Summary of MADmap processing on PACS bolometer data: GP-field, blue filter.

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A. History

<table>
<thead>
<tr>
<th>Version</th>
<th>Date</th>
<th>Author</th>
<th>Change Record</th>
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<tbody>
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<td>21-Sep-2009</td>
<td>Babar Ali</td>
<td>First writeup.</td>
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</table>

B. Summary

This report summarizes findings on using MADmap code to process PACS data to a level 2 map product. For the purpose of this report a “drift” is defined as change in the signal level with time that has instrument or optical origin rather than from variation from sky brightness.

NOTE: No accounting is made for glitches. In the initial processing, it was clear that MMT deglitcher removed a number of peak sources as well as allowed many glitches to remain in the images. Thus, deglitching was ignored.
The main findings are:

1. The use of MADmap on PACS bolometer arrays requires a significant preprocessing for monotonic drift corrections for the individual modules (likely pairs of modules). These drifts are correlated for all pixels of the individual module and are, thus, considered a separate phenomenon from the 1/f drifts. These drifts are likely the biggest obstacle for using MADmap on PACS data.

2. The new invntt files described in RD1 do not lead to the bright point source artifact seen in previous MADmap reductions. Some ideas about the reason for this improvement are provided.

3. The overall median level of individual modules appears to drift and is well-modeled as a linear monotonic change with respect to ad hoc picked “reference” module (in this case #5).

4. The reference module itself also appears to drift. The drift is again linear and monotonic but shows an abrupt jump in level and magnitude during the middle of scan and the cross-scan data. Glitches are ruled out for this abrupt change. The implication is that the remaining modules also experienced similar changes/jumps.

5. The final MADmap still shows some residual 1/f-ish streaks and offsetting scan and cross-scan lines. The reason for the former is likely that another tweak is necessary on the invntt files. The reason for the latter is likely inaccuracies in the best-fit model of the monotonic drifts.

6. Use high-pass filter when possible. The high-pass filter neatly removes the type of drifts seen in PACS data at the cost of flattening/zero-ing out some of the spatial structures at scales comparable to the size of the high-pass filter. For cases when structures at those scales aren’t present (e.g. fields with point- or point-like sources only) or don’t affect the science (e.g. isolating single objects in a complex field), the use of high-pass filter is highly recommended for removing the complex drifts in PACS signals (pending any caveats on photometry of the high-passed sources).

7. Several open questions are asked to better understand this observed drift behavior.

C. Data

To Be Written.
D. Procedure & Discussion

The point of using MADmap for creating the final mosaics is to account for signal drift due to 1/f noise without flattening the signal using a high-pass filter or similar technique. This way, all spatial structures are preserved. However, the MADmap algorithm, and most similar codes, assume and expect that the observed differences between different bolometer detectors is entirely due to the so-called 1/f variation of said detectors. The PACS arrays show a significant (indeed dominant) variation in signal as electronic offsets variation from pixel-to-pixel. This effect must be removed for MADmap to work accurately. The expected processing for the MADmap branch, thus, starts by subtracting an image containing the pixel-to-pixel offsets (with the assumption of constancy in said image). Figure 1 shows the subtracted image.

![Image](image_url)

*Figure 1 The raw signal frame after the offset (pixel-to-pixel) image removal step. While the pixel-to-pixel variation is mitigated, the result shows two modules are systematically at a different signal level than the rest.*

Once the pixel-to-pixel variations are mitigated, a systematic offset is clearly visible between modules 1 and 2 (lower-left corner) and the remaining 6 modules. Further, depending on which offset image is used, different pairs of
modules appear errant, but always in pairs (1&2, 3&4, 5&6, or 7&8). Three different offset images were tried: (i) the median of all frames in the observation, (ii) the median of selected frames showing mostly “sky”, and (iii) a calibration offset image obtained as in RD1 from the long staring 1/f noise investigation observations. In the worst case, two pairs were offset simultaneously. Generally, the pair 1&2 is always systematically off.

Figure 2 shows the result of further investigation where the median level of the module is subtracted from a reference module (in this case #5) and plotted against the readout index. The “spikes” in the data are due to actual variation in the sky signal. The apparent “break” in the trend around index 14800 is the difference between scan and cross-scan readouts that have been merged for this analysis.

As is the case for the pixel-to-pixel variation, the MADmap code will also not handle module-to-module variation, since this amounts to the same effect as the pixel-to-pixel variation. I de-“trended” the data as follows: (i) select only data with median level between +/- 50 counts (see Figure 2) to ignore the variation due to sky brightness. This is not the best, but a practical way to do this in the prototype. (ii) Fit a straight line to the data as a function of the reset index. (iii) Subtract the fit from all pixels of the module.

Figure 3 shows the resulting linear fits to the module drifts. Some fits were pulled one way or another by the larger variations caused by the real sky brightness variation over the scanned region. A better methodology is needed, but the current one is forced in order to illustrate the point. There is no evidence that a higher order model is needed.

Figure 4 shows the resulting frames (same index as the one in Figure 1) after the best-fit signal drift is subtracted from each of the module’s pixels.
Figure 2 The systematic module-to-module drift. The difference is shown in the median level of the module minus the reference module as a function of readout index. The most discrepant modules are 1&2 (shown in reddish tints) but all appear to show some drift in the median level of the frame.
Figure 3 The best-fit linear model to the module-to-module drifts (red line). The left column shows the fits to the scan readouts, the right column the same to the cross-scan readouts.
Figure 4 The frame from Figure 1 after module-to-module correction as described in the text.

After the module-to-module drift correction, the data are such that systematic differences in the median level of the frame are not significant. However, most assuredly, we expect the reference module itself to drift as well. The effect of such a drift produces detector readouts that are systematically offset in signal from the beginning to the end of the scan. This produces essentially the same effect as the pixel-to-pixel variation, and once again, must be removed prior to running MADmap.

Establishing a systematic drift in the signal of the reference module is much more difficult as no “constant” or “relative” comparison data are easily available. Figure 5 shows the median signal of the entire array as a function of the readout. The reader may be able to convince his/herself that a trend exists despite the sources coming on and off the array. To do this more quantitatively, I created 1000 readout wide bins and assumed that the minimum value in these bins corresponds to the few actual “blank” sky measurements. Figure 6 shows these minimum values plotted as a function of the readout index where they are found.
Figure 5 The global median of the image as a function of the readout for the scan and xscan data. Is there a trend downwards in the signal?
The minimum median (as described in the text) plotted versus its readout index. An overall drift in the module level is now more apparent than Figure 5. However, there also appears to be a change in the drift magnitude. Hence, two best-fit lines are shown.

While a linear trend a-la-Figure 2 is expected for the reference module, there is an additional complication in that there are clearly two different trends present in the data. Figure 7 shows a potential “smoking gun” for the scan data. There is a discontinuity in the signal near the index where the magnitude of the drift changes in Figure 6. Not glitches are seen at that location. No similar “smoking gun” is evident in the cross-scan data.
Figure 7 An expanded region of Figure 5, near where the drift shows an abrupt change in magnitude on Figure 6. There is a clear break in the signal marked by the arrow. No glitch events are detected at that location.

1/f removal and MADmap.
Once the drifts are removed, in theory the only drift left in the signal should be due to the 1/f noise. Figure 8 shows the power spectrum of the data cube (averaged for all pixels) after the drifts are accounted for. The shape is clearly 1/f-ish (if not f^-1). Further comparison of this power spectrum is TBW.
Figure 8 The power spectrum of the full data stream after the drift removals (averaged for all pixels). Some structure is expected due to the astrophysical sources (bumps in the middle frequencies?) and from the un-removed glitches (bump at ~1 Hz?).

The data can now be fed to MADmap, and Figure 9 shows the resulting final map. The map is created using the invntt files for each detector as described in RD1; However, it was necessary to scale the first element of the invntt file by factor 1e-4. The first element of the invntt file is correlated with the amount of white noise present in the data (a different report). By scaling it to lower values, one artificially forces MADmap to fit more of the 1/f noise. Empirical experimentation shows that using the files as provided does not improve on the map significantly compared to the ‘naïve’ (projected) map; thus, several scaling factors were tried. A few preliminary conclusions (to be expanded in the next version) are:

- The new invntt files do not leave the bright source artifacts (see Appendix). This is either because significant 1/f spectrum variations exist between bolometer detectors, or that the new invntt files significantly over-estimate the white noise levels.
- There is still significant streaking left in the final map. Further investigations are needed to determine if we are not being more aggressive with 1/f noise removal, or if it is caused by inaccuracies in the best-fit monotonic drifts.
• A more detailed comparison is needed between the power spectrum in Figure 8 and the one used in RD1. It may be necessary to re-derive the invntt files by applying suitable drift corrections first.

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**Figure 9** The final MADmap produced mosaic of the Galactic Field. The remaining cosmetic effects are likely due to non-removal of glitches, bad pixels and inaccuracies in the best-fit drift model.

### E. Open questions.

- What is the origin of module-to-module offset?
- Can we assume the trend to be linear based on detector physics?
- Is the trend always a constant … say after the first cal block the drift w.r.t. the reference module is always the same?
- Is there a Housekeeping parameter that mimics these trends? (Nicolas suggests I_VSS_BU – current on the individual module readouts.)
- Are the new invntt files digging into the 1/f noise correction significantly?
F. Bibliography

| RD1 | PICC-NHSC-TR-020 | PACS InvNtt Calibration Files and Noise Analysis (D. Frayer, author) |

G. Appendix

Some examples of MADmap artifacts, etc.

![MADmap mosaic without drift correction](image)

*Figure 10* MADmap mosaic without drift correction. The checkered pattern is due to offset variations between modules.
Figure 8 MADmap mosaic with the old averaged INVNTT file and no drift correction for the reference module. The bright source artifacts are evident as is a gradient between the bottom and top of the image.