Improvement of the Polarization Performance of ALMA Band 9

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***Abstract*—In the framework of the project "Study Towards a Producible ALMA2030-Ready Band 9 CCA" funded by ESO, we present the results of the feasibility of improving the beam squint of ALMA Band 9 receivers by adjusting the mechanical alignment of the optical components on an existing Cold Cartridge Assembly.**

***Keywords*— ALMA Band 9, Beam squint, Polarization, Submillimeter astronomy, Grid, Optical analysis.**

I. Introduction

THE ALMA Band 9 (600–720 GHz) receivers are dual channel heterodyne systems capable of detecting orthogonally polarized signals using a grid.

The cross–polar performance of the existing receivers is ~-18 dB and it does not meet the requirements specified for the ALMA channels, i.e. a cross-polar level lower than -23 dB. Moreover, they show a relatively large beam squint, which makes this channel not suitable for extended-source polarimetry. However, polarization in Band 9 is essential to better understand the physics in planet-forming disks and to better constrain the properties of the magnetic fields in very dense molecular environments around evolved stars and high mass star-forming regions [1-2].

In a previous study, we found that the limitation of the current polarimetric performance can be explained by the deviation of the grid mounting angle for the beam squint and by the presence of the grid in combination with mirrors for the cross-polar level [3-4]. For these reasons, one of the goals of our project "Study Towards a Producible ALMA2030-Ready Band 9 CCA" [5] is to reduce the worst-case beam squint by an order of magnitude by shimming the grid, based on measured beam squint data. If this is found sufficient for polarimetric observation, it would be the most cost efficient way to address the issue and it would also avoid the higher loss associated with the use of an orthomode transducer to split the two orthogonal polarizations.

II. Measurement Setup

We constructed a rotating test source to obtain high-quality dual-polarization near-field beam patterns (amplitude and phase). From the near-field scans, we can derive far-field beam patterns, co-alignment of the two orthogonal beams on the sky (beam squint) and the common aperture, polarization and focus efficiencies.

The test setup incorporate several measures and corrections to obtain reliable data:

- phase correction due to electronic, thermal and mechanical drifts during scans based on a center-field phase reference sample before each scan line;
- standing wave compensation by scanning two planes spaced at $\lambda/4$;
- spurious reflections minimization by careful baffling;
- correction for probe misalignment by measuring one polarization at 0° and 180°; the probe offset for the 90° measurement can then be inferred;
- active cable phase correction by measuring the round-trip phase delay of an out-of-band pilot signal (plus phase-stable cables suspended with low-strain).

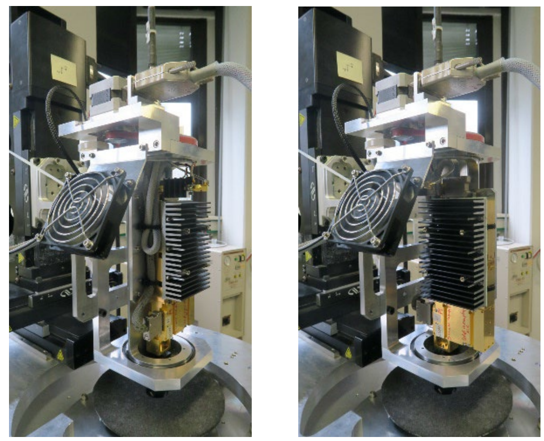

Fig. 1. Rotating test source at 0° (left) and 90° (right).

III. Data Reduction Pipeline

We developed a data analysis pipeline to calculate the beam squint from the measured complex field. We define the beam squint as the distance of the beam pointing relative to the Full-Width Half-Maximum (FWHM) on-sky. This is equivalent to the distance of the foci in the focal plane relative to the FWHM in focal plane. The steps of the analysis are:

1. compute the far field beam pattern from the complex fields measured;
2. consider field truncation at the secondary mirror and amplitude/phase distribution (asymmetry);
3. subtract a spherical phase front with center (x, y, z) from the far field phase over the extent of the secondary mirror;
4. calculate the overlapping integral between the resulting far field and a top hat function with the size of secondary mirror to evaluate aperture efficiency;
5. repeat the process for different (x, y, z) values until a local maximum of the aperture efficiency is found to determine the nominal telescope focus position;
6. find the focus for the two polarizations individually with a gaussian fit.

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IV. Beam Squint Analysis

We measured the beam pattern at 12 frequencies from 620 to 708 GHz at 0°, 90° and 180°. The signal to noise ratio of the measurements is ∼−72 dB. The value of the beam squint calculated from the measurements is shown in Fig. 2, where is compared with the measurements performed on the same CCA in the same way as during Band 9 production phase. Although there are some significant differences, the overall shape and magnitude of the deviations are comparable.

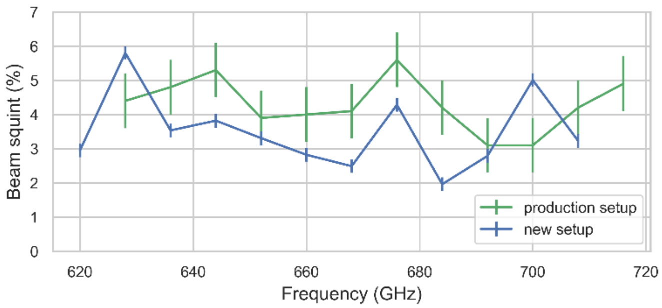

Fig. 2. Beam squint measured and analyzed in the same way as during Band 9 production phase (green) and with the new setup and data reduction (blue).

We notice that the data show rather strong frequency dependence, which suggests that a single correction of the grid is not an option for beam squint mitigation. This effect can be explained by the accuracy of the machined parts, especially the shape of the mirror surfaces. This was verified by means of optical simulation performed with GRASP.

V. Results of Mechanical Alignment

Despite the apparent infeasibility of grid adjustment, we still performed a test of the grid adjustment procedure to perform a proof of concept. We modified the original grid holder brackets with small adjustment screws and removed the original reference surfaces. With this arrangement, the grid can be adjusted over three degrees of freedom: azimuth (angle around vertical axis), inclination (angle around horizontal axis) and offset normal to grid surface.

For the initial reference measurement, the grid was set close to its nominal position as before the modification of the grid holder. After the first run, the beam squint was determined as described in section III. The results are shown in Fig. 3, blue points, where we observed again a large spread over frequency. We decided to correct the squint halfway in the inclination direction. The azimuth angle, and therefore the normal offset, were virtually unchanged. After this adjustment, the beam squint measurements were repeated (red points). For both point clouds the average position and standard deviation were determined (crosses and circles in the figure, respectively). The magnitudes of the beam squints, before and after adjustment, are plotted in Fig. 4 as function of frequency. The results show that the magnitude of the correction is consistent with the amount of correction applied.

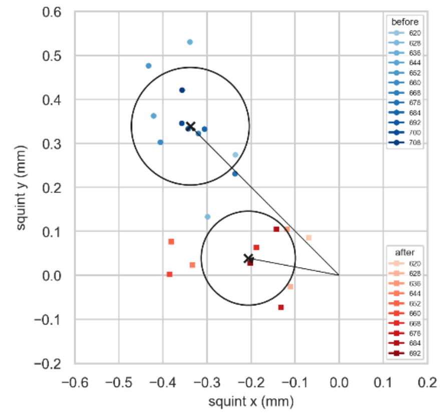

Fig. 3. Beam squint results in the x-y plane before (blue) and after (red) adjusting the grid angle by about half the desired value.

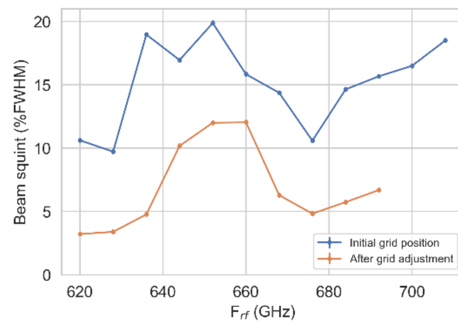

Fig. 4. Magnitudes of the beam squints, before and after adjustment of the grid, as function of frequency.

VI. Conclusion

We conclude that the beam squint can be minimized by grid angles and offset shimming with the limitation that the effect on the pointing angle to the ALMA secondary mirror should be minimized at the same time. Nevertheless, the large frequency dependence of the beam squint probably makes it impossible to do over the full band with the current optics

References

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