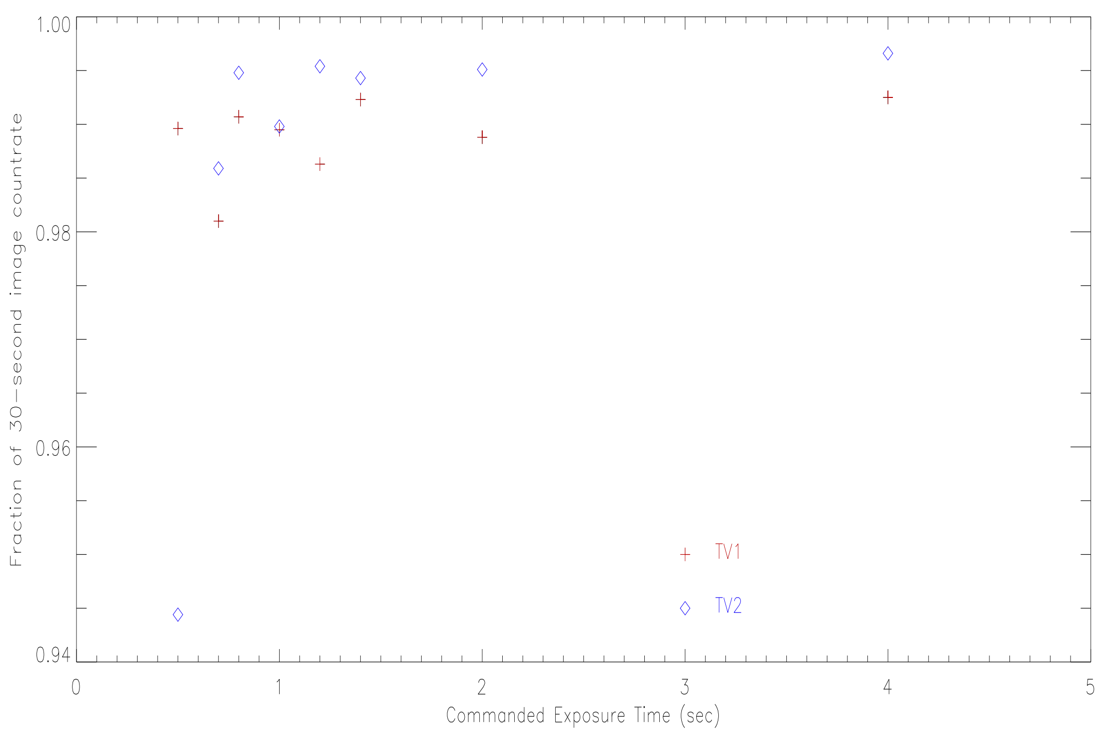

Illustration 2 Shutter accuracy measurements for TV1 and TV2 testing. Exposure times for TV2 appear more accurate in all except the 0.5-second case.

Shutter Repeatability

The final shutter characterization performed using this dataset was the shutter repeatability. The measured exposure times reported above were calculated using the mean image for each exposure time. In this case, we wanted to examine how the measured exposure time varied from image to image within a set of files of the same commanded exposure time. The analysis technique for this study was nearly identical to that for the shutter accuracy study. In this case, we replaced the *mean* $image_n$ in Equation 1 with an individual image. As before, we calculated the mean of the ratio image R_n, to obtain a fractional countrate relative to the countrate of the mean 30-second image. Multiplying this countrate by the commanded exposure time gave the measured exposure time for the image. The CEI Spec we are comparing against in this case specifies an image-to-image difference in exposure time of no more than 0.01 seconds for a set of images with a given commanded exposure time. Therefore, after calculating the measured exposure times for all images in this dataset, we calculated, for each commanded exposure time, the difference between the longest and shortest measured exposure time. Results are detailed in Table 4, and indicate that for 5 of the 9 commanded exposure times, the UVIS shutter fails the repeatability specification. Another detail to note is that for more than half the commanded exposure times, we only have 4 images with which to perform this analysis. This results in large error bars on the fraction of time where the shutter fails to meet the specification. For example, with a larger set of 1.0-second images, it may become clear that the shutter fails to meet the specification in that circumstance also. Many more exposures at all exposure times would be needed in order to obtain an accurate distribution of measured exposure times for each commanded exposure time.

Commanded Exposure Time (sec)	***Variation in Measured Exposure Time (sec)***	***Number of Images in Set***
0.5	0.005	16
0.7	0.018	16
0.8	0.021	16
1.0	0.004	4
1.2	0.007	4
1.4	0.010	4
2.0	0.016	4
4.0	0.02	12
8.0	0.025	4

Table 4 Variations in measured exposure time for each commanded exposure time. The CEI Spec dictates a variation no greater than 0.01 seconds.

Finally, we searched for any timing differences between the two sides of the shutter. In 2004, during TVI testing, we found that shutter repeatability and timing had no dependence on shutter side, except in the case of the 0.5 second images (Hilbert 2004b). For those exposures, side "A" of the shutter repeatedly produced exposure times closer to the commanded 0.5 seconds than did the "B" side of the shutter.

For the dataset collected in TV2 testing, we find an identical situation. For all commanded exposure times other than 0.5 seconds, there is no correlation between shutter side and measured exposure time. For the 0.5 second images, side "A" of the shutter is consistently closer to 0.5 seconds than side "B". Figure 3 illustrates this fact, by showing the measured exposure times for the 0.5 second images plotted for each shutter side. It is also important to note that despite this behavior, the variability in exposure time for the 0.5 second images falls within the CEI Spec.

Figure 4 shows the same plot for the 0.7 second images. As a group, these images fail the shutter repeatability CEI Spec. However, as shown, there is no correlation between shutter side and exposure time.

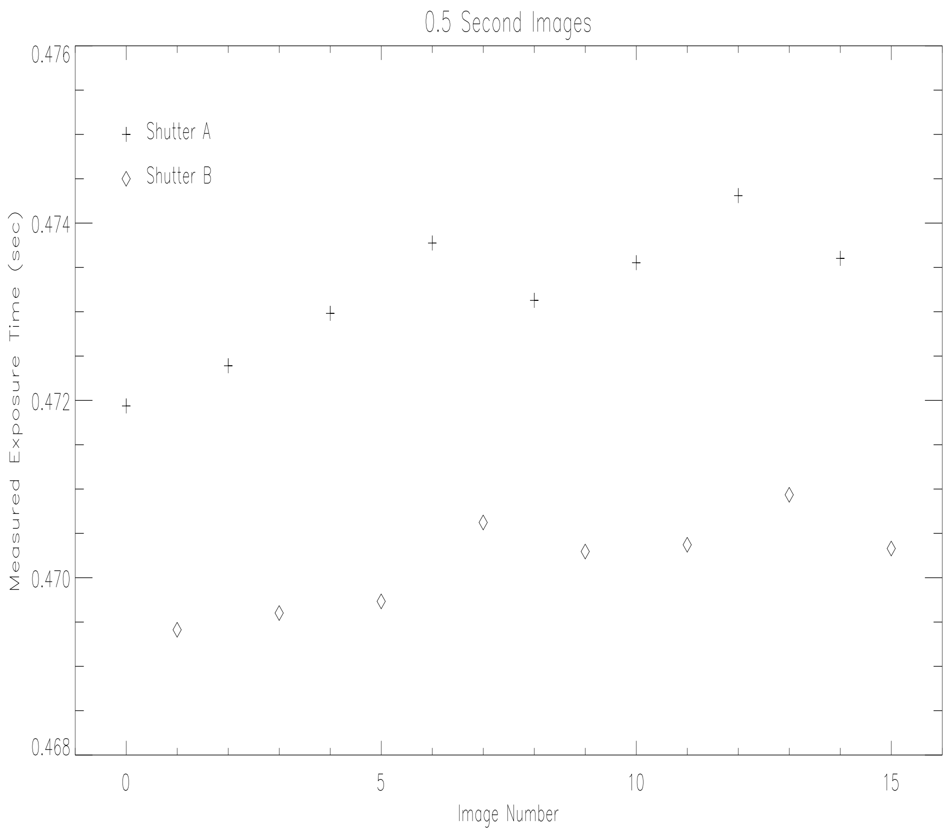

Illustration 3 Measured exposure time repeatability for the 0.5 second images. Images taken using shutter side "A" are consistently closer to 0.5 seconds than those using side "B".

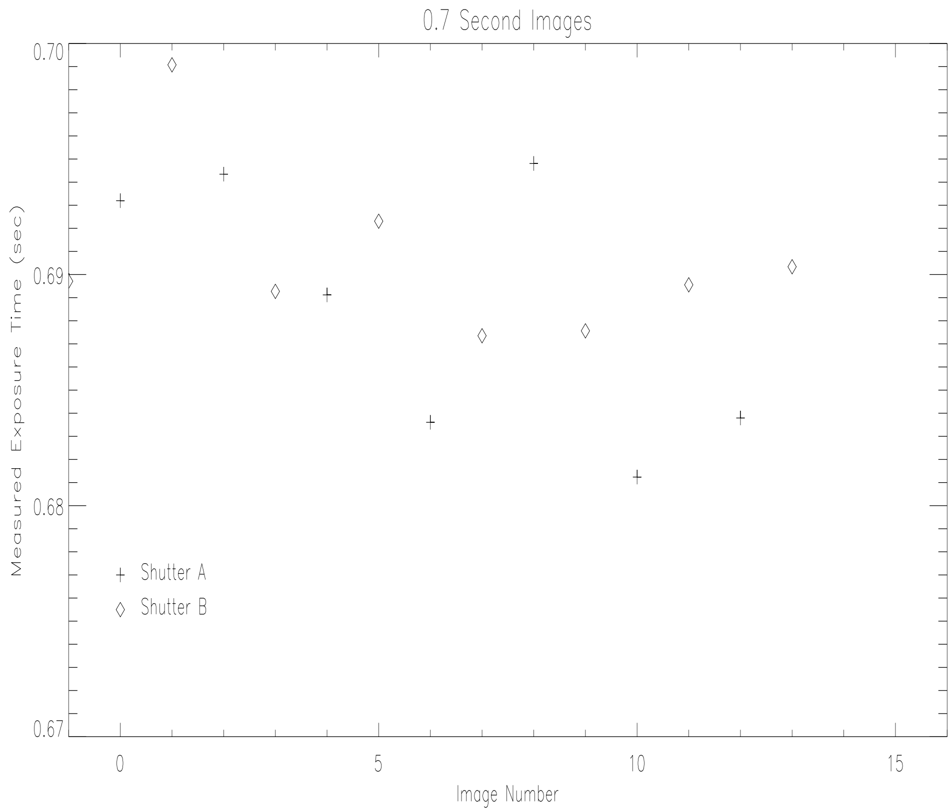

Illustration 4 Exposure time versus shutter side for the 0.7 second images.

Conclusions

During the shutter shading test in TV2, the UVIS shutter's performance was roughly consistent with that seen during TV1. Shutter shading effects are roughly 2.5 times lower than dictated by the CEI Spec. The shutter accuracy, in terms of commanded versus measured exposure times, appears slightly better now versus TV1 for all cases except in the 0.5 second images, where it is worse by a factor of 5.5. Also, as in TV1, the shutter fails to meet the CEI Spec for repeatability for several exposure times. Finally, for the 0.5 second images, shutter side "A" is consistently closer to the commanded exposure time than side "B", although both sides are well within the CEI Spec.

References

Hilbert, B. (2004a) Basic IDL Data Reduction Algorithm for WFC3 IR and UVIS Channel   WFC3 ISR 2004-10. http://www.stsci.edu/hst/wfc3/documents/ISRs/WFC3-2004-10.pdf . 10 June 2004.

Hilbert, B. (2004b) ISR 2004-14: Stability and Accuracy of the WFC3 UVIS Shutter WFC3 ISR 2004-14. http://www.stsci.edu/hst/wfc3/documents/ISRs/WFC3-2004-14.pdf 20 December 2004.