# SMA Technical Memo 169
# Holography Analysis Software - HOLISv2

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## 1. INTRODUCTION

This memo describes HOLISv2, the current version of the SMA holography analysis software HOLIS. HOLISv2 has been extensively used for holographic measurements of the 6-meter diameter antennas of the Submillimeter Array (SMA) and the 12-meter antennas of the Atacama Pathfinder EXperiment (APEX) and the Greenland Telescope (GLT). It incorporates several new features and improvements which were added as needed during the course of its use. For the APEX and GLT work, appropriate modifications were made to the routines, specific to the panel and adjuster lay-outs of these antennas.

The basic structure of the software as incorporated in the core package stays the same, which is described in SMA Technical Memo 117 (*HOLIS*, X. Zhang, 1997). Here, we only present the additional features implemented.

The new features are (1) data regridding (2) enhanced masking (3) phase unwrapping (4) fits for coma and astigmatism (5) planar and flexure panel fits (6) adjustment plots (7) additional plots: radial, radial averages, azimuthal, azimuthal averages (8) complex averaging and differencing of maps and (9) analysis pipe line, each of which is described below.

## 2. DATA REGRIDDING

The current technique of holography measurements at the SMA uses on-the-fly (OTF) mapping and the data are regridded off-line (Sridharan et al., 2002, 2004, 2014). The `regrid` routine produces amplitude and phase measurements on a regular grid centered on the bore-sight position. It computes averages (complex) over bins centered on the grid points whose details are specified in the input parameter file `regrid.prm`. An example parameter file is given below:

```
96 96 53.673 0.009244 17.627 0.009244 0.006 0.006 # 04Jan17 z=72000 pad4
nx ny AzStrt AzStep   ElStrt ElStep   AzBin ElBin comment
```

This parameter file is for generating a 96×96 regular grid data with a starting (AZ, EL) of (53.673, 17.627), azimuth and elevation step sizes of 0.009244 degrees (33.28″) and bin widths 0.006 deg (21.6″ or ± 10.8″) in both az and el. The regrid routine is invoked as:

```
regrid 0208_2234.holo3 regrid_232G_96_a3.prm > rgrd.out
```

which uses the input data file `0208_2234.holo3`, parameter file `regrid_232G_96_a3.prm` and the output is redirected to `rgrd.out`. A temporary output file (`tmp1`) with extensive details of the rebinning is also generated, which can be examined for debugging if there are unusual results. This file is overwritten.

## 3. MASKING ENHANCEMENTS

The previous version HOLIS only allowed minimal masking possibilities. Masking is now handled by the use of a *magic value*: −9999, and is propagated through the various elements of data analysis. All the analysis codes have been modifed to incldue magic value masking - i.e. data values of −9999 are not used in any analysis. This scheme allows arbitrary masking, by the use of a mask file. Masking the blockage due to the subreflector support structure is now available (in addition to the central subreflector blockage and a region outside of a chosen outer edge diameter on the primary which were available in HOLIS), through the specifications in the inversion parameter file `withphase.prm`. It is also now possible to mask out individual panels through the routine `mask_panel`. The `mask_panel` routine is usually run on a phase data file and the name of the panel to be masked is an input, for example a_1, d_3 etc. for the SMA. This is extremely useful in situations where an individual panel is sometimes out of alignment by a significant amount, *e.g.*, due to mechanical problems with an adjuster, and leaving it in the data can affect the large scale fits. Figure 1 shows an example of masking individual panels.

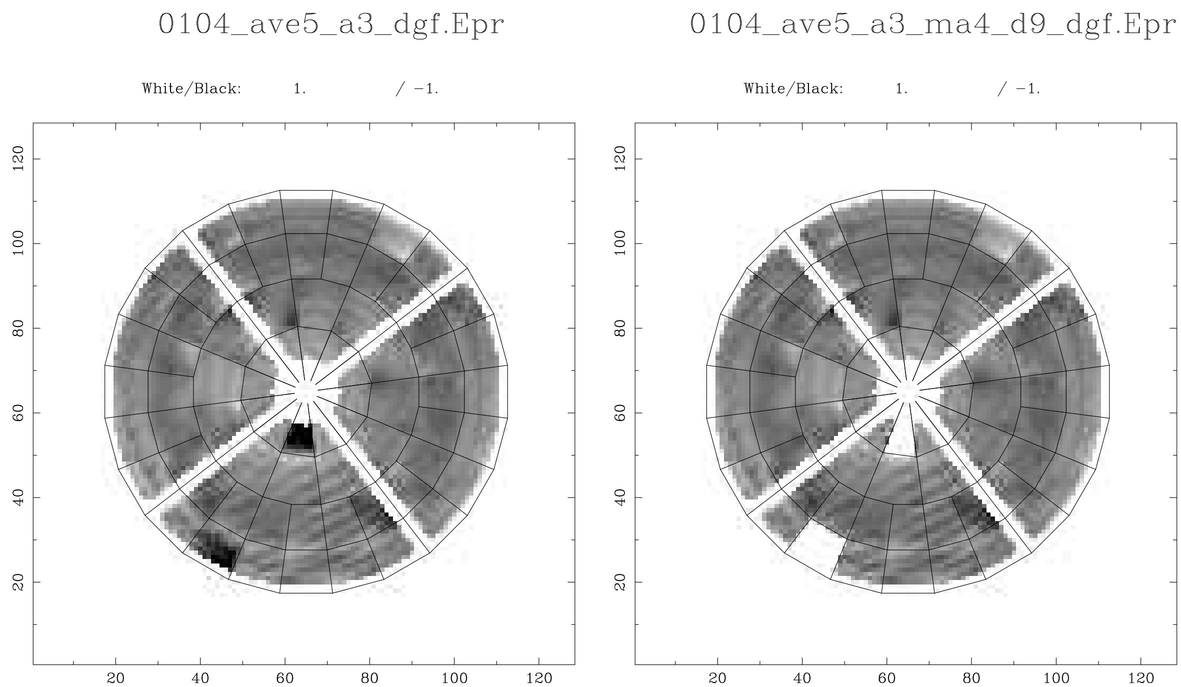


**Figure 1.** Two bad panels, one each in the outer most and the inner most rings, have been masked using `mask_panel`

## 4. UNWRAPPING PHASE

Sometimes, individual panels can have large errors, especially in the intial stages of the holographic measurement/adjustment cycle. In addition, a combination of pointing and focus errors can cause a large phase variation across the aperture. This can be large enough to cause wrapping of the phase when the excusrions are larger than $\pm\pi$ radians. The data are still perfectly usable and the phase needs to be unwrapped before large scale fits can be applied or large panel errors can be correctly rendered. This is done by the routine `unwrap`. There are two versions of this routine, `unwrap` and `int_unwrap`. The routine `unwrap` works in normal situations, when the wrapped regions have simple topology. In more complicated cases `unwrap` is only partially successful and the interactive version `int_unwrap` is used. The wrapping boundary is identified by visual inspection and a correction is applied by clicking on the appropriate boundary pixel. Unwrapping is done on the aperture phase file `Ep.dat`, in the `unwrap/` directory. The unwrapped phase file is copied back to `inversion/` and can be used by choosing the 'use an unwrapped file' option while running `holis`. In this case, `holis` discards the `Ep.dat` generated by Fourier inversion of the beam domain data and instead uses the unwrapped file in its place for further analysis. Unwrapping is done by copying `Ep.dat` to the unwrap directory and running `unwrap` as:

```
unwrap Ep.dat unw Ndim
```

`Ep.dat` is the input file and `unw` is the output file. `unwrap` allows the user to set a threshold for the wrapping step which can be usually chosen to be about 3.5 radians. Trying different numbers here can sometimes unwrap somewhat complicated data thus avoiding interactive unwrapping. Interactive unwrapping is invoked by simply typing `int_unwrap` and answering the ensuing questions. `int_unwrap` uses PGPLOT for displaying the data and for the cursor interactions. Multiple unwraps can be done in a single session. After each mouse click for unwrapping at a point, the data are replotted with new grey scale and further points for unwrap can be located and clicked on. Figure 2 shows an example of the result of `unwrap`.

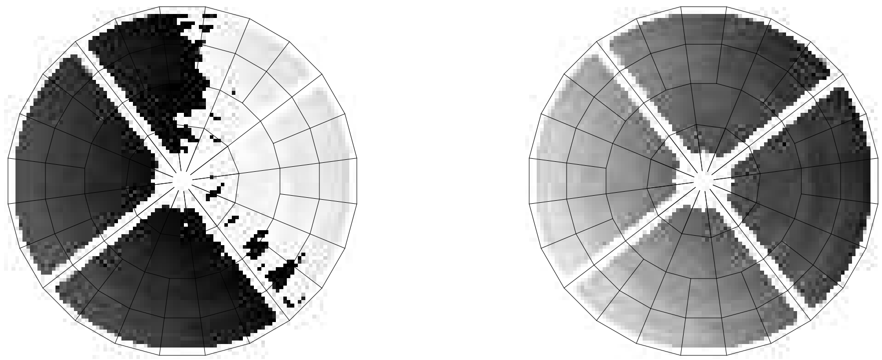

**Figure 2.** Phase wrapping is seen on the left panel. The right panel shows the aperture phase after using `unwrap`, to remove the wrapping.

## 5. FITS FOR COMA AND ASTIGMATISM

The large scale fits now include coma and astigmatism. The coma is fitted as two terms with orthogonal orientations, one along $x$ and another $y$. These are intended to correspond to subreflector positioning errors in $x$ and $y$. The astigmatism is only allowed to have either vertical or horizontal orienation and a single term is fitted for this purpose. Options to fit astigmatism and coma are included in the large scale error fits and the choice is made in `withphase.prm`.

## 6. PLANAR AND FLEXURE PANEL FITS

The panels of the SMA antennas have four adjusters and therefore corrections for flexures are possible, and indeed essential to acheive the 12 $\mu m$ goal. However, it is only possible to correct for certain kinds of flexures. More specifically, saddle like flexures can be corrected whereas flexures with an extremum within the panel cannot be corrected using four adjusters at the four corners of the panels. The default panel fit now corresponds to the four allowed adjustment modes for a panel with four corner adjusters. The four terms are normally called *piston, tiltx (radial), tilty (tangential)* and *torsion* and are represented by the four parameter function $er1 + er2 \times x + er3 \times y + er4 \times y \times x$. Here, the $(x, y)$ co-ordinate system is tied to the centre of an individual panel and is oriented such that $x$ is along the radius increasing outward and $y$ is along the tangential direction. Since the map is in the vertical-horizontal (or elevation-azimuth co-ordiantes) the pixels on an individual panel are first transformed to be on the panel co-ordinate system before a fit is made. It is also possible to obtain full 4 parameter fits or 3 parameter fits (only piston and tilts). The 4 parameter fits can be used where additional adjustments are possible and the 3 parameter fits are applied where only 3 adjusters are available. Figure 3 shows an example where a 4 parameter fit was used to remove flexure. The APEX/GLT versions allow fitting for an additional quadratic pattern as the panels have a central fifth adjuster.

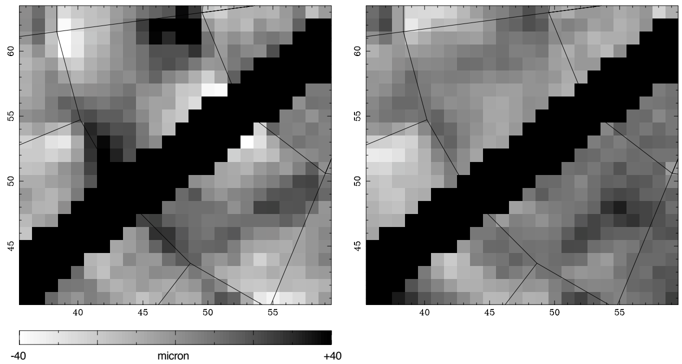


**Figure 3.** A region with two panels showing flexure. The flexures seen on the left were removed using 4 parameter fits to generate adjustments for the adjusters at the 4 corners of the panels (the diagonal band is the masked area due to the subreflector support legs).

## 7. ADJUSTMENT PLOTS

Figure 4 shows an example of the adjustment plot used to carry out the adjustments in the field. Adjustments below a specified limit are not plotted. The routine `plot_cor` produces this plot. It takes as inputs a name for the file containing the correction table and the adjustment limit. The adjustments are plotted as two numbers (turns, degrees), indicating the number of full turns of the adjuster and the number of degrees of arc which add up to the required total adjustment. The sign indicates clock-wise or anti-clockwise rotations.

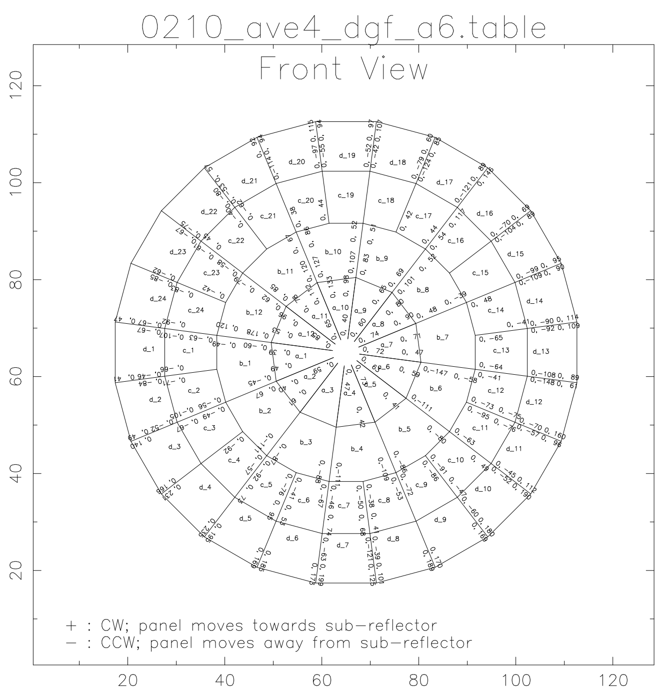


**Figure 4.** An adjustment plot used in the field, generated by `plot_cor`

## 8. ADDITIONAL PLOTS: RADIAL & AZIMUTHAL

To help visualize the data in different ways, the routines `radial` and `azimuthal` produce radial and azimuthal plots of the data. The radial plot is useful in checking edge illumination, for example. The routines `radial_avg` and azimuthal_avg produce radial plot after averaging in azimuth and azimuthal plot after averaging in radius respectively. The necessary inputs are obtained interactively.

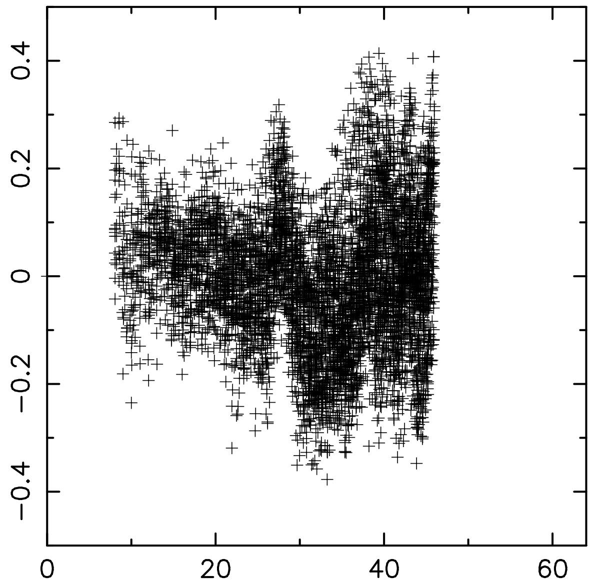


**Figure 5.** A radial aperture phase distribution plot produced using radial. The x-axis is in pixles and the y-axis is in radian.

Figures 5 and 6 show results of radial and radial_avg of the aperture phase and illumination respectively. The averaging routines also generate an output file which can be used to plot the data along with other curves as needed, using gnuplot for example. Figure 6 was producded in this way. Masking is correctly handled by these routines.

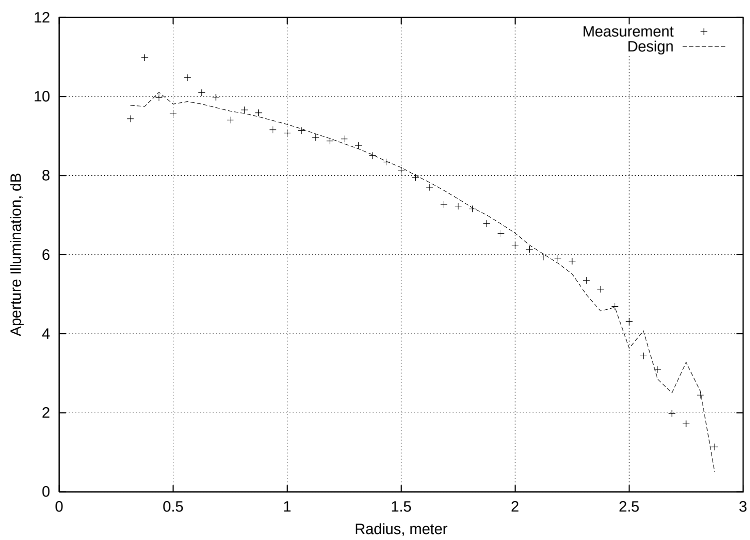


**Figure 6.** An aperture illumination plot for Antenna 8, produced using radial_avg followed by gnuplot

## 9. AVERAGING AND DIFFERENCING MAPS (COMPLEX)

We mitigate the effects of multiple reflections by complex averaging maps obtained with different subreflector positions (spaced $\lambda/8$). This is done by the routine average (this a perl script). The names of the files to be averaged are input without the extensions `Ea` or `Epr`. It uses the amplitude and phase data in the files `name.Ea` and `name.Epr` to generate the complex (vector) average. To calculate the repeatability of two measurements, the routine `rms128` is used which computes the average and difference of two maps and produces the output files `average` and `difference`. Masking is correctly handled by these routines.

## 10. ANALYSIS PIPE LINE

In an attempt to automate the data analysis, a data reduction pipe line has been created. It uses an input parameter file `holo.prm`, an example of which is listed below:

```
2
0504
1454
96
64975
232.4
7.0
```

The lines in the file are antenna number, date, time (used to construct the file name, in this case `0504_1454.holo2`, grid size, subreflector axial (z) position (in counts), frequency and ADC offset. Running `holo.pl` generates a command file (shell) `holo.com` which can, in principle be executed. However, the data analysis almost always needs manual intervention, supervision and judgement. Therefore, usually the commands from `holo.com` are executed by hand one by one, and the results are examined using the plotting routines and gnuplot. Any corrective action needed is taken before progressing with further steps.


**Acknowledgements**

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**References**


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3. Sridharan, T. K., Saito, M., Patel, N. A., Christensen, R., 2004, *Holographic Surface Setting of the Submillimeter Array Antennas, in Astronomical Structures and Mechanisms Technology*, Antebi, J., and Lemke, D., Eds., Proc. SPIE, 5495, 441446
4. Sridharan, T. K., Saito, M., Patel., N. A., 2014, *Holographic Validation Measurements of the SMA Antennas*, in SMA: The First Decade of Discovery