SMA memo # 167

SMA Alignment Optical Insert

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1 Introduction

The Submillimeter Array (SMA) has been operating for more than 15 years. During this time, field maintenance gradually degraded the alignment of optical assemblies that were originally laboratory-aligned, leading to significant pointing offsets. To recover alignment, it was necessary to check the optics cage alignment in all the antennas. This work describes an alignment optical insert which has been built and used to check the azimuth and elevation offsets of the combiner mirror and grid with the optical autocollimation method.

2 Alignment Optical Insert Design

Figure 1 shows a model of the alignment optical insert, which was built from components of the retired high frequency (600 GHz) band SMA optical inserts. Two Raspberry Pi cameras (camera A and camera C) were mounted inside the optical insert with their pointing directions perpendicular to the combiner mirror (45° mirror) and a flat mirror mounted on the back of the grid frame. The distance from camera A to the combiner mirror was 306.3 mm and the distance from camera C to the grid mirror was 452.8 mm. To achieve better spatial resolution, we replaced the original Raspberry Pi camera lenses with 25 mm F/1.2 lenses. Figure 2 shows the front of the cameras with two-dimensional line scales attached for x- and y- direction offset measurement. The line scale had a resolution of 1.0 mm per line. During the alignment calibration procedure (see Section 3), each camera was pointed at a calibration mirror at the exact distance and angle as the combiner (or grid) and a reference image was taken of the line scale at the front of each camera. In the field, the alignment optical insert was installed in different positions in the optics cages and new images (measurement images) were taken of the line scale. By overlaying the measurement images on the reference image, we could determine the linear offsets in both azimuth (x-) and elevation (y-) directions and convert them into sky offsets.

The alignment optical insert was designed and built as a self-contained high-precision device. The overall assembly tolerance was within 1.0 mil (25.4 μm) measured at the four corners of the insert. As shown in figure 3, the cameras were controlled by a Raspberry Pi

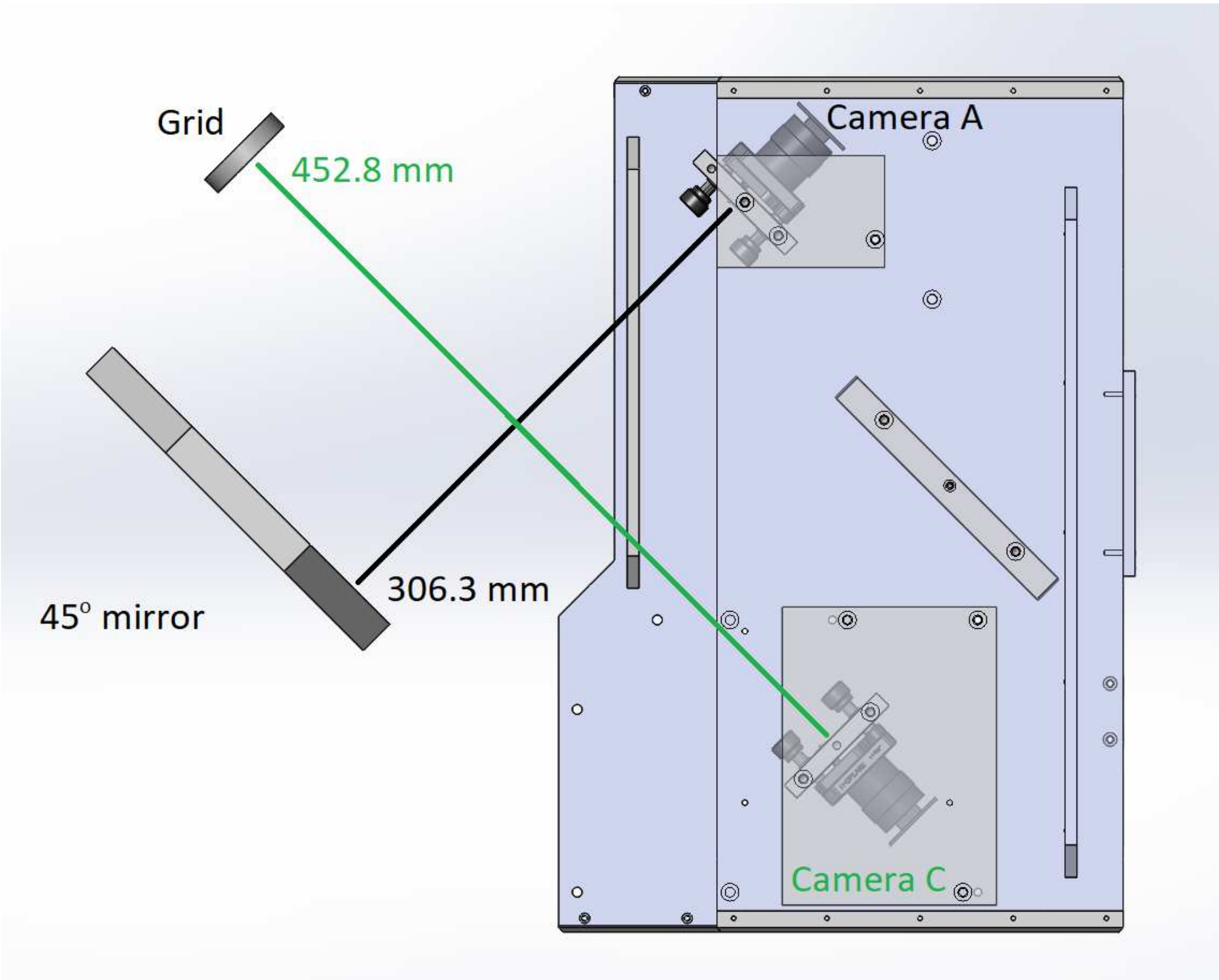

Figure 1: CAD model of alignment optical insert.

Figure 2: Front view of the alignment insert. The resolution of two-dimensional line scales at the front of each camera is 1.0 mm per line.

computer through a multi-camera adapter module. The computer could be operated using a 7 inch touch-screen monitor built into the insert. The computer, monitor and cameras were powered by an external battery pack, which can power the alignment insert for several days after a full charge.

3 Alignment Insert Calibration

The alignment of the optical insert itself was calibrated on a flat granite surface plate, using precision angle blocks and parallels. As shown in figure 4, the clean surface of a 45° angle block was used as a mirror and placed perpendicular to the camera at the exact distances shown in figure 1 to represent the combiner mirror and grid. The cameras took images of the line scale seen through the angle block and saved them as reference images. The tolerance of the calibration was about 0.1 mm linear offset in both x- direction and y- direction, corresponding to an angular offset of about $0.5'$ for the combiner and $0.4'$ for the grid. The calibration was performed in the SMA laboratory in Cambridge and repeated in Hilo to verify that it survived the shipping.

4 Software and Operation

The software is based on the Python package installed in the Raspberry Pi Debian Linux operating system. The images were taken with Raspicam commands "raspistill" and then overlapped over the reference images using the "composite" command from the open-source software ImageMagick. There were two Python scripts named "camera A" and "camera C" saved to the desktop directory. These scripts were written to capture and stack the images automatically. After installing the insert in position, one only need to run these scripts and save the output images.

5 Field Measurement Results

The alignment optical insert took images in the antenna optics cages and overlayed them on the reference images to show the offsets in x- and y- directions. Figure 5 shows an example of an image through the combiner mirror, which has an x- offset = + 2.2 mm and y- offset = - 1.2 mm. Table 1 converts 1.0 mm linear offset to on-sky offset (in arc seconds) for both combiner and grid, using the conversion factor ($12''$ on sky / degree of combiner or grid rotation) from [1]. Based on Table 1, the example shown in figure 5 has sky offsets of + $2.5''$ in x- direction and - $1.3''$ in y- direction, where x- is the θ and y- is the ρ direction of the cryostat, respectively.

The raw images from the pre-correction measurements of all 8 antennas are posted in the SMA log (link). Analysis results are listed here (link) also in this table (link). From this table, most of the y- offsets were within $1''$ on sky (equivalent). For the combiner mirrors, ant1-400, ant3-230, ant4-400, ant6-345, ant7-230, ant8-240 and ant8-345 have y- offsets greater than $1''$. For the wire grids, ant6-230, ant8-240 and ant8-345 have y- offsets greater than $1''$. It appears that antenna 8 240 GHz and 345 GHz have relative large offsets in both

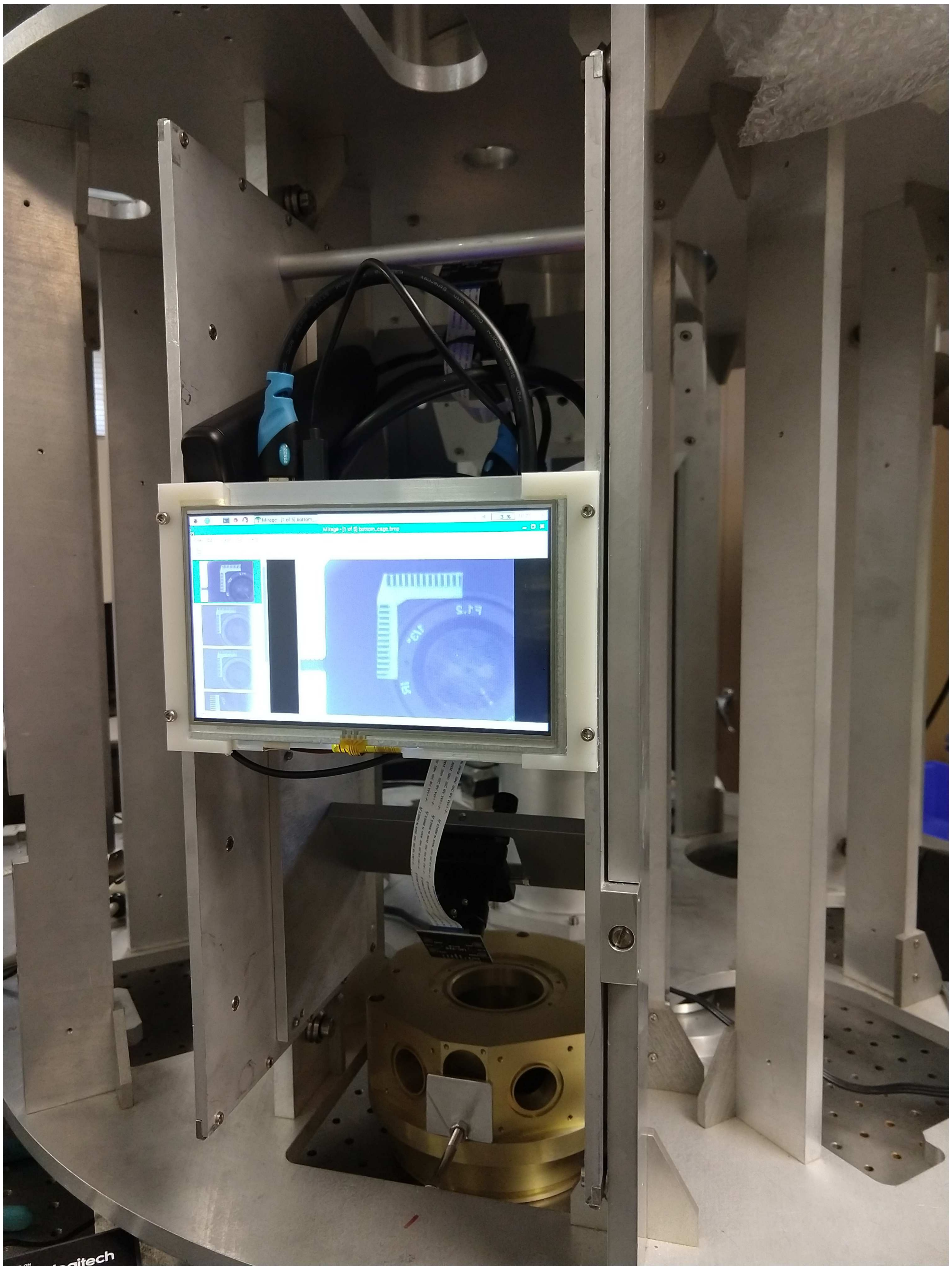

Figure 3: Back view of the alignment insert. The cameras are controlled by a Raspberry Pi computer with a 7 inch touch-screen monitor.

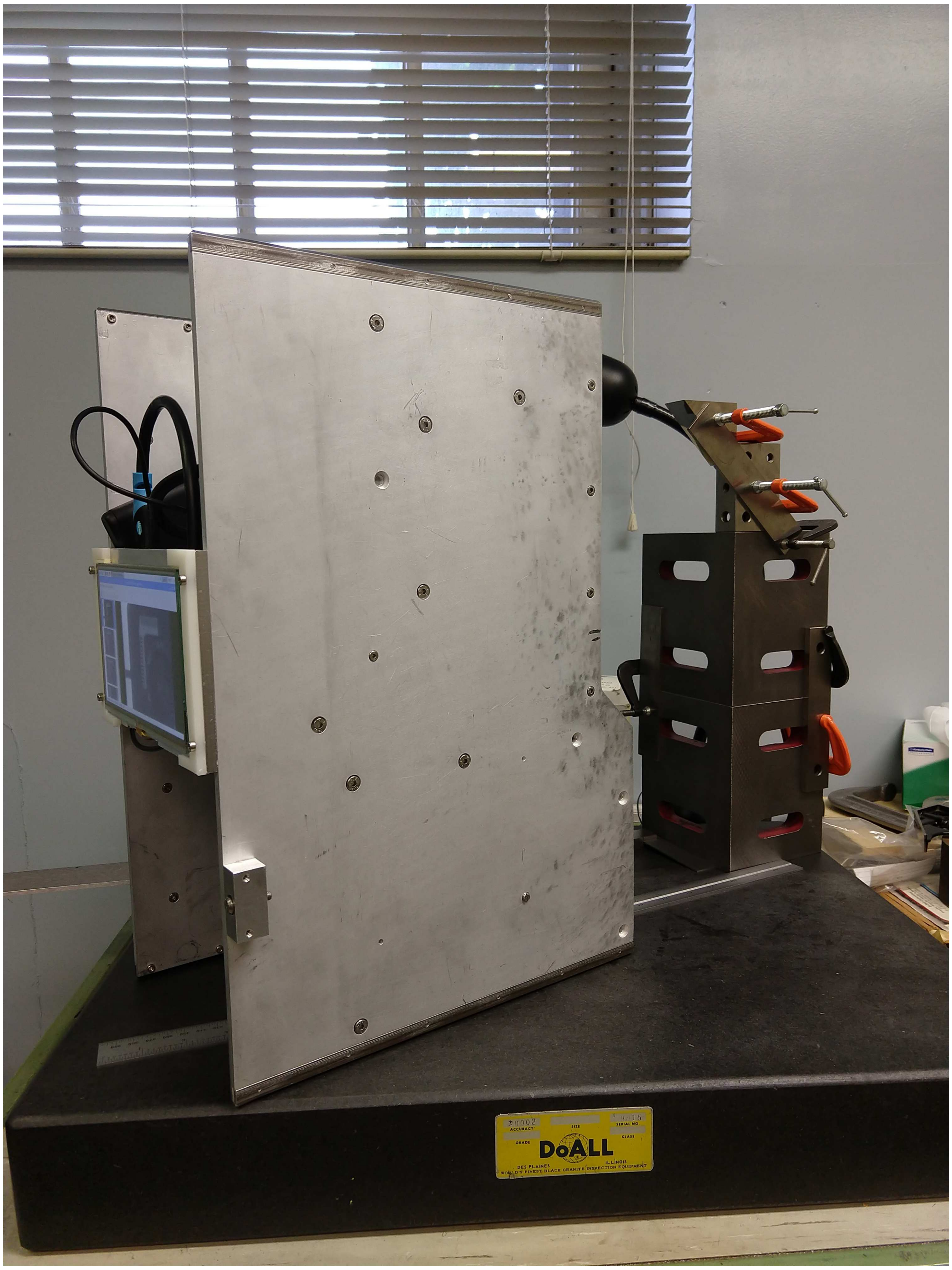

Figure 4: Insert is calibrated on a granite flat surface, using precision angle blocks and gauges.

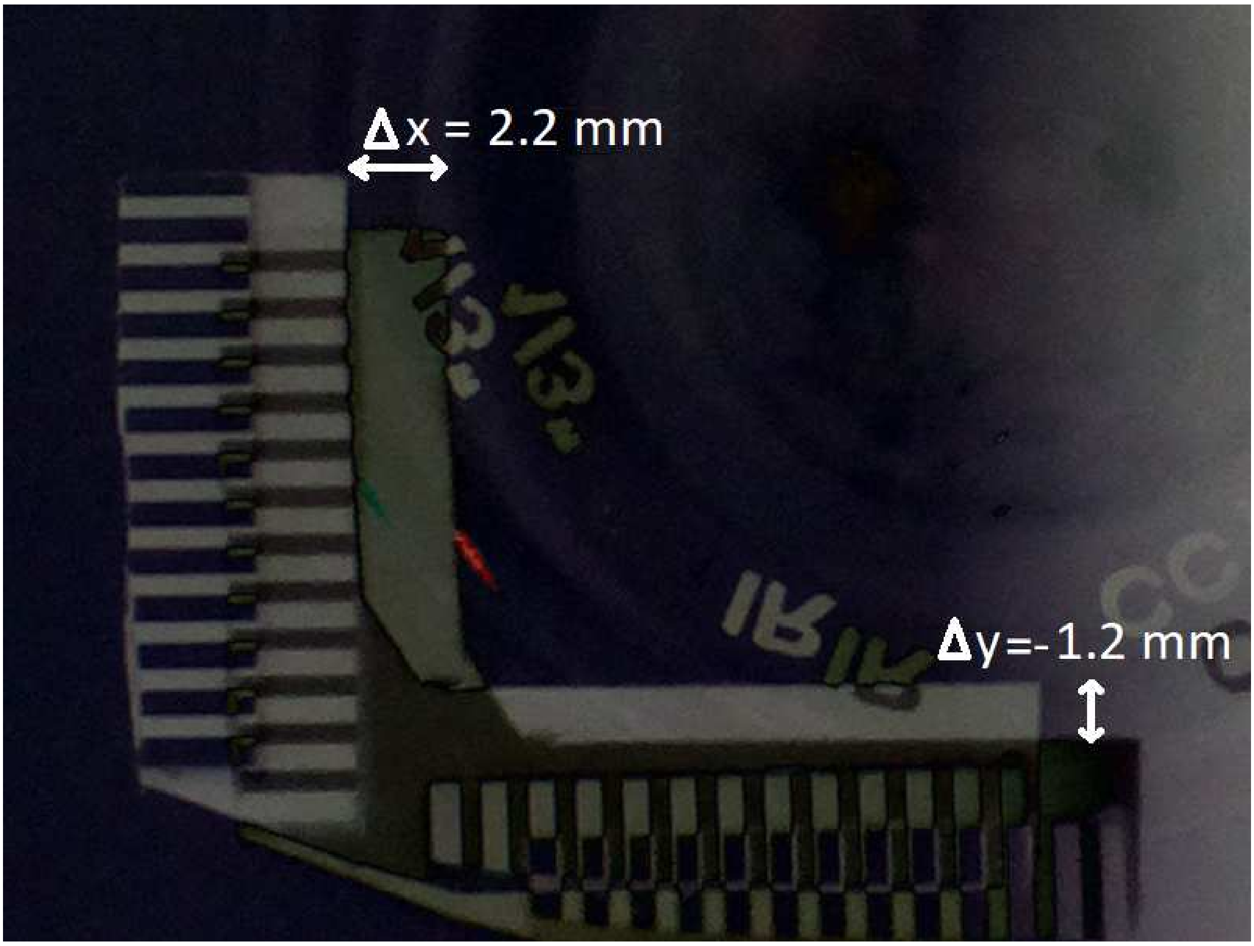

Figure 5: An example showing the offsets in x- any y- directions when overlay the measurement image (transparent) on the reference image (solid white).

Table 1: Conversion of 1.0 mm linear offset to on-sky offset

Autocollimation Target	Round Trip Distance (mm)	Equivalent Angular offset ($^\circ$)	Sky Offset ($''$)
Combiner	612.6	0.094	1.12
Grid	905.6	0.063	0.76

combiner and wire grid. The x- offsets, which depend on correct encoder positions being assigned to each receiver selection position, were typically larger. New nominal positions were calculated based on the x- offsets and the corresponding corrections have been made in SMA configuration data.

References

[1] Paul K. Grimes, Scott N. Paine, Ramprasad Rao, Tirupati K. Sridharan and Lingzhen Zeng, "Tolerancing of the Submillimeter Array Optics using Physical Optics Simulations", *29th IEEE International Symposium on Space THz Technology (ISSTT2018)*, Pasadena, CA, USA, March 26-28, 2018