INSTRUMENT SCIENCE REPORT
FOC-031

TITLE: Testing of RSDP for FOC: I

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ABSTRACT

A test of Routine Science Data Processing (RSDP) for FOC data has been performed. Images were run through the pipeline to check processing of three types of FOC images: dark count, flat-field, and normal imaging mode. Spectrographic mode image processing was not checked in this test. No problems were found with the processing of dark count and flat-field images. The only errors encountered with normal mode image processing were in the geometric distortion correction step. All of the trials used to test geometric correction produced results that do not agree with results obtained by performing the same corrections in the Calibration Data Base System (CDBS). Operations Problem Report (OPR) 13488 has been filed regarding this problem. It is scheduled to be worked on after the completion of the OPRs related to GST-4. The tests that have been performed so far are certainly not exhaustive, but they show that a large portion of RSDP for FOC is working properly.

DISTRIBUTION:

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1 Introduction

This report is the first in a series describing the ongoing testing of Routine Science Data Processing (RSDP) applied to FOC observations. RSDP is part of the Post Observation Data Processing System (PODPS) which, in turn, is a component of the Science Operations Ground System (SOGS) produced for NASA by TRW. RSDP is a processing pipeline through which HST science data passes upon arrival at STSci. It automatically performs calibrations that are typically needed before the science data can be analyzed. Naturally, the calibrations performed depend on which science instrument produced the data. The processing of FOC data by RSDP is relatively complex due to the FOC's large number of operational modes. Hence, full testing of RSDP for the FOC is particularly important. This report describes a test of RSDP conducted by passing trial FOC observations through the pipeline. The version of SOGS running during this test was 18.0.5-B.1. In the descriptions of the trials, I assume some knowledge of the nature of FOC images, and of the calibrations they require. Those readers unfamiliar with routine calibration of FOC data should probably read the FOC Instrument Handbook and Instrument Science Report (ISR) FOC-017, "Prelaunch Calibration Files for RSDP", in conjunction with this report. The really serious reader will want to look at the pertinent sections of the PODPS to CDFS Interface Control Document (ICD-47) and the SOGS Design Manual, SE-06.

As far as RSDP is concerned there are four general types of FOC observations: normal mode images, spectrographic mode images, dark count images, and flat-field (internal LED) images. RSDP determines the type of an observation by checking certain instrument configuration flags and indicators. For example, if the FOC shutter is closed and the internal LEDs are off for an observation, RSDP concludes that it is dealing with a dark count image. The processing steps that RSDP applies to an image are dependent upon its type.

In order to perform a particular processing step, RSDP may need a calibration value (such as the absolute detective efficiency of the FOC for a given configuration), or a reference file containing a calibration image (such as a dark count image). The correspondence between each instrument configuration and the calibration values and reference file names needed for that configuration are kept in the reference relations. Thus, RSDP testing not only involves checking the algorithms, but also includes checking that the correct reference values and reference files are used.

Nineteen trial observations were passed through the pipeline in this test. The FOC configuration for each is given in Table 1. The name of each trial indicates what part of the pipeline it was designed to test:
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Table 1: Instrument configuration for each trial

**DRK:** Processing of dark count exposures.

**LED:** Processing of flat-field exposures, taken with the calibration LEDs.

**BAC:** Dark count correction for normal image mode.

**ITF:** ITF correction for normal image mode.

**GEO:** Geometric distortion correction for normal image mode.

You will notice that no full format (512 × 1024 zoom) observations were included in this test. This is because, at the time of the test, RSDP could not process full format images (see Instrument Science Report FOC-026 and OPR-12813). Since the time of this test, this problem was reportedly fixed. Full format observations will be included in the next test series to verify this.

At the time of the test, the CDBS to RSDP link was not available for installing files in SOGS; therefore our data was entered directly into the system at the SOGS console. The input image for each trial, the reference files that would be needed for all trials in the formats described in ICD-47, and a text file of information similar to that in Table 1 were written.
on tape in VMS backup format. This tape was given to Merle Reinhart who loaded the reference files into the SOGS database and used the instrument configuration text file to set up the reference file relations. For each trial, the input image was inserted into the pipeline by means of programs known as the FOC data generator and simulator. Essentially, these programs fool RSDP into thinking that the image I supplied by carrying a tape across San Martin Drive is really coming from HST. RSDP produced numerous output files, which were given to me for analysis.

2 Processing of Dark Count Images

Dark count observations are made in orbit for later use as reference files for RSDP's background correction of science images. The dark count images are not themselves calibrated in RSDP; they are simply converted to a "generic format" image file (a FITS-like format that is compatible with IRAF/SDAS). To verify this, a flat-field image, DRK1, was provided to RSDP via the FOC data generator and RSDP was told that for this observation, the shutter was in the beam and that the calibration LEDs were off. This information signifies that the image is a dark count observation. The input and output images for trial DRK1 were found to be identical indicating that RSDP does what it is supposed to—nothing—to dark count observations.

3 Processing of Flat-field Images

Flat-field images taken in orbit of the internal calibration LEDs will be used to generate at least two types of RSDP reference files: relative DE files and geometric distortion correction files. RSDP does not perform any processing of flat-field images related to the generation of the relative DE reference files; it does, however, produce a file of reseau positions that can be used for geometric correction. In order to perform geometric correction, RSDP must have geometric distortion reference files that contain the true positions of the reseau marks and their observed (distorted) positions. RSDP processes flat-field images to determine the distorted positions of the marks. Using routines in CDBS, these distorted positions are combined with the known true positions to form the required reference file. The RSDP algorithm that locates the reseau marks in the flat-field image must be given approximate positions of the marks so it knows where to look, and templates of reseau marks so it knows what to look for. The positions are supplied in RSDP reseau position reference files and the
templates are supplied in RSDP reseau model reference files.

As Table 1 shows, RSDP flat-field processing was tested with six trials. The input images for these trials were created from LED exposures taken as part of the FOC Calibration III. RES2, RES4, RES5, and RES6 were zoom pixel format exposures. The reference files for these cases contained approximate reseau positions given in zoom pixel coordinates since I thought that flat-field images were not dezoomed prior to reseau mark finding. These tests showed this to be wrong; RSDP does dezoom zoom pixel format flat-fields prior to locating the reseau marks. Hence, the approximate positions given in the reference files for these tests were incorrect. These trials will be rerun with corrected reference files in the next RSDP test series.

The other flat-field trials, RES1 and RES3, were normal pixel format exposures. For these, the reference files were correct and RSDP produced output files of reseau mark positions. These positions were compared to the results obtained by using the CDBS routine *rsfnd*. The sample and line coordinates of all reseau marks agreed to within one pixel. This level of agreement is deemed to be satisfactory.

4 Processing of Normal Mode Images

RSDP processing of normal mode images is done in six steps in the following order:

1. Dark count subtraction.

2. Intensity transfer correction based on functions obtained from flat-fields.

3. Dezooming: split rectangular pixels of zoom format images into two square pixels each with half the counts of the original.

4. Relative detective efficiency correction.

5. Absolute detective efficiency correction (multiplication by the appropriate w factor).

6. Geometric distortion correction.

There were two goals in testing the pipeline processing of normal mode images: to check the accuracy of the corrections, and to verify that the correct reference file or w factor is selected.
based on the flags and indicators for the observation. The latter was accomplished by varying
the flags and indicators for each observation and having distinct reference files in the database
for each requested combination. This is the reason that often two or more observations that
are identical except for the flags and indicators were run through the pipeline. The accuracy
of the results was verified by comparing the RSDP output to the image obtained by doing
the same processing outside of RSDP. In most cases, this entails simple image arithmetic
that can be done very easily in IDL (a commercial scientific data processing environment).
For a more specialized correction, like geometric distortion correction, the appropriate CDBS
routine was used to check the RSDP output.

The trials were divided into groups based on the particular correction (dark count, ITF,
or geometric distortion) that was to be explicitly tested. Since dezooming, relative DE
correction, and absolute DE correction had been tested previously with no problems (see
ISR FOC-026), no images were submitted to RSDP for the sole purpose of checking these
elements of the pipeline. Instead, these processing steps were verified as part of the explicit
checks run on dark count, ITF, and geometric corrections. For example, Table 1 shows that a
group of four exposures were used to check dark count correction. The reference relations for
these trials were set up so that a null ITF, and a null geometric distortion reference file would
be selected. These null files were created so as to not alter the image making it easier isolate
the effect of the dark count correction. The relative and absolute DE corrections were not
excluded, however. Thus, in addition to being an explicit check on dark count subtraction,
these exposures were also used implicitly to check relative and absolute DE correction.

4.1 Dark Count Correction

The dark count reference file supplied to RSDP contains the dark count rate in counts/second
at each pixel of the photocathode. The correction is performed by dividing the incoming
image by its exposure time and then subtracting the reference file from the result. The dark
count reference file is selected on the basis of optical relay (F/48 or F/96) and pixel format
(normal or zoom). Its size is 1024×1024 for normal pixel format and 512×1024 for zoom
pixel format.

The input images for the dark count correction tests were obtained by taking subsections
of calibration image 3601. Table 1 shows the subsections used for each trial. Since image
3601 is a 512×1024 zoom pixel image, the normal pixel test images were created from it by
first dezooming. The dark count reference files used for the test were created by dividing the
count values in image 3601 by 1320 seconds to simulate count rate data. The CDBS routine
rdsphoc was then used to convert the image to the format required by RSDP.

In all four BAC trials the correct dark count reference file was chosen based on the optical relay and pixel format. The accuracy of the four output files was checked by performing in IDL the dark count subtraction as described in SE-06. The results obtained in IDL were identical to the RSDP results, indicating that the dark count correction is performed correctly.

4.2 ITF Correction

The purpose of the ITF correction is to compensate for the nonlinearity in the response of the FOC's detectors. It has been recognized for some time that the algorithm implemented in RSDP is not applicable to FOC observations because it assumes that the ITF for a given pixel is independent of neighboring pixels. It has been suggested that the ITF correction might be put to good use correcting the video format dependence of the detective efficiency (see ISR FOC-019 and FOC-024). The reason this would have to be done in the ITF correction step is that RSDP does not use video format (i.e., the size and offset of the frame) as a criterion for selecting the relative DE reference file for an observation. Since the ITF reference file is selected based on video format, perhaps a fake ITF file could be created that would remove the format dependent effect. The current relative DE correction would still be used to correct for the wavelength dependence. Thus, it is important to test the ITF correction to make sure it is doing what it is supposed to and to check if it can be used to perform the image multiplication needed to remove format dependent DE.

Two of the three ITF tests, ITF1 and ITF3, were designed to test the reference file selection and to ensure that the algorithm is working in accordance with SE-06. The format of the ITF reference file is described in detail in ICD-47. Briefly, it is a 3-dimensional array, c(k,i,j), in which are stored k=1,N images each of size i=1,1024 samples (1,512 in the case of zoom images) and j=1,1024 lines. The N values stored for each pixel location are used to construct a piecewise linear approximation to the ITF for that pixel.

The array, c(k,i,j), contained in the reference files used for tests ITF1 and ITF3 was created as follows (the data used for these trials are fictitious and have no physical significance):

1. Let $a(i,j) =$ calibration image 3601 (a 512 x 1024 zoom image).
2. For $i = 1, 512$ and $j = 1, 1024$

\[
  c(1,i,j) = a(i,j)/1320 \\
  c(2,i,j) = \sqrt{c(1,i,j)} \\
  c(3,i,j) = \sqrt{2c(1,i,j)} \\
  c(4,i,j) = \sqrt{3c(1,i,j)}
\]

The CDBS routine \textit{rsdpif} was used to convert the array, \textit{c}, into two reference files, one for F/48 and one for F/96. The input observations for ITF1 and ITF3 were made by multiplying calibration image 3601 by $2/3$ and then extracting a $512 \times 512$ subsection with a 0 sample, 0 line offset. RSDP was told that the ITF1 observation was in F/48 and that ITF3 was in F/96.

The RSDP output for these two trials showed no errors in reference file selection. The accuracy of the results was checked using a program written in IDL that performs the same processing as described in SE-06 for the ITF correction. The results obtained from this program for ITF1 and ITF3 are identical to those produced by RSDP indicating that algorithm is implemented correctly in RSDP.

The purpose of trial ITF2 was to demonstrate that the ITF correction can be used to remove the detective efficiency format dependence. The input observation for trial ITF2, is calibration image 3734, a $512 \times 512$ centered image taken at wavelength, $\lambda = 2500\AA$. The RSDP relative DE correction is made using the center $512 \times 512$ area of a $1024 \times 1024$ reference file called F48UNI\text{250B1}. F48UNI\text{250B1} was part of the Build 1 delivery of reference files to the pipeline (see ISR FOC-026). Since the uniformity of the $512 \times 512$ centered image does not match the uniformity of the central portion of the full $1024 \times 1024$ format, the relative DE result will not be fully corrected for nonuniformity. The additional step that is needed is to multiply the observation by the ratio, $r(i,j)$, equal to a $1024 \times 1024$ flat-field divided by a $512 \times 512$ centered flat-field. This ratio is the difference in spatial uniformity between the format of the observation and the format of the relative DE reference file.

The ITF correction, in essence, multiplies each pixel $(i,j)$ of the science image by the local slope of the piecewise linear curve defined by the values $c(k,i,j), k = 1, N$ in the ITF reference file. To accomplish the format dependent nonuniformity correction, the slope defined in the ITF reference file for pixel $i,j$ must be equal to the ratio, $r(i,j)$. To create such an ITF reference file, the following steps were performed:
1. Let $a(i, j) = \text{calibration image 3734 (a 512 \times 512 centered, 2500\text{\textmu}m\text{-}\text{flat-field}) inserted into the center of a 1024 \times 1024 \text{zero image.}}$

2. Let $f(i, j) = \text{calibration image 3634 (a 1024 \times 1024, 2500\text{\textmu}m\text{-}\text{flat-field).}}$

3. $b(i, j) = a(i, j)/f(i, j)$ ($b$ is the reciprocal of the image, $r$, described above).

4. $d(i, j) = \text{normalization of } b(i, j) \text{ using the CDBS routine } znorm \text{ (if it is determined that the absolute ratio is needed, then this step would be eliminated).}$

5. $e(i, j) = 1000 \times d(i, j)$ ($\text{the reasoning behind steps 5, 6, and 7 will be clear upon reading the definition of an ITF reference file in ICD-47 or SE-06.}$)

6. $g(i, j) = 1000 \text{ (a 1024 \times 1024 image).}$

7. $h(i, j) = 2000 \text{ (a 1024 \times 1024 image).}$

8. $c(1, i, j) = e(i, j); c(2, i, j) = g(i, j); c(3, i, j) = h(i, j); \text{ the CDBS routine } \text{zinterle} \text{ can perform these assignments in one step.}$

9. Transform $c(k, i, j)$ into an RSDP format file using $\text{rsdputf}$ in CDBS.

This results in an ITF reference file that has a slope at each pixel equal to $1/d(i, j)$. Applying the ITF correction to the science image, $s(i, j)$, is equivalent to forming $s(i, j)/d(i, j)$.

The results of trial ITF2 are shown in Figures 1-3. Lines 200 and 400 of the input observation for ITF2 are plotted in Figure 1a and 1b (for plotting purposes, photon noise was removed with a $9 \times 9$ median filter). Since ITF2 is an exposure of a flat source, ideally the curves in Figure 1 should be flat. They are not flat due to the spatial variation in detective efficiency. Figure 2 shows the same image lines after the standard RSDP relative DE correction, but without format correction using the fake ITF file. This image is not flat either, because the format effect has not been removed. Figure 3 shows lines 200 and 400 of the result obtained when the relative DE correction is applied and the ITF correction is used to remove the format dependence. The flatness of this image demonstrates that ITF reference file can be used to perform the image multiplication needed for format dependent nonuniformity correction.
4.3 Geometric Distortion Correction

An RSDP geometric correction file consists of two sets of reseau mark positions: one contains the true locations (sample, line) of each mark and the other contains the locations that were measured from a flat-field observation. Geometric distortion correction of a science image is accomplished by determining what geometric transformation will place the measured reseau mark positions in their true positions and then applying this transformation to the science image.

The reference files for the five tests of geometric correction were created as follows:

1. \( A = \) CDBS reseau file containing the "true" positions of the reseau marks. This file contains 289 reseau positions evenly spaced in a 17 \( \times \) 17 square grid. Position 1 is located at \((\text{sample}, \text{line}) = (1,1), \) position 289 is at \((1024,1024), \) and the center position in the grid is located at \((512.5,512.5).\)

2. \( B = \) CDBS reseau file containing the distorted positions of the reseau marks. Three different distorted grids were created. For trials GEO1 and GEO2 the distorted grid was identical to the true grid except the center reseau mark was moved from \((512.5,512.5)\) to \((480.5,480.5).\) An image corrected with this reference file should have its center region stretched toward the location \((1024,1024).\) For trials GEO3 and GEO4, the distorted grid was produced by rotating the true grid 45 degrees clockwise about the position \((512.5,512.5).\) An image corrected with this combination should be rotated 45 degrees counter-clockwise. For GEO5, the distorted grid contained the reseau mark positions measured in calibration image 3601. This should produce a result in which the reseau marks line up in their true rectangular grid.

3. The CDBS routine, \texttt{r0dpgic}, was run on A and B to produce the required RSDP GEO reference files.

The five trials GEO1 through GEO5 showed no problems with reference file selection. Previous tests had shown that reference files for geometric correction were not being selected on the basis of optical relay (see OPR-12662). This problem has been corrected.

The accuracy of the RSDP output images was checked by examining them on an image display and comparing them to images obtained by performing the same geometric correction using \texttt{zgeom} in CDBS. For trials GEO1 and GEO2, only the central part of the image defined by a square containing the nine central reseau marks should have been affected.
by geometric correction. This was indeed the case for both the RSDP and CDBS results. However, the results obtained from RSDP inside of this central region were substantially different than those obtained in CDBS. Figure 4a shows the central image section in the original image, Figure 4b shows the same section after correction in RSDP, and Figure 4c is the result obtained in CDBS. The differences between the RSDP result and the CDBS result are easily seen in this Figure. The difference in values is as much as 100% in some areas.

The output images from trials GEO3 and GEO4 should be rotated 45 degrees counterclockwise about their centers with respect to the input images. Figure 5 shows the input image (a), the RSDP result (b), and the CDBS result (c). The CDBS result is correct; the RSDP result is obviously in serious error. The border of the RSDP result shows that a 45 degree rotation was attempted, but the interior of the image is totally erroneous.

Trial GEO5 is representative of the degree of geometric distortion that RSDP will be required to correct in normal operations. Since the input image for trial GEO5, shown in Figure 6a, is a subsection of the image from which the distorted reseau positions were measured, the reseau marks in the geometrically corrected image should lie in a rectangular grid. Figure 6b and 6c show results of geometric distortion correction obtained from RSDP and CDBS. Both the RSDP and CDBS output images did show the expected rectangular reseau. The RSDP result has, however, a noticeable "checker-board" appearance signifying discontinuities between adjacent regions of interpolation. This effect is clearer in Figure 7 which contains plots of the percentage difference between the RSDP and CDBS images along lines 100 and 200. The pixel values in the two images differ by as much as 25%.

Operations Problem Report 13488 was filed on 25 September 1987 regarding the discrepancies found in the geometric distortion trials. Fixing of this problem will be delayed until after the OPRs related to GST-4 are corrected.

4.4 Dezooming, Relative DE Correction, and Absolute DE Correction

These processing steps were checked implicitly as part of the trials of the other normal image processing steps described above. For example, dezooming of zoom format images is done automatically by RSDP and must be accounted for when reproducing the RSDP result in other image processing systems. Since the DE corrections were non-null for all of the normal imaging trials, they too were accounted for in the validation of the RSDP output. In all normal imaging trials, the RSDP photometrically calibrated output agreed with the results produced outside of RSDP. This means that dezooming, relative DE correction, and
absolute DE correction were performed accurately using the correct reference values and reference files.

5 Summary

The following list summarizes the results of RSDP testing for the FOC. It also describes testing that remains to be done.

- Processing of dark count exposures is working properly on 512 x 512 centered images. It will be checked with 512 x 1024 zoom format images now that RSDP can handle the large format.

- Processing of LED exposures is working properly with 512 x 512 centered images. It will be checked with the 512 x 1024 zoom format in the next test.

- Dark count subtraction is correct in terms of accuracy of the result. Reference file selection has been partially exercised with no problems. A full test of reference file selection will be done.

- ITF correction is performing as described in SE-06. A fake ITF reference file has been successfully used to perform the image multiplication needed for removal of format dependent detective efficiency. Similar tests will be run with the other video formats.

- Geometric distortion correction is producing results that are in error. Three distortion fields were used for the trials. The lowest distortion trials produced results that were similar in overall appearance to the expected image, but differed from the CDBS result by as much as 25%. The highest distortion (45 degree rotation) trials produced totally erroneous images.

- Relative DE correction is working properly for 512 x 512 images. It will be checked with all FOC normal imaging modes listed in the FOC Handbook in the next test series.

- Absolute DE correction has been verified with a full set of w factors for F/48 (i.e., the w factor reference relation contains a value for every F/48 filter combination), and with a subset of the w factors for F/96 and F/288. A subsequent test will check RSDP's ability to handle the full set of w factors for F/96 and F/288.
Calibration Image 3734, Line 200

Counts

Sample

Figure 1a.

Calibration Image 3734, Line 400

Counts

Sample

Figure 1b
After Relative DE Correction, Line 200

Figure 2a.

After Relative DE Correction, Line 400

Figure 2b.
Figure 5a. Original image

Figure 5b. RSDP Result
Figure 5c. CDBS Result

Figure 6a. Original Image