ABSTRACT

Eight runs of the IR science monitor program were executed during WFC3 Thermal-Vacuum test #3, which provides a performance monitor of the IR channel via dark, flat field, PSF, and throughput test exposures. The results show very good repeatability and stability of all measured performance parameters and the IR channel easily meets or exceeds all of the Contract End Item requirements that can be assessed with these data.

Introduction

During Wide Field Camera 3 (WFC3) system-level thermal-vacuum testing campaign #3 (TV3), which took place at Goddard Space Flight Center from February to April 2008, the IR Science Monitor test was executed periodically in order to assess and monitor the overall performance of the camera over the 2-month duration of TV3. The science monitor includes darks, internal and external flat fields at different wavelengths, observations of calibrated sources for measuring instrument throughput, and observations of unresolved sources to monitor imaging quality. These data allow us to measure and track the stability and repeatability of fundamental parameters of the IR-4 flight detector and the WFC3 instrument, such as dark current, read noise, dead and hot/cold pixels, optical throughput, and PSF stability.

The IR science monitor was executed a total of eight times during TV3, using WFC3 ground test Science Mission Specification (SMS) IR19S01. The IR-4 detector was at a flight-like temperature of -128° C for all runs. Four of the runs were performed during
standard system functional tests of WFC3 and the remaining four were performed in the midst of long blocks of science calibration tests. Furthermore, four of the runs were performed with WFC3 operating on the Side 1 Main Electronics Box (MEB) and the other four on Side 2. Table 1 lists specific information for each of the eight runs, including dates, the SMS version, MEB in use, and the section of the overall TV3 test flow in which the run occurred. For this last item, the abbreviations used in the table are as follows: SFT = System Functional Test, SC-1 = Science Calibration campaign 1, SC-2 = Science Calibration campaign 2.

Table 1. Test Run Information.

<table>
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<tr>
<th>Run</th>
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<th>SMS</th>
<th>MEB</th>
<th>TV3 Section</th>
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<td>IR19S01D</td>
<td>2</td>
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<td>2</td>
<td>SC-2</td>
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</table>

Test Contents

The IR19S01 SMS consists of a total of 19 exposures. The parameters for the individual exposures are listed in Table 2. All exposures were obtained using the nominal commanded detector gain setting of 2.5 e-/DN. The test contains a combination of full-frame and sub-array exposures. Flat field exposures were obtained using both internal and external sources. The internal flat field exposures were obtained using the built-in WFC3 Calibration Subsystem. External sources were provided by the optical stimulus (OS), which provides individual point and extended targets, as well as flat field illumination. The point-source exposures are used to monitor optical quality and PSF characteristics at two different wavelengths. The extended-source exposures are used in conjunction with OS flux measurements of the incident light to monitor the absolute throughput of WFC3 at two wavelengths. Versions D, E, and F of the IR19S01 SMS listed in Table 1 differ only in exposure times for a few of the exposures, in order to optimize signal levels.

Data Reduction

The dark and flat-field images included in the science monitor program could in principle be used to calibrate the remaining exposures in the test. However, because much larger sets of darks and flats were obtained in other tests during TV3, we decided to use the
calibration reference files generated from those programs to reduce the science monitor data. The only exception to this is for the case of 64x64 sub-array darks: at the time the IR science monitor data were processed there were not any 64x64 sub-array mode darks available in CDBS, so we used the science monitor 64x64 darks to construct reference files and used those to calibrate all other 64x64 sub-array mode exposures.

Table 2. IR Science Monitor Exposure Parameters.

<table>
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<th>Size</th>
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<td>OS Tungsten lamp</td>
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<td>OS Tungsten lamp</td>
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<td>14</td>
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<td>OS Tungsten lamp</td>
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<td>Tungsten 1050nm point source; 10 nm bandwidth</td>
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<td>Point Source</td>
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<td>Tungsten 1600nm point source; 10 nm bandwidth</td>
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<td>17</td>
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<td>Full</td>
<td>Tungsten 1600nm 200µm source with flux calibration</td>
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<td>18</td>
<td>Extended Source</td>
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<td>19</td>
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<td>Rapid</td>
<td>F105W</td>
<td>Sq64</td>
<td>Tungsten 1050nm 200µm source with flux calibration</td>
</tr>
</tbody>
</table>

Calwf3 version 1.2 was used to process all of the science monitor images, using darks, flats, and non-linearity reference files appropriate for the MEB in use for each run. The calibration reference files (except for the 64x64 sub-array darks noted above) were selected from the latest set of files available in CDBS, all of which were generated from TV3 ground-test data. All exposures were processed with a minimum of the DQICORR (data quality initialization), BLEVCORR (reference pixel bias correction), and
ZOFCORR (zero-read subtraction) calibration steps turned on. Processing for darks stopped there. Flats received the additional steps ZSIGCORR (zero-read signal correction), DARKCORR (dark subtraction), and NLINCORR (non-linearity correction). The five point- and extended-source exposures in each run (exposures 15-19 in Table 2) received all of these calibration steps plus FLATCORR (flat-field correction). In the remaining analysis we will assume a mean gain value for the IR-4 detector of 2.37 $e^{-}$/DN, for the purpose of converting detected counts to electrons (Hilbert 2008c).

**Analysis**

**Dark Images**

Four different types of dark images are included in the science monitor: a 64x64 sub-array readout using the RAPID sequence (exposure 1), two full-frame readouts using the RAPID sample sequence (exposures 2 and 3), a 64x64 sub-array readout using the STEP25 sample sequence (exposure 4), and a full-frame readout using the STEP25 sample sequence (exposure 5). All of the dark exposures used the maximum of 16 readouts.

The mean dark current of the IR-4 detector is sufficiently low to make it difficult to reliably measure the dark signal in the relatively short duration of the exposures using the RAPID sample sequence and from the relatively small number of pixels in the sub-array exposures. We will therefore only present dark currents measured from exposure 5, which is a full-frame readout using the STEP25 sample sequence, resulting in a total exposure time of 274 seconds. The dark current was measured by computing a histogram of the pixel values in each readout of the exposures and then fitting the peak of the histogram with a gaussian. The resulting mean signal versus exposure time relation was then fitted with a linear function, the slope of which gives the dark current.

The results for the 8 iterations of exposure 5 are shown in Figure 1. The result for iteration 5 is significantly higher than the rest of the measurements, the cause of which is currently unknown. All of the dark exposures in iteration 5 of the science monitor show an elevated dark rate. The only thing unusual about this run is that it was executed within a few hours after recooling the IR detector following a WFC3 side switch from MEB2 to MEB1. The situation was the same, however, for iteration 4, which shows normal dark current. The overall mean dark current measured from all science monitor runs except iteration 5 is 0.053 $e^{-}$/sec, with a scatter from run to run of 0.009 $e^{-}$/sec (again excluding run 5). This compares very well with the median dark current value of ~0.048 $e^{-}$/sec reported by Hilbert (2008b) for STEP25 dark exposures taken as part of the full TV3 IR dark current program.
Figure 1. Dark current measurements from exposure 5. Open symbols are for images taken with MEB1 and filled symbols are for MEB2. The dotted line indicates the mean dark current.

We have used all of the dark exposures to also measure the detector readnoise. This was done by simply taking the difference of the first two reads in each exposure and then computing the sigma-clipped standard deviation within the difference images. The results are shown in Figure 2, which shows two trends. First, the readnoise in the sub-array exposures is consistently lower than that in the full-frame exposures. Second, the readnoise for exposures taken with MEB2 is consistently lower than those taken with MEB1. The mean readnoise values for the four different cases are 21.6 e⁻ (full-frame MEB1), 21.2 e⁻ (full-frame MEB2), 20.2 e⁻ (sub-array MEB1), and 19.9 e⁻ (sub-array MEB2). This again compares well with the readnoise values derived independently by Hilbert (2008a) from other TV3 IR test data. The scatter in the measurements from exposure to exposure is ~0.05 e⁻ for the full-frame exposures and ~0.4 e⁻ for the sub-array exposures. The increased scatter in the sub-array measurements is consistent with the much smaller number of pixels from which the measurements are derived.
Flat Field Images

A total of nine flat field exposures are included in the IR science monitor, six using the WFC3 internal calibration subsystem and three using the external optical stimulus (OS) for illumination. The flats are obtained using a mixture of filters, array sizes, and internal lamps (see Table 2). For each set of exposures for a given lamp, filter, and array size combination the calibrated images from all iterations of the science monitor were combined to form a mean flat, using the IRAF task “imcombine”. Each of the individual exposures was then divided by the corresponding mean flat in order to assess the effectiveness of the mean flats in removing pixel-to-pixel sensitivity variations in the images. Statistics for the mean flats and the individually flat-fielded exposures were measured and are presented in the following sections. The ratios of many individual flats against each other were formed, in order to assess the stability of the flat-field structures over time.

Internal Flats

The IR science monitor includes six flat-field images using the internal calibration subsystem, using the F160W, F098M, and F167N filters (exposures 6-11 in Table 2). Two flats are taken for each filter, one using internal Tungsten lamp #2 and one using lamp #4. The F160W exposures are full-frame, while the F098M and F167N use 64x64 sub-array readouts. The primary purpose of the F098M and F167N sub-array exposures –
which span the wavelength range of the IR channel – is to monitor the spectral stability of the internal Tungsten lamps.

The mean F160W full-frame flat taken with lamp #2 (exposure 6) is shown in Figure 3. Signal roll-off in the corners of the image is due to vignetting of the IR calibration subsystem beam within WFC3. The roll-off reaches a maximum depth of ~50% relative to the mean signal level in the rest of the field. The effect is similar for Tungsten lamp #4. The mean signal level in the individual exposures that went into the combined F160W flat is about 53,000 e⁻/pix, which would lead to an expected Poisson noise of ~0.4%. The measured standard deviation of pixel values within the stack of input images is in fact 0.45%, indicating that there are no significant sources of systematic noise.

Figure 3. Combined F160W internal flat-field image, shown with a positive stretch. The roll-off in some corners is due to vignetting of the calibration subsystem IR beam.

An example of the ratio of individual F160W flats from two different science monitor runs is shown in Figure 4, which is the ratio of the images acquired in runs 7 and 8 using lamp #2 (spanning an interval of 7 days). The rms noise in the ratio image is 0.6%, which is exactly what is expected from two images that had signal levels of 54,000 e⁻/pix. The only residual spatial features that can be seen are near the lower right corner of the image and correspond to the most prominent flat-field structures in the IR-4 detector. In this ratio image these features have residuals of +/- 0.6% relative to the mean, which is at the 1-sigma noise level of the image.
Figure 4. The ratio of the F160W internal flats from runs 7 and 8. The rms noise is 0.6% and the residual features seen near the lower right corner are at levels of +/- 0.6% relative to the mean.

Another aspect of the internal flat-field series is the stability of the lamp fluxes over time. Figure 5 shows the mean signal level in each of the internal flat-field images over the 8 iterations of the science monitor. Note that there was a mistake in the science monitor SMS during its first two iterations that caused the wrong internal lamp to be turned on for the three flat-field exposures that were supposed to have used lamp #4 (exposures 9-11 in Table 2), so there are useable data for those exposures only in iterations 3 through 8. The data plotted in Figure 5 show the percentage deviation in the signal level for each iteration relative to the mean over all iterations. The rms scatter about the overall mean ranges from 0.3% to 1.2% for the different sets of exposures, with the scatter generally being a bit larger for the sub-array exposures (F098M and F167N) due to the smaller number of pixels involved. These data show marginal evidence for an overall decrease in lamp flux over the course of the 8 iterations, which encompassed 39 calendar days of testing. The decrease in flux over this time is 0.2-2.0% for the different lamps at the various wavelengths of the flats, with a rather large uncertainty in these values. There does not appear to be any correlation between the MEB in use and the lamp output stability. Overall these data show that the internal lamps are quite stable and repeatable.
We have also used the internal flat-field exposures to compare and track the performance of the two IR channel Tungsten lamps (lamps 2 and 4) in the calibration subsystem. This has been done by taking the ratios of various sets of the exposures. Figure 6 shows three sets of ratios: the ratios of the F160W flats using lamps 2 and 4 (exposure 6 divided by exposure 9), the ratios of the F098M and F167N flats using lamp 2 (exposure 7 divided by exposure 8), and the ratios of the F098M and F167N flats using lamp 4 (exposure 10 divided by exposure 11).

The mean ratio of the F160W lamp 2 vs. lamp 4 exposures is 0.92 with a scatter about the mean of 0.007, indicating test-to-test variations in the relative lamp fluxes of less than 1%. The mean F098M/F167N lamp 2 ratio is 4.00 with a scatter of 0.02 and the mean F098M/F167N lamp 4 ratio is 4.31 with a scatter of 0.02. The approximately 4-to-1 ratio in signal is expected, due to the larger bandwidth of the F098M filter relative to the F167N; the ratio in overall WFC3 throughput using these two filters is ~4.4. There does not appear to be any overall trend in the F098M/F167N ratios for either lamp over the course of these tests, indicating that the spectral properties of the lamps are stable to at least ~2%.
Figure 6. Mean flux ratios of the internal flat-field exposures, including (from bottom to top) the ratios of the F160W exposures using lamps 2 and 4, the ratios of the F098M and F167N exposures using lamp 2, and the ratios of the F098M and F167N exposures using lamp 4. Note that there are no lamp 4 exposures available for test runs 1 and 2.

A final test for changes in the lamp properties was done by taking the F160W lamp 2 to lamp 4 image ratios (exposure 6 divided by exposure 9) from different test runs and taking their ratios. An example is shown in Figure 7, which is the image ratio of the F160W lamp 2 to lamp 4 flat ratio from test runs 3 and 8. The mean value in the ratio image is 0.997, with a pixel-to-pixel rms of 0.008. This level of scatter in the “ratio of a ratio” image is exactly as expected from the signal levels in the input images. The mean of the ratio tells us that there was only 0.3% change in the lamp 2 to lamp 4 illumination over the 25 days separating the acquisition of the images. There is little to no structure seen in the image ratio, except for the faint features visible in the lower right corner, which are elevated by ~0.5%. These appear to be due to slight changes in the illumination pattern provided by the calibration subsystem that result from movement of the WFC3 IR corrector mechanism, which took place between runs 5 and 6 during optimization of the WFC3 optical alignment. Additional information on the performance of the IR calibration subsystem lamps is given by Pavlovsky (2008).
Figure 7. The run 3 to run 8 image ratio of the F160W internal flat-field lamp 2 to lamp 4 image ratio. The mean is 0.997 with a pixel-to-pixel rms of 0.008.

External Flats

Three external flat-field images were taken during each iteration of the IR science monitor: full-frame F105W and F160W flats and a F160W sub-array flat (exposures 12 through 14 in Table 2). The mean full-frame F160W external flat is shown in Figure 8. The images that were used to create this combined flat had mean signal levels of \( \sim 50,000 \) e\(^{-}\)/pixel, from which we would expect a noise per pixel of 0.45%. The measured standard deviation about the mean in the stack of eight images is in fact 0.55%, only 0.1% higher than that expected from pure Poisson noise. The same results were achieved for the F105W full-frame flats. The F160W sub-array images had slightly lower mean signal levels of \( \sim 42,000 \) e\(^{-}\)/pixel in each image, with predicted and measured noise levels of 0.49% in the resulting combined flat. This again indicates that there are very little, if any, systematic or other non-Poissonian noise sources present.

Figure 9 shows an example of one of the individual flats divided by the mean flat, in this case using the individual F160W full-frame flat from run 7 and the mean F160W flat. The overall rms residual in the flattened image is \( \sim 0.5\% \), which is again just what is expected for the signal level in the individual flat. There are no obvious residual flat-field structures, but there are other two other types of features present, which were previously described by Bushouse (2008) in an analysis of IR flat-field images.
Figure 8. Combined F160W external flat-field image, shown with a positive stretch.

Figure 9. The ratio of the run 7 F160W external flat to the mean F160W external flat.
First, there are a couple dozen small features (10-20 pixels in size) scattered around the field that are due to particles located on the WFC3 Channel Select Mechanism (CSM) mirror, which is in the optical path (and nearly in focus) for IR channel images. Second, there is a large, diffuse “X” pattern with residuals of a few tenths of a percent. This pattern is due to the fact that the obscurations of the external OS are not in a conjugate plane to the IR cold mask. The OS structures and WFC3 cold mask structures, notably the spiders, thus move relative to one another as a function of field position, causing variations in the illumination pattern.

These two sets of features appear as residuals in the combined flats because of movement of the IR corrector mechanism between various runs of the IR science monitor, causing the patterns to shift spatially between runs. What is important for this analysis of the IR science monitor data, however, is the fact that there are no residuals of the intrinsic flat-field structure itself, indicating stability of the pixel-to-pixel QE structure in the IR-4 detector to at least 0.5% or better over the nearly 40 day span of the tests.

Another test performed using the external flats was a check of the stability of the wavelength-dependence of the flat-field structure. This was done by taking the ratio of the F105W and F160W full-frame flats obtained in each run of the science monitor and then taking the ratio of those ratios between runs 1 and 8. Figure 10 shows the result. This “ratio of a ratio” image shows no residual flat-field structures and has a pixel-to-pixel rms of 0.9%, which is the expected noise level based on the input image signals. We therefore see no evidence for changes in the wavelength dependence of the IR-4 flat-field structure over the 39 days spanning these exposures.

Figure 10. Ratio of the F105W/F160W ratio images from runs 1 and 8.
**PSF Monitoring Images**

Point-source images were obtained near the center of the field-of-view at wavelengths of 1050 and 1600 nm (exposures 15-16 in Table 2). The external targets were supplied by the OS 10 micron source fiber, with a monochromator bandwidth of 10 nm. The 1050 nm source was placed a bit to the lower left of center in the field, in quadrant B of the detector, and the 1600 nm source was placed a bit to the upper right of center, in quadrant D. Encircled energy (EE) measurements of the exposures were kindly performed by G. Hartig, using the same analysis routines used for the regular WFC3 focus and alignment procedures (see, e.g., Hartig 2008). The results are presented in Figure 11. The measurements at 1050 nm were done using an aperture diameter of 0.37 arcsec and the ones at 1600 nm used a 0.60 arcsec aperture.

![Figure 11. Encircled energy measurements. Triangles are measurements at 1050 nm in a 0.37” diameter aperture and squares are measurements at 1600 nm in a 0.60” aperture. Test runs 1 and 2 were performed before the WFC3 optical alignment was optimized, resulting in lower EE values. The dashed and dotted lines indicate the mean of runs 3-8 for the two sets of measurements.](image)

Runs 1 and 2 of the IR science monitor occurred before the WFC3 optical alignment had been optimized, resulting in lower EE values for those first two runs. The remaining runs have mean a EE of 0.71 at 1050 nm and 0.79 at 1600 nm, which is in very good agreement with the results of Hartig (2008). The slowly decreasing values of the 1050 nm measurements during runs 6 through 8 are due to the source drifting onto a pair of bad detector pixels and are not due to actual changes in the EE. The scatter in the remaining 1050 nm measurements is ~1%, while the scatter in the 1600 nm measurements is less
than 1%. This indicates good stability of the optical alignment and image quality of the WFC3 IR channel over the span of the science monitor runs.

**Photometric Monitoring Measurements**

The final three exposures in the science monitor procedure (exposures 17-19) are designed to monitor the photometric performance and stability of the WFC3 IR channel. They all use the external OS 200 micron source fiber, which produces an extended source of ~20 pixels diameter in IR images, and they also use a 5 nm monochromator bandwidth. Flux calibration measurements were obtained within the OS system for each exposure, which provides a measurement of the photon flux incident on the WFC3 pick-off mirror (POM). Exposure 17 uses a monochromator central wavelength of 1600 nm with the WFC3 F160W filter and places the source a bit to the lower right of field center in the detector C quadrant and uses a full-frame readout. Exposures 18 and 19 use a monochromator central wavelength of 1050 nm with the WFC3 F105W filter. The source is near the upper left corner of the field (quadrant A) in full-frame exposure 18 and is to the upper left of center (quadrant A) in the 64x64 sub-array exposure 19.

Aperture photometry was performed on the calibrated images using the IRAF “phot” routine. A source aperture of 30 pixels radius and a sky annulus extending from 35 to 55 pixels radius was used to make the measurements in the full-frame exposures. For the sub-array exposures, where the source was located relatively close to one edge of the images, a smaller source aperture of 12 pixels radius and a sky annulus of 15-20 pixels radius was used. The net source counts were normalized by the OS flux calibration measurement for each exposure, which then provides a total throughput measurement for WFC3 and also removes variations in the OS source flux from image to image.

The resulting throughput measurements are shown in Figure 12. The upper line in the plot (using filled squares) represents the 1600 nm measurements, the middle line (filled triangles) represents the 1050 nm measurements in full-frame exposures, and the bottom line (open triangles) represents the 1050 nm measurements in sub-array exposures. Note that it turned out to be a challenge to get the OS source well-placed within the sub-array field of exposure 19. In science monitor runs 1 and 2, WFC3 had not yet been fully aligned with the OS and therefore the source did not appear within the sub-array field at all. Furthermore, in run 6 the source landed close enough to the edge of the image to cause a significant amount (several percent) of flux to be missed. Therefore there are no entries for runs 1, 2, and 6 in Figure 12. It appears that the misalignment during runs 1 and 2 also had some anomalous effect on the measurements in the full-frame exposures, therefore we have excluded all of the run 1 and 2 values in the following statistical analyses.
Figure 12. WFC3 throughput values. The symbols correspond to: filled squares=1600 nm; filled triangles=1050 nm in full-frame; open triangles=1050 nm in sub-array. The dotted and dashed lines indicate the mean of runs 3-8 for each set of measurements.

The mean 1600 nm throughput value over runs 3-8 is 0.701 with a measurement-to-measurement scatter of 0.0025 (0.36%). The mean 1050 nm full-frame throughput value is 0.671 and also has a scatter of 0.0032 (0.48%). The mean 1050 nm throughput value measured from the sub-array exposures is 0.644, with a scatter of 0.005 (0.8%), which is ~4% lower than the full-frame measurements. This difference appears to be entirely due to the use of a smaller source aperture for the sub-array exposures. A comparison of measurements using the two aperture sizes, when applied to a full-frame exposure, shows that the aperture correction factor for the sub-array measurements is ~3%, which then brings the two mean values to within their uncertainty range. There is no obvious trend over time in any of the measurements, indicating that the WFC3 IR photometric response was stable over this period and the individual measurement scatter of a few tenths of a percent indicates excellent photometric repeatability.

CEI Specifications

The wide variety of data in the science monitor and the long time baseline over which they were acquired makes this dataset suitable for verifying whether WFC3 meets many of its Contract End Item (CEI) specifications. The following sections address various CEI specifications one at a time. CEI specifications related to IR readnoise, dark current, and
flat field uniformity have been addressed in previous WFC3 ISRs (Bushouse 2008; Hilbert 2008a; Hilbert 2008b).

**IR Detector Correlated Noise**

CEI specification 4.8.6 requires that periodic noise in any image due to electrical interference shall be limited to no more than 20% of the total rms read noise. The FFT analysis procedures that were developed for WFC3 Electromagnetic Interference (EMI) tests were used to analyze many of the individual darks from the science monitor. The results show no correlated noise above a level of 1%, which meets the CEI requirement, at least under the operating conditions encountered during thermal-vacuum testing.

**IR Detector QE Stability**

CEI specification 4.8.10 paragraph 1 requires the absolute QE of the IR detector to be stable to better than ±0.5% peak-to-peak over an hour and paragraph 2 requires stability of better than ±1.0% peak-to-peak over one month. One approach to assessing this requirement is through the results of the photometric monitoring (throughput) measurements included in the science monitor, because the total WFC3 throughput obviously includes the detector QE. The rms scatter in the 1600 nm throughput measurements over a span of 38 days is 0.41%, with a peak-to-peak scatter of 0.49%, which easily meets the 1.0% requirement over a month. Given that the peak-to-peak is on the order of 0.5% over a month, we could safely conclude that it is also at least this stable over an hour, which meets the one hour requirement as well.

A second approach to this analysis was done by using the F160W full-frame external flat field exposures to look for changes in the overall sensitivity of the entire detector. Because the flat field source flux can vary by more than the 1% level of the requirement, we used one half of the detector as a reference for the other half, by taking the ratios of the upper and lower halves of the flat field images. This removes any overall drift in the incident flux. Sigma-clipped means of these ratio images show peak-to-peak variations of ±0.2%, which easily meets the CEI requirements.

**IR Detector Flat Field Stability**

CEI specification 4.8.11.4 paragraph 1 requires that the difference between two flat fields taken 60 days apart using the same instrument configuration not exceed 1% rms, with a goal of 0.5% rms. To assess this specification we took the ratio of the normalized internal F160W flat field images from science monitor runs 3 and 8, which are separated by 26 days. Use of the flats from runs 1 or 2 would give us a longer time baseline, but their use is complicated by the fact that the WFC3 optical alignment that took place right after run 2 significantly shifted the illumination pattern within the field. The run 3 to run 8 ratio image has an rms of 0.6%, which is the expected noise limit for the ratio of two images that each had signal levels of ~54,000 e⁻/pixel. The ratios of individual flats to the combined flat created from all science monitor runs – which yields a lower noise floor –
shows rms deviations of 0.4%. While it is not obvious how to correctly extrapolate this result to a span of 60 days, we believe that we can consider at least the 1% specification to be met, and perhaps the goal of 0.5% as well.

Paragraph 2 of this specification further requires that no more than 5% of the field of view shall exceed 5% variation. Examination of the ratio images used in the preceding analysis shows that only 0.15% percent of the pixels exceed a variation of 5%, which easily meets the requirement.

Conclusions

The eight repetitions of the IR science monitor that were executed during WFC3 TV3 testing show that the IR channel performs well and meets all of the applicable performance and stability requirements. Detector read noise is stable to <0.1 e^-/pixel rms and is ~0.4 e^-/pixel lower overall when operating on MEB2, which will be used on-orbit. Dark current is typically ~0.05 e^-/pixel/sec. Flat field correctability and stability is at a level of 0.5% or better. The IR internal calibration subsystem lamps show little, if any, degradation in output over the course of these tests and their spectral stability is ~2%. The encircled energy of point sources is repeatable to ~1% and photometric throughput is stable to 0.5% or better.

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References

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