estec

European Space Research
and Technology Centre
Keplerlaan 1
2201 AZ Noordwijk
The Netherlands
Tel. (31) 71 5656565
Fax (31) 71 5656040
www.esa.int

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Author(s): G. Giardino
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Dependency of reference pixel Fourier-space weighting on temperature and environment

Abstract:

In this report we summarize the results of the analysis of the dependency of the reference pixel weighting on the operating temperature of the detector and the test environment. The method for deriving this Fourier-space weighting follows that described in JWST-RPT-015348 and is here briefly illustrated. Usage of the software package *RefsubWeights* that computes the weighting function is outlined in the Appendix. The Fourier-space weighting of the reference pixels provides only marginal improvements on the detector total noise figures for dark exposures, but does help in suppressing part of the striping present in the dark images due to the $1/f$-noise component of the read noise. We find no signficant dependency of the weighting function on detector temperature changes of a few degrees.

1 INTRODUCTION

In the current version of NIRSpec pre-processing pipeline (Birkmann 2011) the step of reference pixel subtraction is included to remove some common $1/f$-noise from all outputs. This is done by using the four reference columns to the left and right of the frame. The eight pixels in each column are averaged row-by-row, giving 2048 values along the column. Then, an FFT based smoothing is applied to the data and the result is subtracted from every row (Moseley et al. 2010). The smoothing function is specified in reference files `FFTR_49[1,2]_xxx.fits`. This step is only applied to full frame exposures.
The weighting function to be applied to the FFT of the reference pixels is derived by computing the FFT of the average of the 8 columns of reference pixels and of the average of the 8 columns of regular pixels which were read out simultaneously with the reference columns according to the following recipe (which is applied to every group in an exposure):

- For each reference (or regular) column, subtract the a_i term from the up-the-ramp fit $s_i = a_i + b_i t$

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- In the array of 8 reference (or regular) columns (array dimension 8×2048), replace statistical outliers with values drawn randomly from the parent distribution (2σ iterative rejection)
- Average together the (cleaned) 8 reference columns and 8 normal columns to obtain two arrays of 2048 elements each
- Fast-Fourier Transform these two arrays

All the FFTs of reference columns and normal columns from a set of n dark exposures are then combined in two $n \times 88$-arrays (88-group dark exposures are assumed here) and then the complex-ratio of these pair of arrays is calculated. The weighting function is then obtained by performing a fit to the amplitude of the (complex) average of these $n \times 88$ complex ratios. This processing is implemented by the Python package `RefsubWeights` described in more detail in the Appendix.
In this report we analyze the dependence of the weighting function on the detector operating temperature and the test environment. For this analysis we used the following sets of darks:

- from FPA104:
  - DCL data acquired at 36.5 K (96 exposures)
  - DCL data at 38.5 K (100 exposures)
  - FM-Test Cycle 1 at 38.5 K (40 exposures)
- from FPA105
  - DCL data acquired at 38.5 K (149 exposures)
  - DCL data at 41.0 K (237 exposures)

2 FREQUENCY DEPENDENT REFERENCE PIXEL GAIN

By analyzing the data to derive the FFT-weighting function according to the algorithm outlined in the previous section, one notices that the results in terms of average power spectrum of the reference and normal columns are quite sensitive to the chosen sigma rejection level and to the allowed maximum number of iterations in the iterative-sigma clipping step applied to the 8×2048 arrays. Fig. 1 provides the plot of the noise power spectra for SCA491 and SCA492 for the first data set (FPA104 – DCL, $T = 36.5$ K) that we obtained using 2σ iterative clipping with a maximum number of iterations equal to 5, using the package `RefsubWeights`. These can be directly compared to those given by B. Rauscher in JWST-RPT-015348[1] and appear to show the presence of a frequency dependent gain g_ν between the reference pixels and the regular pixels.

[1]The plots are qualitatively very similar to those in JWST-RPT-015348, however, we were unable to reproduce exactly their results as we do not know their choice of processing parameters

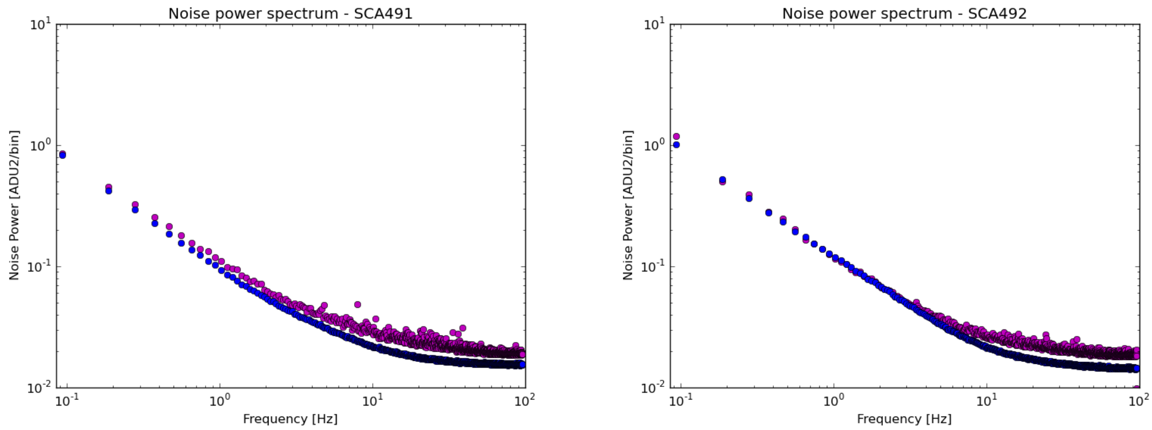

Figure 1: Average noise power spectra for 8 columns of references pixels (blue) and 8 columns of regular pixels that are read out at the same time (magenta). Data set: 96 dark exposures from FPA104 taken at Goddard DCL.

To derive the actual weighting function the complex-ratios of the FFT of the reference column over the FFT of the normal column has to be derived. The amplitude of the average of this complex ratio (g_ν) over 96×88 frames for this same data set is shown in Fig. 2, together with the fitted functions. As in JWST-RPT-015348, the behaviour of $|g_\nu|$ was modeled with a 4 parameter function of the form:

$$|g_\nu| = c_0 + \frac{c_1}{1 + c_2 \nu^{c_3}} \tag{1}$$

As can be seen from Fig. 2, the shape of $|g_\nu|$ for SCA491 and SCA492 as derived here are different from those derived in JWST-RPT-015348 and that are available in reference files:
`FPA104_T3650/FFTR_xxx_001.fits`.
The newer version of the weighting functions have been saved in reference files:
`FPA104_T3650/FFTR_xxx_002.fits`.
To assess the impact of different weighting functions on the effectiveness of this method of $1/f$-noise reduction we compared the total noise from the count-rate images of the 96 darks exposures of SCA491 (FPA104) obtained with our pre-processing pipeline in the following three different ways: *i)* without any Fourier weighting of the reference pixels, *ii)* with Fourier weighting using the fit to $|g_\nu|$ from JWST-RPT-015348 (reference file `FFTR_xxx_001.fits`), *iii)* using the fit to $|g_\nu|$ from this work (reference file `FFTR_xxx_002.fits`). The three total-noise distributions over the detector array (SCA491) obtained in this way are shown in Fig. 3. The difference among the three histograms are very small, with the improvement introduced by Reference pixel Fourier weighting over no weighting being only marginal. The weighting function derived here appear to marginally improve the noise level over the weighting function derived in JWST-RPT-015348. Beside these negligible improvements in the overall noise level, however, by comparing visually the dark count-rate maps obtained with and without Reference pixel Fourier weighting, one will notice an improvement in the overall

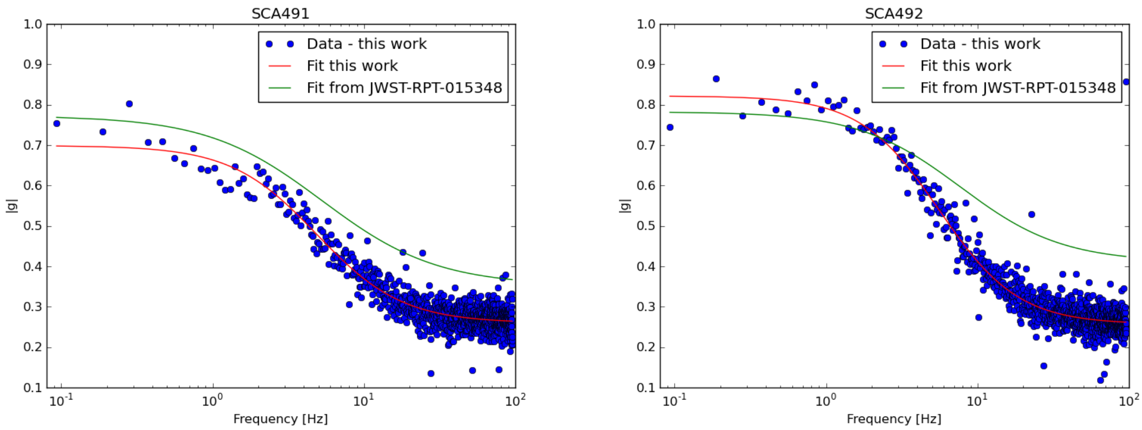

Figure 2: The amplitude of g_ν for SCA491 and SCA492 of FPA104 as derived here from DCL data (T$= 36.5$ K). The data are well represented by the model in Eq. 1. The fit to the present data can be compared to the fit obtained in JWST-RPT-015348 (data processed with different parameters).

appearance of the dark images, with the exposures that were processed using Reference pixel Fourier weighting displaying somewhat less striping (in the row direction) than those for which the reference pixels were not weighted. For this cosmetic improvement, however, there is no appreciable difference in using reference file `FFTR_xxx_001.fits` or the newer `FFTR_xxx_002.fits`. Given that the shape of the fits to the JWST-RPT-015348 data and the shape of the fits obtained here using `RefsubWeights` are rather different, this implies that the cosmetic improvements on the dark images are not very sensitive to the detailed shape of the weighting function.

3 WEIGHTS DEPENDENCY ON TEMPERATURE AND TEST ENVIRONMENT

The dark exposures taken at DCL with FPA104 operating at $T = 38.5$ K were also processed using `RefsubWeights` and the derived fits to $|g_\nu|$ compared with those derived from the DCL darks at $T = 36.5$ K and from the darks acquired during Cycle 1 of NIRSpec Performance and Calibration Campaign also at $T = 38.5$ K. The comparison between the derived fits to the amplitude of the averaged g_ν is shown in Fig. 4. The plots shows that there is very little variation of this function with temperature and test environment, with the apparent small differences being likely due to the data noise. The fits coefficients are provided in tables 1 and 2

Note that, for SCA492, the fitting program was unable to converge to a fit with Eq., 1 in the case of g_ν for Cycle 1. This is likely due to the average of this data being noisier than the data acquired at DCL due to number of available darks being only 40. In Fig. 5 the plot of the g_ν data for Cycle 1 can be compared with that for the DCL data (at the same temperature of 38.5

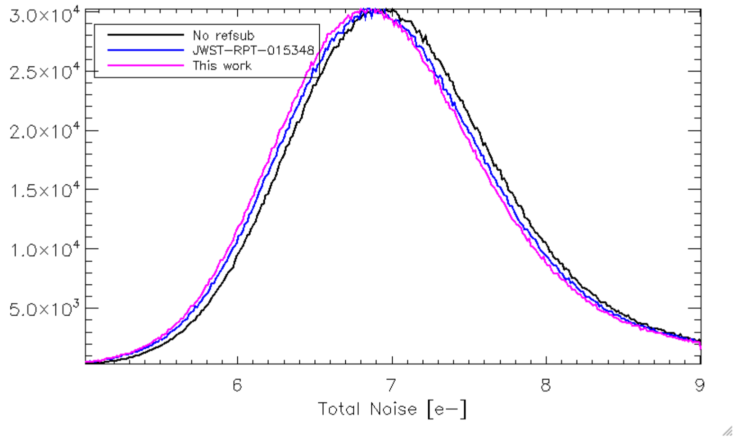

Figure 3: Comparison among the total noise distributions derived from the count-rate images of the 96 dark exposures (SCA491) processed in three different ways: *i)* without any Fourier weighting of the reference pixels, *ii)* with Fourier weighting using the fit to $|g_\nu|$ from JWST-RPT-015348 , *iii)* using the fit to $|g_\nu|$ from this work. The differences are marginal.

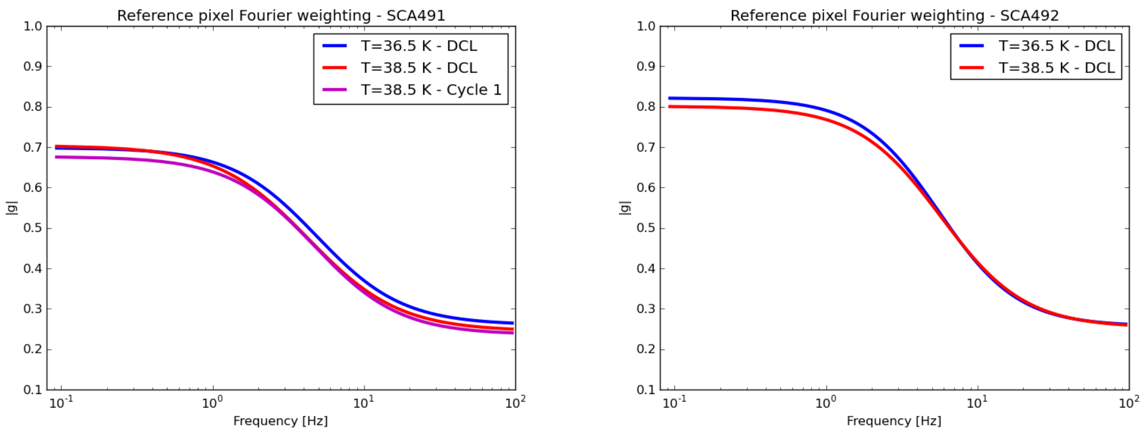

Figure 4: Weighting function for different detector operating temperatures and for the same temperature but in different test environments for FPA104. There appears to be negligible dependency of the weights on these factors.

Table 1: Fit coefficients for Eq. 1 for SCA491 for the three different data sets for FPA104 and the two sets for FPA105.

FPA	Test	c_0	c_1	c_2	c_3
104	$T = 36.5$ K - DCL	0.260	0.439	0.088	1.530
104	$T = 38.5$ K - DCL	0.245	0.460	0.123	1.443
104	$T = 38.5$ K - Cycle 1	0.236	0.441	0.094	1.534
105	$T = 38.5$ K - DCL	0.344	0.497	0.043	2.072
105	$T = 41.0$ K - DCL	0.317	0.600	0.049	1.778

Table 2: Fit coefficients for Eq. 1 for SCA492, the three different data sets for FPA104 and the two sets for FPA105. Fit to Cycle 1 data did not converge.

FPA	Test	c_0	c_1	c_2	c_3
104	$T = 36.5$ K - DCL	0.257	0.565	0.057	1.662
104	$T = 38.5$ K - DCL	0.253	0.548	0.064	1.572
104	$T = 38.5$ K - Cycle 1	-	-	-	-
105	$T = 38.5$ K - DCL	0.244	0.554	0.618	1.002
105	$T = 41.0$ K - DCL	0.225	0.616	0.305	1.439

K). The two data sets appear to be similar. Given the little dependency of the effectiveness in reducing the $1/f$-noise component from the detailed shape of the weighting function (as discussed in the previous section), the fit to the DCL data provides an acceptable weighting function also for the Cycle 1 data set.
For FPA105, the reference pixels weighting functions were derived for the two data sets acquired at DCL for the two different detector temperatures of 38.5 and 41.0 K. The coefficients of the fit are given in tables 1 and 2 and the two weighting functions can be compared in Fig. 6. Also in the case of FPA105 the dependency of the weighting function on detector temperature appears to be small, although somewhat more pronounced than in the case of FPA104.

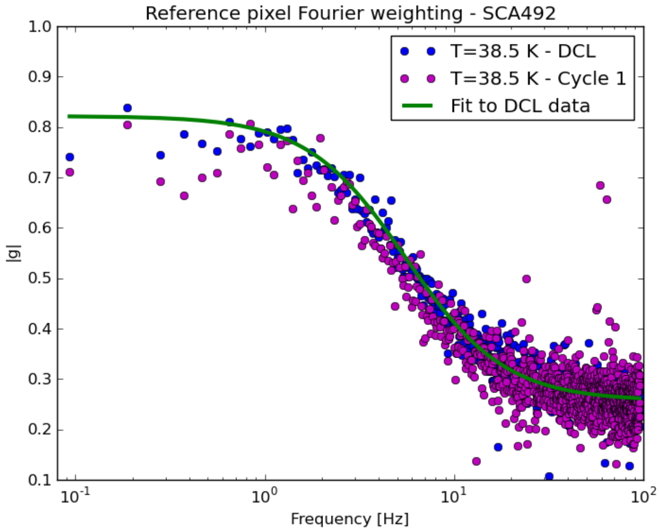

Figure 5: $|g_\nu|$ **for SCA492 from from DCL data darks (100) compared to that from Cycle 1 darks (40) . The two data sets appear to be quite similar, however, a fit with Eq. 1 to the second data set does not converge.**

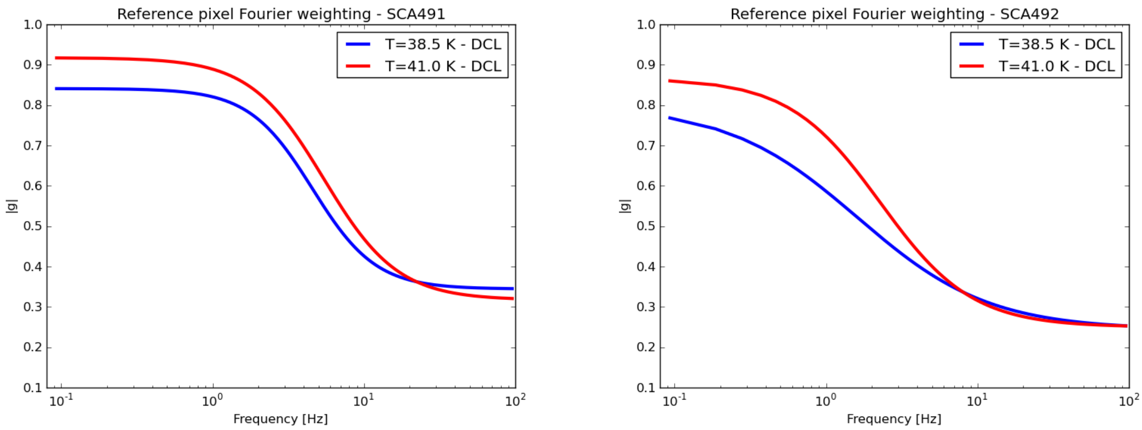

Figure 6: Weighting function for different detector operating temperatures for FPA105.

4 CONCLUSION

The dependency of the reference pixels Fourier-space weighting function on the detector temperature and test environment was analyzed. For this purpose the software package `RefsubWeights` was developed. Three different data sets (at two temperatures of 36.5 and 38.5 K) for FPA104 and two different data sets (at two temperatures of 38.5 and 41.0 K) for FPA105 were reduced using this package. We find that Fourier-space weighting of the reference pixels reduces the dark total noise figure only marginally, but reduces somewhat the horizontal striping visible in the dark images. The effectiveness of this cosmetic improvement however seems to be fairly independent on the detailed shape of the weighting function. In this light, no significant dependency of the weighting function on the detector operating temperature was found.

Currently an effort is underway at NASA-Goddard (Rauscher et al. 2011) to generalize this approach and develop a more efficient $1/f$-noise rejection process. The technique named IRS^2 (Improved Reference Sampling & Subtraction) is based on: (1) making better use of the H2RGs reference output, (2) sampling reference pixels more frequently in the time domain, and (3) optimal subtraction of both the reference output and reference pixels in the Fourier domain.

APPENDIX

`RefsubWeights` is a software package written in Python to derive the Fourier-space weighting function for the reference pixels. This weighting is applied to the reference pixels before their values is subtracted from the normal pixels by our pre-processing pipeline during default processing of a full-frame exposure (see Birkmann (2011) for more details on our processing pipeline). `RefsubWeights` enables creation of the reference files `FFTR_49[1,2]_xxx.fits`. The package is stored in the Software repository in directory `JWST_python/SQUAT/RefsubWeight`. It consists of 6 executable programs. Below we describe their functions and how to run them.

- **getNoiseFT.py** – Given a dark exposure, it derives, for each group in the exposure, the FFTs of the average of the 8 reference columns and of the average of the 8 normal columns which are read-out simultaneously with the reference columns. It saves these (typically) 88 pair of FFTs in two FITS file in the current directory with the same root name as the input exposure and extensions `_ref_fft.fits` and `_norm_fft.fits`

  To run the program call (e.g):
  `getNoiseFT.py dark_exposure.fits`

- **runNoiseFT.py** – Run command `getNoiseFT.py` on a list of dark exposures.

  To run the program call (e.g):
  `runNoiseFT.py '/JWST/DS_DCL/DS_FLIGHT_TESTDATA/*36_5*TotalNoise*/*491*[0-9].fits'`
  NOTE the quotes!

- **plotAveragePS.py** – Given a list of files containing the FFTs produced by program `getNoiseFT.py`, generates a plot of the average of the noise power spectra of the reference column and of the normal column of the type shown in Fig. 1.

  To run the program call (e.g):
  `plotAveragePS.py '/JWST/Gio/RefPixFPA104/*491*_ref_fft.fits'`

- **plotAverageFT.py** – Given a list of files containing the FFTs produce by program `getNoiseFT.py`, computes the average complex function g_ν, plots the amplitude of this function ($|g_\nu|$) and save the complex valued function to file `abs_gv_49[1,2].fits`. Examples of this plots are given in Fig. 2 (without the fitting function).

  To run the program call (e.g):
  `plotAverageFT.py '/JWST/Gio/RefPixFPA104/*491*_ref_fft.fits'`

- **plotAveragePhase.py** – Given a list of files containing the FFTs produced by program `getNoiseFT.py`, computes the average complex function g_ν and plots its phase.

  To run the program call (e.g):
  `plotAveragePhase.py '/JWST/Gio/RefPixFPA104/*491*_ref_fft.fits'`

- **fitG.py** – Given the data points of g_ν, as generated by program `plotAverageFT.py`, fits the data points with a function of the form given in Eq. 1, plots the fit-function (over the data points) and save the function in a file with name `FFTR_49[1,2]_001.fits` (see fig. 2 for an example).

To run the program call (e.g):

```
fitG.py abs_gv_491.fits
```

NOTE If you are producing a newer version of the same reference file, then, before posting it the FTP site, you need to rename the file to the correct version by hand.

5 REFERENCES

Birkmann, S. 2011, Description of the NIRSpec pre-processing pipeline, NIRSpec Technical Note NTN-2011-004, ESA/ESTEC available at http://www.rssd.esa.int/index.php?project=JWST

Moseley, S. H., Arendt, R. G., Fixsen, D. J., et al. 2010, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 7742, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series

Rauscher, B. J., Arendt, R. G., Fixsen, et al. 2011, Proc SPIE, 8155, 45