INSTRUMENT SCIENCE REPORT
FOC-039

TITLE: FOC Flat Field Response

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DATE: 5 June 1989

ABSTRACT

This report describes the analysis of the flat field data from Calibration III and the generation of the Build 2 calibration files for RSDP. I report the analysis of the large spatial scale response of the FOC as a function of time, LED, and wavelength. I find the general repeatability of LED images to be better than 1-2%. Aside from the red LED exposures, the wavelength dependence of both F/48 and F/96 large scale spatial response appears to be less than 10%. The determination of flat field response from external illumination is found to be limited by the errors in determination of the illumination nonuniformity. All the data are consistent with the LED illumination being flat to at least 3% though, because of the errors in calibrating the spatial illumination of the external flat fields, no conclusive statement can be made. I conclude that LED exposures, when available, are preferable to external exposures for flat field calibration, and used them to generate most of the RSDP Build 2 calibration files.

DISTRIBUTION:
FOC Project: R. Laurance, M. Miebach, B. G. Taylor, R. Thomas, N. Towers
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ST/ECF: P. Benvenuti, R. Fosbury, R. Hooke, S. di Serego Alighieri
1 Introduction

An important, if mundane, aspect of FOC calibration is FOC flat field response and the accuracy in correcting it. The most recent calibration of the FOC (Calibration III) has allowed us to examine FOC flat fields for the existing detectors from 2000\AA{} and up, something that wasn’t possible previous to Calibration III (all previous calibration data was taken with different detectors or detectors since modified or moved). The key issues regarding FOC flat field response are

- Repeatability or stability
- Spatial scale of variations
- Wavelength dependence
- Format dependence
- Flatness of LED illumination

Exposures were taken specifically to answer these issues. (A more complete description of Calibration III can be found in Instrument Science Report FOC-032.) I will report the results of the analysis of these data and describe how the Build 2 version of the uniformity correction calibration reference files for the RSDP (Routine Science Data Processing) pipeline were generated.

Not all aspects of the above list of issues have been answered fully yet, however. In particular, the small scale spatial structure of the response is not addressed in this report and will be discussed in a subsequent report. This includes effects such as scratches, pattern noise, target burn-in, reseau marks, and any other fine scale variations. Format dependence of flat field response will also be taken up in a later report. The main focus of this report is the large scale spatial response of the detectors, and all results shown involve heavy smoothing of the calibration exposures.

2 Calibration Data

All of the data presented came from one of the three phases of Calibration III. The first two phases were done in July and October 1987 and involved the LAS C14 external flat field
illumination setup. The last phase, done in January and February of 1988 involved only LED exposures. Flat fields were done for both F/96 and F/48, but none were done for F/288 since the F/288 mode uses the same part of the photocathode as F/96. With the exception of those exposures taken to check dependence of response on format, exposures generally used the 512 zoomed \( \times \) 1024 video format. Three wavelengths were used for external flat fields for each relay; 2000, 4800, and 6000 \( \text{Å} \) for F/48 and 2000, 4000, and 6000 \( \text{Å} \) for F/96. Table 1 lists the external exposures used for this report. At least one exposure was taken with each available LED for F/48 and at least one LED exposure for each possible color LED for F/96 (there are two LEDs for green, yellow, and red). Table 2 lists the LEDs used for this report.

Generally speaking, most images had to be corrected for an erratic most significant bit in the data which was the result of problems with the external FOC data interface. While this was easy for 16-bit images (it just required masking the most significant bit) it was more troublesome for 8-bit images where a more complicated correction procedure had to be used (based essentially on the fact that for flat fields we should not see jumps of about 128 from one pixel to another). Another complication with 8-bit images was that many had overflowed pixels. Again, correcting that effect was always possible for flat field images using the fact that jumps of nearly 256 from one pixel to another should not exist.

The alignment of the C14 projector (the one used to do flat fields) with the FOC optics was difficult without the ability to open the FOC up. (See LAS document LA.TN.FC.220065 for detailed descriptions of C14 and the hardware used as part of it.) Attempts to verify that the system was in fact optimally aligned met with little success, and as a result, we must assume that there may have remained significant misalignment. The consequences for flat fields is primarily in the measurement of vignetting. According to the FOC handbook (Paresce, 1985), vignetting is negligible on the F/96 relay, but may be as much as 16% at the edges of the full format in the F/48 relay. Since the C14 projection setup had a beam equivalent to F/300, it is likely that the vignetting seen would not be the same as for the OTA. The possible misalignment of the C14 setup with the FOC has possibly introduced further discrepancies in vignetting.

LAS and MATRA recognized that the illumination of the detectors by the C14 setup would not be uniform and included as part of the setup a mechanism to measure the uniformity of the illumination so that the data could be corrected for any nonuniformity. This was accomplished by inserting a beamsplitter in the beam and using a photomultiplier with a small aperture (either 3.0 or 0.69 mm diameter depending on the circumstances) to scan a relatively coarse grid on the diverted beam while the exposure was being made. Although workable in principle, as implemented, this method had some shortcomings which result in questionable corrections for the beam nonuniformity. I will elaborate on this in a later section.
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Table 1: External Illumination Exposures used in Flat Field Analysis.
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Table 2: LED Exposures used for Flat Field Analysis.
3 Data Analysis

3.1 Image processing

All results shown, unless mentioned otherwise, had the following processing applied to the images. Images first were corrected for the erratic most significant bit problem and any overflows. The resulting image was reduced to $512 \times 512$ by averaging pairs of rows and scaled and converted into a byte image. Median filtering was applied by using a $7 \times 7$ pixel box in order to remove reseau and bad pixels. An $11 \times 11$ boxcar filter was applied to smooth the image and the result subsampled to produce a $128 \times 128$ image. In general, geometric correction of the images resulted in insignificant changes in the large scale response and was not used in the following analysis. The data analysis was carried out using primarily IDL (Interactive Data Language). All contour plots involve further smoothing ($11 \times 11$ boxcar) on the $128 \times 128$ image for smoother and easier to interpret contours.

3.2 Stability and Repeatability

We checked the stability and repeatability of flat fields using repeated exposures using the same LED. Figures 1 and 2 show contour maps of the ratio of G2 (green #2) LED exposures for the F/48 and F/96 relays respectively. (Note that these and subsequent ratios were normalized to 1 at the center and the contours shown as percentage deviations from unity.) These pairs of images were taken 11 days and 1 day apart respectively and show typical differences of $\pm 1\%$ in large scale response. A possible explanation for this level of difference is nonlinear response to the count rates encountered; that is, one image at a slightly higher count rate will see somewhat more nonlinearity than the other and this will be reflected in the ratio.

A reasonable check on the consistency of illumination between different LEDs is to look at the ratios of the same color, but different LED flat fields. This was done for F/48 and is shown in Figures 3, 4, and 5—the G1/G2, Y1/Y2, and R1/R2 ratios respectively (the green, yellow, and red LEDs). From this we see that the ratios are consistent to better than 2% for the red and green LEDs. The yellow LEDs show differences up to 4% in the corner but these two also show the largest difference in average count rates suggesting we are seeing residual nonlinearity. There is no reason to believe there is a significant difference between the LEDs in F/48 as far as differences in spatial illumination. Since F/48 should be the relay where these difference would be most apparent, the same should be true for F/96.
Figure 1: Ratio of smoothed F/48 G2 LED exposures. Contours are at -2, -1, 1, and 2% deviation from unity.

Figure 2: Ratio of smoothed F/96 g2 LED exposures. Contours are at -2, -1, 1, and 2% deviation from unity.

Figure 3: Contours at -2, -1, 1, 2%

Figure 4: Contours at -5, -4, ..., 4, 5%
3.3 Wavelength Dependence of LED Flat Fields

Using the G2 LED as a reference, similar ratios were calculated for other LEDs for both relays. Figures 6, 7, 8, 9, and 10 show the ratios for the B1 (blue), Y1, Y2, R1, and R2 LEDs relative to the G2 LED in the F/48 relay. Figures 11, 12, and 13 show the ratios for the Y2, B1, and R2 LEDs relative to the G2 LED in the F/96 relay. From this we see that the wavelength dependence in the visible range is relatively small except for the red LEDs where differences range up to 70%. For the rest, the differences are generally less than 10%. So, changes in the spatial sensitivity as a function of wavelength are minor between 4800 Å and 6000 Å. Examining the wavelength dependence below 4800 Å requires examining the external flat fields.

3.4 Consistency and Accuracy of External Flat Fields

External flat fields must be corrected for the nonuniformity of illumination. In practice this was to be carried out using the results of the scanning photomultiplier which, during each flat field exposure, provided a grid of measured relative intensities. An example is shown in Table 2. All illumination nonuniformity grids are taken from the FOC Calibration III post-test meeting minutes for phase 1 (5 August 1987) and phase 2 (23 October 1987). The H and V coordinates are in units of millimeters and are measured essentially at the equivalent of the OTA focal plane. In order to use these measurements to correct for the nonuniformity
Figure 7: Contours at -4, -3, ..., 3, 4%

Figure 8: Contours at -4, -3, ..., 3, 4%

Figure 9: Contours at -10, -5, 5, ..., 65, 70%

Figure 10: Contours at -10, -5, 5, ..., 65, 70%
Figure 11: Contours at -2, -1, 1, 2%

Figure 12: Contours at -4, -2, 2, 4%

Figure 13: Contours at -8, -6, ..., 14, 16%
it is necessary to determine the coordinate transformation between \((H, V)\) and \((x, y)\) where \((x, y)\) are the pixel coordinates. A two-dimensional third order polynomial was fit to the measured nonuniformity grid and the polynomial evaluated at all pixel locations, using the coordinate transformation to determine the corresponding \((H, V)\), to form an illumination nonuniformity correction image.

The following defines the coordinate transforms determined by MATRA (given in the phase 2 post test meeting minutes).

**F/48:**

\[
x = 2 \cdot 40(-H \cos(\theta_{F/48}) + V \sin(\theta_{F/48}) + A_{F/48})
\]
\[
y = 2 \cdot 40(H \sin(\theta_{F/48}) + V \cos(\theta_{F/48}) + B_{F/48})
\]

**F/96:**

\[
x = 4 \cdot 40(-H \cos(\theta_{F/96}) + V \sin(\theta_{F/96}) + A_{F/96})
\]
\[
y = 4 \cdot 40(H \sin(\theta_{F/96}) + V \cos(\theta_{F/96}) + B_{F/96})
\]

where

\[
\theta_{F/48} = 25^\circ 5
\]
\[
\theta_{F/96} = 21^\circ 3
\]

**Phase 1:**

\[
A_{F/48} = -1182
\]
\[
B_{F/48} = 2076
\]
\[
A_{F/96} = -2311
\]
\[
B_{F/96} = 4728
\]

**Phase 2:**

\[
A_{F/48} = 308
\]
\[
B_{F/48} = 1194
\]
\[
A_{F/96} = -3360
\]
\[
B_{F/96} = 8169
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Table 3: Illumination nonuniformity grid for REL 4801

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<td>0.0000000160</td>
<td></td>
</tr>
<tr>
<td>c₉</td>
<td>0.00000000</td>
<td>0.0000000160</td>
<td>0.0000000160</td>
<td>0.0000000160</td>
<td>0.0000000160</td>
<td>0.0000000160</td>
<td>0.0000000160</td>
<td>0.0000000160</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Illumination nonuniformity polynomial coefficients

Here \((x, y)\) refer to normal-sized square pixels. In generating the illumination nonuniformity image, the appropriate scaling factors were applied to match the format of the image.

Table 3 is an example of an illumination nonuniformity grid measured for one of the flat fields listed in Table 1. As mentioned a two-dimensional polynomial was fit to the nonuniformity grids. The form for the polynomial was

\[
I = c₀ + c₁h + c₂v + c₃h^2 + c₄hv + c₅v^2 + c₆h^3 + c₇h^2v + c₈hv^2 + c₉v^3
\]

where \(h = H - H_{\text{center}}\) and \(v = V - V_{\text{center}}\). Both \(H_{\text{center}}\) and \(V_{\text{center}}\) represent the center of the grid and may vary from one illumination nonuniformity grid to another. With one notable exception, the peak residuals of the polynomial fits were less than 2%. Table 4 lists the polynomial parameters used for each of the illumination nonuniformity grids. These polynomial coefficients are the weighted (by exposure time) average of the coefficients of the
individual flat fields that make up the summed flat field (this is equivalent to a weighted average of the illumination nonuniformity images for each of the individual flat fields). The resulting illumination nonuniformity images are shown in Figures 14-21.

The nonuniformity of the F/48 illumination is especially large and varies as much as a factor of two from the center (again, all images have been normalized to 1 at the center and contours shown as percent deviations from unity).

The external flat fields undergo the same processing as the LED flats with the addition of division by the appropriate illumination nonuniformity image. There are three questions that need to be answered before the corrected flat fields can be used to calibrate data.

- Are two different flat fields taken at the same wavelength but at different times consistent? This checks the repeatability of the illumination nonuniformity measurement and the accuracy of the coordinate transformation.

- Do external flat fields agree with the LED flat fields at the same wavelength? If not, this reflects either a nonuniformity of LED illumination or error in the determination of the external illumination nonuniformity.

- Do the external flat fields vary much in wavelength?

Figures 22 and 23 show ratios of repeated externals for F/48 at 4800Å and 6000Å. Deviations
Figure 16: Contours at -50, -45, ..., 15, 20% (including 0)

Figure 17: Contours at -50, -45, ..., 15, 20% (including 0)

Figure 18: Contours at -50, -45, ..., 15, 20% (including 0)

Figure 19: Contours at -10, -8, ..., 8, 10% (including 0)
Figure 20: Contours at -10, -8, ..., 8, 10% (including 0)

Figure 21: Contours at -4, -3, ..., 3, 4% (including 0)

Figure 22: Contours at -18, -15, ..., 15, 18%

Figure 23: Contours at -50, -45, ..., 45, 50%
<table>
<thead>
<tr>
<th>H</th>
<th>V</th>
<th>-14.15</th>
<th>-11.90</th>
<th>-9.65</th>
<th>-7.40</th>
<th>-5.15</th>
<th>-2.90</th>
<th>-0.65</th>
<th>1.60</th>
<th>3.85</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.62</td>
<td>0.711</td>
<td>0.720</td>
<td>0.724</td>
<td>0.738</td>
<td>0.739</td>
<td>0.737</td>
<td>0.734</td>
<td>0.642</td>
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<td></td>
</tr>
<tr>
<td>0.37</td>
<td>0.769</td>
<td>0.783</td>
<td>0.793</td>
<td>0.799</td>
<td>0.803</td>
<td>0.802</td>
<td>0.798</td>
<td>0.790</td>
<td>0.134</td>
<td></td>
</tr>
<tr>
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<td>0.825</td>
<td>0.840</td>
<td>0.851</td>
<td>0.863</td>
<td>0.866</td>
<td>0.865</td>
<td>0.858</td>
<td>0.757</td>
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<td></td>
</tr>
<tr>
<td>-4.13</td>
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<td>0.916</td>
<td>0.925</td>
<td>0.929</td>
<td>0.931</td>
<td>0.923</td>
<td>0.815</td>
<td>0.111</td>
<td></td>
</tr>
<tr>
<td>-6.38</td>
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<td>0.974</td>
<td>0.989</td>
<td>0.997</td>
<td>1.000</td>
<td>1.000</td>
<td>0.994</td>
<td>0.886</td>
<td>0.105</td>
<td></td>
</tr>
<tr>
<td>-8.63</td>
<td>1.030</td>
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<td>1.063</td>
<td>1.066</td>
<td>1.062</td>
<td>1.058</td>
<td>0.941</td>
<td>0.096</td>
<td></td>
</tr>
<tr>
<td>-10.88</td>
<td>1.088</td>
<td>1.111</td>
<td>1.115</td>
<td>1.122</td>
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</tr>
<tr>
<td>-13.13</td>
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<td>1.174</td>
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<td>0.077</td>
<td></td>
</tr>
<tr>
<td>-15.38</td>
<td>0.591</td>
<td>0.683</td>
<td>0.756</td>
<td>0.782</td>
<td>0.822</td>
<td>0.829</td>
<td>0.874</td>
<td>0.839</td>
<td>0.067</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Illumination nonuniformity grid for REL 4807

of 5% are common in the 4800 Å comparison with 10% differences seen towards the edges. The 6000 Å ratio shows sizable differences of up to 20%. In neither case can repeatability be considered good, and it is awful in one. Closer examination of the illumination nonuniformity grid for the 6000 Å exposure (Table 5) shows it to be very suspect. Many values change abruptly near the edge. Even when these values are removed from the fit, the resulting comparison, although improved, shows unacceptable discrepancies with other exposures. We must conclude that the measurement of the illumination nonuniformity in at least that case was seriously flawed.

Well then, how do the external flat field compare with the LED ones at similar wavelengths? Figures 24-27 show the ratios of the external flat fields with the corresponding LEDs (F/48: B1/4800 and Y2/6000, F/96: B1/4000 and Y2/6000 respectively). The F/48 Y2/6000 ratio shows large differences, in agreement with the above conclusion that the 6000 Å illumination nonuniformity correction is bad. The F/48 B1/4800 ratio is much better but still shows differences greater than ±5%. Note the sudden change in the upper right corner. This is apparently the result of the LED illumination falling off rapidly at the corner. The LEDs illuminate the detectors by means of circular mirrors placed on the back of the shutters. We apparently are seeing the edge of F/48 LED mirror. Both F/96 ratios are better with typical differences less than 3% over nearly all of the image.

Figures 28 and 29 show the ratio of the F/96 4000 and 6000 Å images to the F/96 2000 Å image. Both show relatively small differences—typically less than 3%. Figure 30 shows the ratio of the F/48 4000 Å image to the 2000 Å image. The differences are larger here and become greater than 6% towards the edge.
Figure 24: Contours at -10, -8, ..., 8, 10%

Figure 25: Contours at -20, -18, ..., 8, 10%

Figure 26: Contours at -4, -3, ..., 3, 4%

Figure 27: Contours at -4, -3, ..., 3, 4%
Based on these results, it appears that the most likely explanation of the greater inconsistency of the external flat fields has to do with errors in determining the illumination nonuniformity. If we presume that the beam intensities are measured correctly, except for the case already noted, then errors must arise from an error in the coordinate transformation between the scanning photomultiplier coordinates and image (pixel) coordinates. There appear to be two likely sources of error. Apparently, the angle between the two coordinate systems was calculated assuming the reseaux on the photocathode are oriented in a known way relative to the FOC. Although past detectors have been carefully installed with this orientation in mind, the installations of the current ones may have been done less carefully. It is important to stress that the angles provided by MATRA are not based on actual exposures that show the orientation of the reseaux relative to an external reference but instead based on presumed orientations. It is difficult to give the upper limit on such a possible error other than to say that it is not gross, i.e., 45°.

The other source of error is in fixing the correspondence between the same point in the two coordinate systems. MATRA accomplished this by placing a large (3 mm) pinhole in front of the C14 projector resulting in a large, somewhat unfocused disk in FOC exposures. By finding the center of this disk in the image and the center of the disk in $(H,V)$ by using the scanning photomultiplier to find the centroid, a correspondence was established. Unfortunately, during phase 1 of the calibration, a test sequence of exposures revealed a serious problem with this method.

The pinhole, and thereby the projection system, is aligned with the FOC by use of two
alignment mirrors, each of which can be rotated on two axes by remote control. After alignment the alignment mirror are moved on occasion, to move the beam from one relay to another, for example, and usually returned to the previously noted position of the mirrors. A sequence of exposures designed to observe the direction and size of changes in the image position of the pinhole revealed that the pinhole failed to return to the same position when the alignment mirrors were commanded to return to the original position. In fact, the discrepancy was more than 100 pixels for F/96! There was an attempt to reduce this error for phase 2 but apparently the best that could be done was an approximately 50 pixel minimum error (F/96).

Considering the relatively large changes in F/48 illumination across the image, such an error (25 F/48 pixels) still results in appreciable errors in intensity. This error should only exist if the point correspondence was calculated from pinhole measurements made with one mirror setting and the illumination nonuniformity measured after the mirrors had been moved. There is, unfortunately, no clear record to determine whether this was or wasn’t the case for any F/48 flat fields.

There is another possible source of error, namely plate scale. The numbers used in the coordinate transformation appear to use nominal values, not measured values. It is possible that discrepancies between presumed and true scales could also lead to measurable errors, though it is unlikely to be the dominant effect.

One further source of error may exist. Test exposures from phase 2 suggest that in some cases part of the beam may be missing the beamsplitter. If true, this perhaps could explain the errors in the illumination nonuniformity for the F/48 6000Å exposure.

I attempted to determine if there was a rotation error by calculating F/48 illumination nonuniformity images for several rotation angles and seeing if they produced better results. Figures 30 and 31 show the ratio of the F/48 4800Å image to the 2000Å image for two different angles. Figure 30 is the angle specified by MATRA (25.5°) and Figure 31 uses an angle of 34.5° which produced the best result. There is a notable improvement in the consistency.

4 Conclusions

LED exposures show good repeatability (better than 1.5% peak-to-peak) for large scale spatial response, and wavelength variations are not large except for the red LEDs. External flat
fields show significantly poorer repeatability which is probably due to errors in determining the illumination nonuniformity. Comparisons of external flat fields with LED exposures at similar wavelengths yields errors comparable to those for repeatability (excluding the F/48 6000Å exposure). No firm conclusion can be made as to whether the LEDs provide uniform illumination based on this data alone except to say that F/48 LEDs do not illuminate the upper right hand corner of the images. Nevertheless, considering that the consistency of the external flat fields with the LEDs is comparable with the consistency of the external flat fields with each other, it is reasonable to presume that the LEDs provide uniform illumination to the 3% level and that most of the discrepancy between the LED flat fields and the external flat fields is in the errors in the measurement of the external flat field illumination.

We must conclude that accurate measurements of the flat field response were prevented by the inadequate method of calibrating the external illumination nonuniformity. It is unfortunate that the method of determining the coordinate transformation between the scanning photomultiplier and the image coordinates wasn’t more carefully thought out and tested prior to the actual calibration.

It appears that there are no relative variations in large scale spatial response greater than 10% between 2000 and 6000Å.
5 RSDP Calibration Files

The previous results were used to decide how to generate the RSDP calibration files for flat fielding (the UNI correction). Previous reports have described the problems in trying to do pixel-by-pixel flat fielding in the pipeline (Instrument Science Report FOC-017). We will not attempt to do so using the ground-based data so the data will be heavily smoothed as in the previous analysis. As a result of the analysis, I have greater confidence in the LED results, so LED flat fields will be used over external flats whenever possible. No applicable flat fields exist below 2000 Å; we will have to rely on the 2000 Å flat fields for all UV exposures. I will assume the correct angle between the \((H,V)\) coordinate system and the image coordinate system is \(34.5°\) not the \(25°.5\) provided to us. This is based only on suggestive results and in no way is it clear what should be used.

In the case of the F/48 LED exposures, it was necessary to correct for the unilluminated corner. This was done for the B1 LED by:

- Defining a “splice” region where the LED and the corresponding external flat field would be matched. The region is bounded by the two lines defined by (in pixels of the 512 x 512 version of the flat field) by the equations:

  \[
  y = -1.223x + 954.9 \\
  y = -1.223x + 854.9
  \]

  Figure 32 shows the splice region.

  - The corresponding external flat field, corrected for nonuniformity of illumination, is scaled so that the total in the above defined area equals the total in the same area of the LED exposure.

  - The two images, the LED flat and the scaled external flat, are combined by multiplying the two images by their respective “splice” function and then adding the results. The splice function for the LED image is one that is all 1’s below the splice region, all 0’s above the splice region, and a continuous linear ramp between the two in the splice region. The slice function for the scaled external image is just 1 minus the LED splice function.

In summary, the resulting image is mostly the LED but contains part of the external in the unilluminated corners. This method prevents any discontinuities in the splice. In principle, this could be applied to the other LED images by taking the ratio of the B1 spliced image to
the unspliced B1 image and multiplying any LED image by this ratio (effectively the LED illumination nonuniformity). This approach would lead to large errors in the corner since the statistics there would be poor because of the low light level. There was no need to do this, however, for reasons that will become quickly apparent.

The following table lists the RSDP calibration files for the uniformity correction that were generated for Build 2. We currently expect these to be the ones used immediately after launch. There are only two correction images for F/48 because none of the filter combinations in F/48 resulted in a mean wavelength for the effective bandpass of the filter combination that would have required using a correction file with an effective wavelength greater than that of the B1 LED.

The following summarizes the processing applied to the flat field data to generate the calibration files.

- Correct for overflows and bad most significant bit.
- Sum exposures if more than one.
- Correct for nonuniformity of illumination if external flat using method previously described for generating illumination nonuniformity correction image.
<table>
<thead>
<tr>
<th>Filename</th>
<th>Optical relay</th>
<th>λ Å</th>
</tr>
</thead>
<tbody>
<tr>
<td>F48UNI200B2</td>
<td>F/48</td>
<td>2000</td>
</tr>
<tr>
<td>F48UNI480B2</td>
<td>F/48</td>
<td>4800</td>
</tr>
<tr>
<td>F96UNI200B2</td>
<td>F/96</td>
<td>2000</td>
</tr>
<tr>
<td>F96UNI480B2</td>
<td>F/96</td>
<td>4800</td>
</tr>
<tr>
<td>F96UNI560B2</td>
<td>F/96</td>
<td>5600</td>
</tr>
<tr>
<td>F96UNI660B2</td>
<td>F/96</td>
<td>6600</td>
</tr>
</tbody>
</table>

Table 6: Flat field correction files for RSDP

- Reduce to 512 x 512 image by averaging pairs of rows.
- If F/48 LED image, splice in adjusted external flat field into corner.
- Excluding a small border, insert the result into a larger image (done to exclude bad data at the borders and eliminate edge effects of filters in IDL)
- If external interpolate image values in finger areas and A/D glitch areas.
- Extrapolate edges of smaller, inserted image to fill larger image. If corners are obstructed, extrapolate from good part of the photocathode.
- Convert image to byte values and apply 7 x 7 median filter.
- Convert to floating point image and apply a gaussian filter with a FWHM of 9 pixels (now double sized) using a 21 x 21 kernel.
- Extract central 512 x 512.
- Expand image to 1024 x 1024 using bilinear interpolation.
- Normalize image so that center 31 x 31 has average value of 1.
- Take inverse of image.
- Use IRAF/STSDAS task to convert image into RSDP compatible format.
- Add history to each correction image header manually describing processing involved.

The history sections of each of the RSDP files has been attached. Figures 33-40 show contour maps of the flat fields corresponding to each of the RSDP files (they are the inverse of the
Figure 33: Contours at -100, -90, ..., 90, 100% (including 0)

Figure 34: Contours at -100, -90, ..., 90, 100% (including 0)

RSDP files which multiply the incoming science data). The calibration flat fields for F/48 at 5600 and 6600 Å are shown even though they are not used in RSDP. These contour plots have had the equivalent smoothing applied as in previous plots; note though, that this smoothing has not been applied to the RSDP files.
Figure 35: Contours at -100, -90, ..., 90, 100% (including 0)

Figure 36: Contours at -100, -90, ..., 190, 200% (including 0)

Figure 37: Contours at -50, -40, ..., 40, 50% (including 0)

Figure 38: Contours at -50, -40, ..., 40, 50% (including 0)
Figure 39: Contours at -50, -40, ..., 40, 50% (including 0)

Figure 40: Contours at -50, -40, ..., 40, 50% (including 0)
6 References

1. FOC Calibration III Phase 1 Post-test Meeting Minutes, 5 August 1987.


HISTORY = 'this REL DE image was created using IDL by Perry Greenfield
HISTORY = ' on 2 June 1987 for the build 2 delivery of REL DE files
HISTORY = ' for RSDP. A summary of the processing used to create
HISTORY = ' this image follows, greater detail may be found in the
HISTORY = ' associated Instrument Science Report
HISTORY = ' the input images: 8519(REL4801/1), 8520(REL4801/2), & 8521(REL4801/3)
HISTORY = ' are all EXTERNAL ILLUMINATION at 2000 angstroms wavelength
HISTORY = ' input counts and countrates:
HISTORY = ' image center peak exp time
HISTORY = ' counts ctryt counts ctryt (secs)
HISTORY = ' 8519 118 0.049 125 2400
HISTORY = ' 8520 117 0.049 125 2400
HISTORY = ' 8521 115 0.048 126 2400
HISTORY = ' total 350 0.049 376 0.052 7200
HISTORY = ' correction for bad most significant bit for images 8519, 8520, & 8521
HISTORY = ' no geometric correction
HISTORY = ' summation of images 8519, 8520, & 8521
HISTORY = ' correction for nonuniformity of external illumination using
HISTORY = ' LAS supplied measurements of nonuniformity
HISTORY = ' we have assumed the angle between the h and v coordinates of the
HISTORY = ' and the frame coordinates are 35.5 degrees rather than the
HISTORY = ' value of 25.5 assumed by MATRA in applying the nonuniformity
HISTORY = ' correction
HISTORY = ' reduction to 512 by 512 images by averaging pairs of rows
HISTORY = ' interpolation of pixel values in finger regions
HISTORY = ' interpolation of pixel values near A/D glitches at rows 256 and 768
HISTORY = ' extrapolation of pixel values at obscured corners
HISTORY = ' image embedded into 572 by 572 image excluding 18 pixels
HISTORY = ' on left border, 5 pixels on right border,
HISTORY = ' 3 pixels at bottom (y=0), and 3 pixels at top
HISTORY = ' pixel values at border of extracted image extended to edges of
HISTORY = ' larger image
HISTORY = ' image converted to byte image for median filtering
HISTORY = ' 7 by 7 median filter applied
HISTORY = ' conversion to real*4 image
HISTORY = ' gaussian filtering with 21 by 21 kernel and FWHM of 9 pixels
HISTORY = ' center 512 by 512 extracted
HISTORY = ' image reciprocal taken
HISTORY = ' image enlarged to 1024 by 1024 using bilinear interpolation
HISTORY = ' image normalized so that center 31 by 31 square has average of 1

END
**HISTORY**

- This REL DE image was created using IDL by Perry Greenfield on 2 June 1987 for the build 2 delivery of REL DE files for RSDP. A summary of the processing used to create this image follows, greater detail may be found in the associated Instrument Science Report.
- The input images: 10401 (LREL 4804/1) for most of the flat field, 8435 (REL 4804/1), 8436 (REL 4804/2), 8437 (REL 4804/3), & 8438 (REL 4804/4) for one corner, these are B1 LED (10401, wavelength=4800 angstroms) and EXTERNAL ILLUMINATION at 4800 angstroms wavelength (8435, 8436, 8437, & 8438).
- Input counts and countrates:

<table>
<thead>
<tr>
<th></th>
<th>image center</th>
<th>peak exp time</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.052</td>
</tr>
<tr>
<td>246</td>
<td>0.082</td>
<td>3000</td>
</tr>
</tbody>
</table>

- Correction for bad most significant bit for images 10401, 8435, 8436, 8437, & 8438.
- Correction for overflowed pixels for images 8435, 8437, & 8438.
- No geometric correction.
- Summation of images 8435, 8436, 8437, & 8438 to produce summed external image.
- Correction for nonuniformity of external illumination using LAS supplied measurements of nonuniformity.
- We have assumed the angle between the h and v coordinates of the and the frame coordinates are 35.5 degrees rather than the value of 25.5 assumed by MATRA in applying the nonuniformity correction except for one corner we have assumed the LED illumination is uniform.
- Reduction to 512 by 512 images by averaging pairs of rows because the LED illumination clearly falls off in one corner (at x=512, y=1024 in the zoomed image), we have fixed that corner by splicing the corner of the summed external image with the LED image.
- Interpolation of pixel values near A/D glitches at rows 256 and 768.
- Extrapolation of pixel values at obscured corners.
- Image embedded into 572 by 572 image excluding x pixels on left border, x pixels on right border, x pixels at bottom (y=0), and x pixels at top.
- Pixel values at border of extracted image extended to edges of larger image.
- Image converted to byte image for median filtering.
- 7 by 7 median filter applied.
- Conversion to real*4 image.
- Gaussian filtering with 21 by 21 kernel and FWHM of 9 pixels.
- Center 512 by 512 extracted.
- Image reciprocal taken.
- Image enlarged to 1024 by 1024 using bilinear interpolation.
- Image normalized so that center 31 by 31 square has average 1.

---

**HISTORY**

- FOR F48UN1480B2
The REL DE image was created using IDL by Perry Greenfield on 2 June 1987 for the build 2 delivery of REL DE files for RSDP. A summary of the processing used to create this image follows, greater detail may be found in the associated Instrument Science Report.

The input images: 10335 (LREL 4803) & 10336 (LREL 4803/1) for most of the flat field and 8435 (REL 4804/1), 8436 (REL 4804/2), 8437 (REL 4804/3), & 8438 (REL 4804/4) for one corner, these are G2 LED (10335 & 10336, wavelength=5600 angstroms) and EXTERNAL ILLUMINATION at 4800 angstroms wavelength (8435, 8436, 8437, & 8438).

Input counts and countrates:

<table>
<thead>
<tr>
<th>image</th>
<th>center peak exp time</th>
</tr>
</thead>
<tbody>
<tr>
<td>10335</td>
<td>161 0.046 283 0.063 3500</td>
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<tr>
<td>10336</td>
<td>1800</td>
</tr>
</tbody>
</table>

Correction for bad most significant bit for images 10335, 10336, 8435, 8436, 8437, & 8438.

Correction for overflowed pixels for images 8435, 8437, & 8438.

No geometric correction.

Summation of images 8435, 8436, 8437, & 8438 to produce summed external image.

Summation of images 10335 and 10336 to produce summed LED image.

Correction for nonuniformity of external illumination using LAS supplied measurements of nonuniformity.

We have assumed the angle between the h and v coordinates of the frame coordinates are 35.5 degrees rather than the value of 25.5 assumed by MATRA in applying the nonuniformity correction.

Except for one corner we have assumed the LED illumination is uniform.

Reduction to 512 by 512 images by averaging pairs of rows because the LED illumination clearly falls off in one corner (at x=512, y=1024 in the zoomed image), we have fixed that corner by splicing the corner of the summed external image with the summed LED image.

Interpolation of pixel values near A/D glitches at rows 256 and 768.

Extrapolation of pixel values at obscured corners.

Image embedded into 572 by 572 image excluding x pixels on left border, x pixels on right border, x pixels at bottom (y=0), and x pixels at top.

Pixel values at border of extracted image extended to edges of larger image.

Image converted to byte image for median filtering.

7 by 7 median filter applied.

Conversion to real4 image.

Gaussian filtering with 21 by 21 kernel and FWHM of 9 pixels.

Center 512 by 512 extracted.

Image reciprocal taken.

Image enlarged to 1024 by 1024 using bilinear interpolation.

Image normalized so that center 31 by 31 square has average 1.
this REL DE image was created using IDL by Perry Greenfield.

on 2 June 1987 for the build 2 delivery of REL DE files

for RSDP. A summary of the processing used to create

this image follows, greater detail may be found in the

associated Instrument Science Report

the input images: 10404 (LREL 4801/1) for the flat field

and 8435 (REL 4804/1), 8436 (REL 4804/2), 8437 (REL 4804/3),

8438 (REL 4804/4) & 10401 (LREL 4804/1) for the purposes of

correcting one corner, these are

R2 LED (10404, wavelength=6600 angstroms),

EXTERNAL ILLUMINATION at 4800 angstroms wavelength (8435, 8436

8437, & 8438), and B1 LED (10401, wavelength = 4800)

input counts and countrates:

image center peak exp time

counts ctrt counts ctrt (secs)

10404 85 0.028 243 0.081 3000

'correction for bad most significant bit for images 10404, 8435, 8436'

8437, 8438, & 10401

correction for overflowed pixels for images 8435, 8437, & 8438

'no geometric correction

'summation of images 8435, 8436, 8437, & 8438 to produce summed

'external image

'correction for nonuniformity of external illumination using

'LAS supplied measurements of nonuniformity

'we have assumed the angle between the h and v coordinates of the

'and the frame coordinates are 35.5 degrees rather than the

'value of 25.5 assumed by MATRA in applying the nonuniformity

'correction

'except for one corner we have assumed the LED illumination is

'uniform

'reduction to 512 by 512 images by averaging pairs of rows

'because the LED illumination clearly falls off in one corner (at

'x=512, y=1024 in the zoomed image), we have fixed that corner by

'multiplying by a correction image determined from the ratio of

'a spliced B1 LED image with an unspliced B1 LED image. The

'spliced LED image is made up, in part, of the summed external

'image. See the Instrument Science Report for details

'interpolation of pixel values near A/D glitches at rows 256 and 768

'extrapolation of pixel values at obscured corners

'image embedded into 572 by 572 image excluding x pixels

'on left border, x pixels on right border,

'x pixels at bottom (y=0), and x pixels at top

'pixel values at border of extracted image extended to edges of

'larger image

'image converted to byte image for median filtering

'7 by 7 median filter applied

'conversion to real*4 image

'gaussian filtering with 21 by 21 kernel and FWHM of 9 pixels

'center 512 by 512 extracted

'image reciprocal taken

'image enlarged to 1024 by 1024 using bilinear interpolation

'image normalized so that center 31 by 31 square has average 1
HISTORY = 'this REL DE image was created using IDL by Perry Greenfield
HISTORY = 'on 2 June 1987 for the build 2 delivery of REL DE files
HISTORY = 'for RSDP. A summary of the processing used to create
HISTORY = 'this image follows, greater detail may be found in the
HISTORY = 'associated Instrument Science Report
HISTORY = 'the input images: 8602 (REL9601/1), 8603 (REL9601/2), & 8604 (REL9601/2
HISTORY = 'are all EXTERNAL ILLUMINATION at 2000 angstroms wavelength
HISTORY = 'input counts and countrates:

<table>
<thead>
<tr>
<th>Image</th>
<th>Image Center (cts)</th>
<th>Peak Counts (cts)</th>
<th>Exp Time (secs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8602</td>
<td>256</td>
<td>0.085</td>
<td>338</td>
</tr>
<tr>
<td>8603</td>
<td>165</td>
<td>0.082</td>
<td>223</td>
</tr>
<tr>
<td>8604</td>
<td>147</td>
<td>0.082</td>
<td>200</td>
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<tr>
<td>568</td>
<td>0.084</td>
<td>761</td>
<td>0.111</td>
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HISTORY = 'correction for bad most significant bit for images 8602, 8603, & 8604
HISTORY = 'correction for overflowed pixels for images 8602 & 8603
HISTORY = 'no geometric correction
HISTORY = 'summation of images 8602, 8603, & 8604
HISTORY = 'correction for nonuniformity of external illumination using
HISTORY = 'LAS supplied measurements of nonuniformity
HISTORY = 'reduction to 512 by 512 images by averaging pairs of rows
HISTORY = 'interpolation of pixel values in finger regions
HISTORY = 'extrapolation of pixel values at obscured corners
HISTORY = 'image embedded into 512 by 512 image excluding 9 pixels
HISTORY = 'on left border, 7 pixels on right border,
HISTORY = '3 pixels at bottom (y=0), and 3 pixels at top
HISTORY = 'pixel values at border of extracted image extended to edges of
HISTORY = 'larger image
HISTORY = 'image converted to byte image for median filtering
HISTORY = '7 by 7 median filter applied
HISTORY = 'conversion to real*4 image
HISTORY = 'gaussian filtering with 21 by 21 kernel and FWHM of 9 pixels
HISTORY = 'center 512 by 512 extracted
HISTORY = 'image reciprocal taken
HISTORY = 'image enlarged to 1024 by 1024 using bilinear interpolation
HISTORY = 'image normalized so that center 31 by 31 square has average of 1

END
HISTORY = 'this REL DE image was created using IDL by Perry Greenfield on 2 June 1987 for the build 2 delivery of REL DE files for RSDP. A summary of the processing used to create this image follows, greater detail may be found in the associated Instrument Science Report the input image: 10414 (LREL 9604/3)
HISTORY = 'input is a B1 LED exposure (4800 angstroms)
HISTORY = 'input counts and countrates:
HISTORY = ' image center peak exp time
counts ctrt counts ctrt (secs)
HISTORY = ' 10414 119 0.044 170 0.063 2700
HISTORY = 'we have assumed that the LED illumination is uniform
correction for bad most significant bit
HISTORY = 'no geometric correction
HISTORY = 'reduction to 512 by 512 images by averaging pairs of rows
HISTORY = 'extrapolation of pixel values at obscured corners
HISTORY = 'image embedded into 572 by 572 image exculding 9 pixels
HISTORY = 'on left border, 7 pixels on right border,
HISTORY = '3 pixels at bottom (y=0), and 3 pixels at top
HISTORY = 'pixel values at border of extracted image extended to edges of larger image
HISTORY = 'image converted to byte image for median filtering
HISTORY = '7 by 7 median filter applied
HISTORY = 'conversion to real*4 image
HISTORY = 'gaussian filtering with 21 by 21 kernel and FWHM of 9 pixels
HISTORY = 'center 512 by 512 extracted
HISTORY = 'image reciprocal taken
HISTORY = 'image enlarged to 1024 by 1024 using bilinear interpolation
HISTORY = 'image normalized so that center 31 by 31 square has average of 1

HISTORY FOR F96UNIV18082
HISTORY = '
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HISTORY = ' on 2 June 1987 for the build 2 delivery of REL DE files
HISTORY = ' for RSDF. A summary of the processing used to create
HISTORY = ' this image follows, greater detail may be found in the
HISTORY = ' associated Instrument Science Report
HISTORY = ' the input image: 10321 (LREL 9603)
HISTORY = ' is a G2 LED exposure (5600 angstroms)
HISTORY = ' input counts and countrates:
HISTORY = ' image center peak exp time
HISTORY = ' counts ctzt counts ctzt (secs)
HISTORY = ' 10321 116 0.042 170 0.063 2700
HISTORY = ' we have assumed that the LED illumination is uniform
HISTORY = ' correction for bad most significant bit
HISTORY = ' no geometric correction
HISTORY = ' reduction to 512 by 512 images by averaging pairs of rows
HISTORY = ' extrapolation of pixel values at obscured corners
HISTORY = ' image embedded into 572 by 572 image excuding 9 pixels
HISTORY = ' on left border, 7 pixels on right border,
HISTORY = ' 3 pixels at bottom (y=0), and 3 pixels at top
HISTORY = ' pixel values at border of extracted image extended to edges of
HISTORY = ' larger image
HISTORY = ' image converted to byte image for median filtering
HISTORY = ' 7 by 7 median filter applied
HISTORY = ' conversion to real*4 image
HISTORY = ' gaussian filtering with 21 by 21 kernel and FWHM of 9 pixels
HISTORY = ' center 512 by 512 extracted
HISTORY = ' image reciprocal taken
HISTORY = ' image enlarged to 1024 by 1024 using bilinear interpolation
HISTORY = ' image normalized so that center 31 by 31 square has average of 1
END

HISTORY FOR F96UNI 560B2
HISTORY = 'this REL DE image was created using IDL by Perry Greenfield
HISTORY = on 2 June 1987 for the build 2 delivery of REL DE files
HISTORY = for RSDP. A summary of the processing used to create
HISTORY = this image follows, greater detail may be found in the
HISTORY = associated Instrument Science Report
HISTORY = 'the input image: 10301 (LREL 9601)
HISTORY = 'is a R2 LED exposure (6600 angstroms)
HISTORY = 'input counts and countrates:
HISTORY = image center peak exp time
HISTORY = counts ctrt counts ctrt (secs)
HISTORY = 10301 158 0.044 241 0.067 3600
HISTORY = 'we have assumed that the LED illumination is uniform
HISTORY = 'correction for bad most significant bit
HISTORY = 'correction for overflowed pixels
HISTORY = 'no geometric correction
HISTORY = 'reduction to 512 by 512 images by averaging pairs of rows
HISTORY = 'extrapolation of pixel values at obscured corners
HISTORY = 'image embedded into 572 by 572 image excluding 9 pixels
HISTORY = 'on left border, 7 pixels on right border,
HISTORY = '3 pixels at bottom (y=0), and 3 pixels at top
HISTORY = 'pixel values at border of extracted image extended to edges of
HISTORY = larger image
HISTORY = 'image converted to byte image for median filtering
HISTORY = '7 by 7 median filter applied
HISTORY = 'conversion to real*4 image
HISTORY = 'gaussian filtering with 21 by 21 kernel and FWHM of 9 pixels
HISTORY = 'center 512 by 512 extracted
HISTORY = 'image reciprocal taken
HISTORY = 'image enlarged to 1024 by 1024 using bilinear interpolation
HISTORY = 'image normalized so that center 31 by 31 square has average of 1

HISTORY FOR F96UNI 66082