Electromagnetic characterisation of direct machined corrugated horn for the ALMA band 10 receiver

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1. Introduction

The Atacama Large Millimeter/submillimeter Array (ALMA) is a major new facility for world astronomy. ALMA will be comprised of a giant array of 12-m submillimetre quality antennas, with baselines of several kilometres. The ALMA project is an international collaboration between Europe, Japan and North America in cooperation with the Republic of Chile, [1]. Band 10 is the highest band of the ALMA interferometer ranging from 787 to 950GHz. The cryogenic receiver, capable of orthogonal polarisation signal detection, is a heterodyne radiometer which employs Superconductor-Insulator-Superconductor (SIS) mixer for direct conversion of the RF signal to the 4-12GHz IF band. The orthogonal signal polarisation detection is achieved by means of a suspended wire grid, which allows simultaneous illumination of the secondary reflector of the orthogonally polarised receiver. The SIS mixer is fed by a corrugated horn coupled to the 12-m antenna by means of a couple of off-axis ellipsoidal mirrors, which design guarantees frequency independent illumination of the sub-reflector.

At such high frequencies, fabrication of corrugated horns is in general obtained by electro-formation process, since the corrugation depths reach dimensions as small as ~10^{-1}mm. In this paper the experimental electromagnetic characterisation of corrugated horns obtained from direct machining procedure is presented. A number of two horns made of copper and gold plated have been fabricated and their electromagnetic beam pattern measured in the near-field zone using a custom made amplitude and phase near-field beam pattern measurement system. Far-field beam patterns are subsequently calculated by Fourier transformation and compared with software far-field simulations of the corrugated horn obtained with commercial mode matching software [2].

2. Corrugated horn design and fabrication

The design of the corrugated horn follows well established methods addressed in [3]. The final horn design is characterised by an aperture diameter of $2a=6mm$ and flare angle of $11°$. The number of corrugations is *134*. Each corrugation, as well as the separation wall, has a thickness of $54\mu m$. The horn throat has a radius of *0.17mm* and the first corrugation is *0.127mm* deeper than the aperture throat radius. The first 4th corrugation depths are then optimized for minimisation of return loss and cross-polarisation. Following a slope of $11°$ the subsequent corrugations reach an inner depth of $83\mu m$ up to the horn aperture, *14.47mm* far from the first corrugation. The horn throat is connected to the $300x150\mu m$ single mode rectangular waveguide through a circular-to-rectangular waveguide transformer obtained with electro-discharging machining technology. In Fig. 1, one of the two horns is shown. A special flat disk perpendicular to the horn axis has been designed for alignment purposes with the optical coupling system.

Figure 1. Prototype of the corrugated horn.

As reported in [4] the corrugated horn is characterised by a high degree of power coupling with a fundamental Gaussian beam up to *98%*. The principal parameters of such Gaussian beam can be retrieved from the horn physical dimensions, aperture radius a and slant length R_h through the following relations [4]:

$$w_0 = \frac{0.644a}{1 + [\pi(0.644a)^2/\lambda R_h]^2}, \quad z = \frac{R_h}{1 + [\lambda R_h/\pi(0.644a)^2]^2}.$$

At $\lambda=0.34mm$ ($f=868GHz$), $w0=0.81mm$ and the location of the waist behind the horn aperture plane $z=12.94mm$. These parameters are fundamental for the Gaussian optics design of the tertiary optics coupling the mixer feed horn with the 12-m Cassegrain antenna.

3. Near-field measurement set-up

In order to characterise the electromagnetic properties of band 10 corrugated horn and further optics developments, a customised near-field amplitude and phase beam pattern measurement system has been assembled according to [5]. The frequency coverage of the system is limited to *843-892GHz*, due to the detector diode bandwidth. Dynamic range of more than *60 dB* is generally achieved, which make possible measurements of low level beam features. The issue of standing wave phenomena that occurs between the antenna under test and the transmitter open-ended-waveguide has been minimised by using sub-mm electromagnetic absorbers. Furthermore the common practice of measuring the beam pattern at two planes at a $\lambda/4$ separation distance normal to the scanning plane is also applied in order to reconstruct the measured beam envelope unaffected by standing waves. Typical intensity and phase variations are estimated as *0.01dB* and *1.07°* respectively on a time scale of *2* minutes. The long-term amplitude and phase fluctuations are corrected by calibration at the centre of the raster scan every time one scanned line is accomplished.

In addition alignment procedures by means of dedicated devices involving a laser distance sensor and theodolite autocollimation have been developed for accurate positioning repeatability of measurements. For instance the open-ended-rectangular waveguide probe located on a high-precision XYZ-Θ stage ($4\mu m$ step resolution), can scan a planar area which can be put parallel and centred with the horn aperture plane centre within a linear accuracy of $\pm 100\mu m$ and planarity of $\pm 0.01°$. Rotation Θ around the Z axis by *90°* allows one to measure the cross-polar pattern of the antenna under test.

4. Experimental results

Two horn prototypes (here named KA and KB) were fabricated and tested. The near-field beam pattern intensity of co-polar and cross-polar components are shown in Fig. 2 and 3 for KA and KB respectively. The measurement plane was at *24mm* from the horn aperture plane. Fitting a Gaussian beam to the near field data of KA co-polar pattern gives a *98.5%* of power coupling with a astigmatic Gaussian of $w_{0x}=0.77mm$ and $w_{0y}=0.81mm$ located *12.4mm* inside the horn aperture.

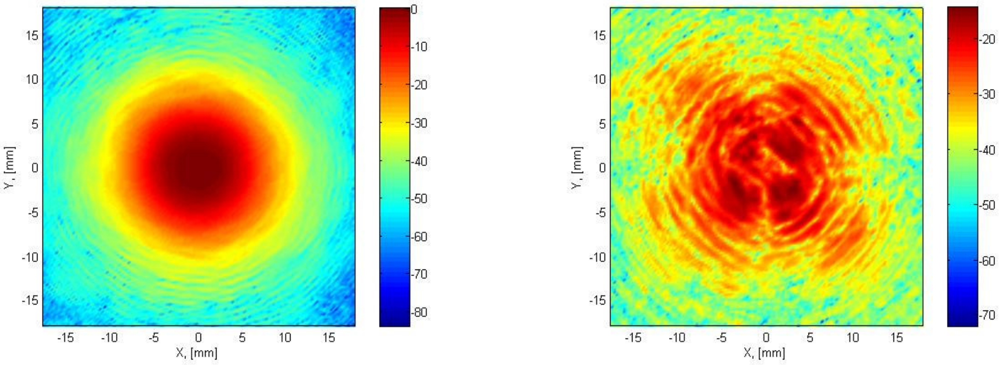


Figure 2. Near field intensity pattern of the KA horn at 868GHz. Cross-polar level -14.6dB.

For the co-polar pattern of KB, similarly the best Gaussian fit has a *97.6%* of power coupling with waist size $w_{0x}=0.78mm$ and $w_{0y}=0.79mm$ located at *12.5mm* behind the horn aperture. High levels of the cross-polar are observed for both horns under test.

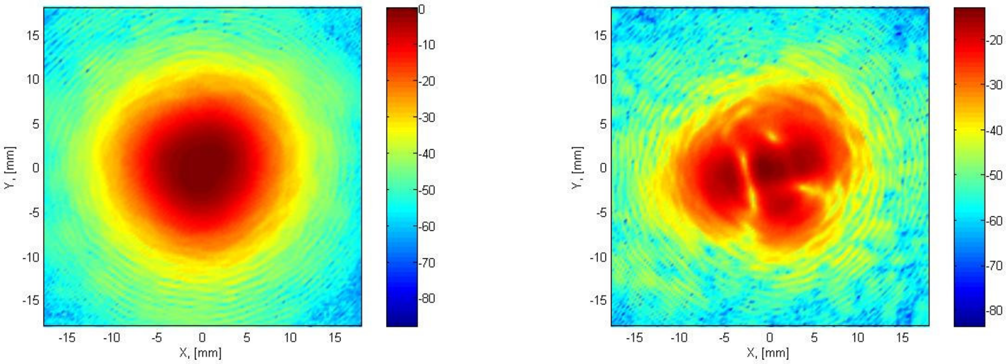


Figure 3. Near field intensity pattern of the KB horn at 868GHz. Cross-polar level -13.2dB.

5. Far Field beam pattern

The measured co-polar and cross-polar near-field beam patterns were then used to obtain the far-field beam distribution of the two horns. The E-plane and H-plane cuts are shown in Fig. 4 and 5 for the near-fields shown in Fig. 2 and 3 respectively. The obtained far-fields are then compared with the mode matching software results. The far-field beam patterns are in good agreement for the co-polar component down to *-30dB*, but the same cannot be said for the cross-polar component.

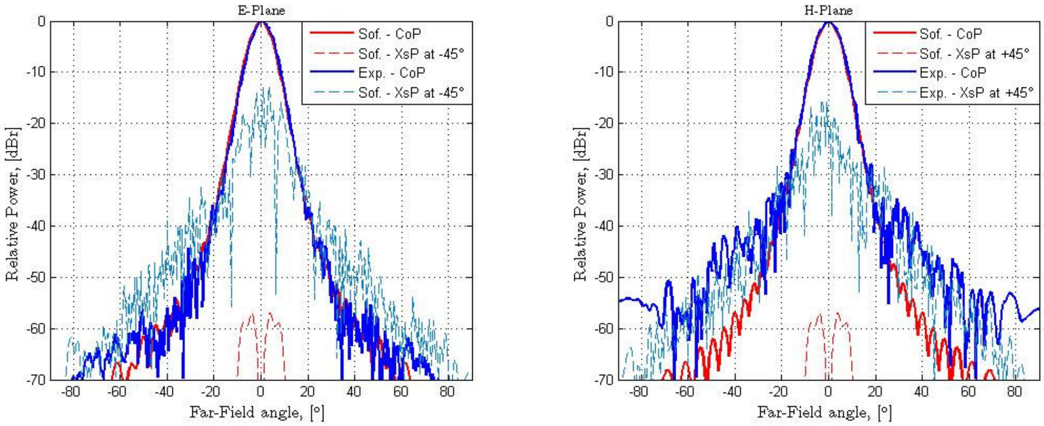


Figure 4. E-Plane and H-Plane far field intensity pattern of the KA horn at 868GHz.

Although the theoretical cross-polarisation is very low to be achieved in practice, it is also clear that the measured cross-polarisation is too high for a corrugated horn type, usually 30dB below the co-polar peak. In the next session pictures of corrugation irregularities are shown being the main cause of such high levels of cross-polarisation.

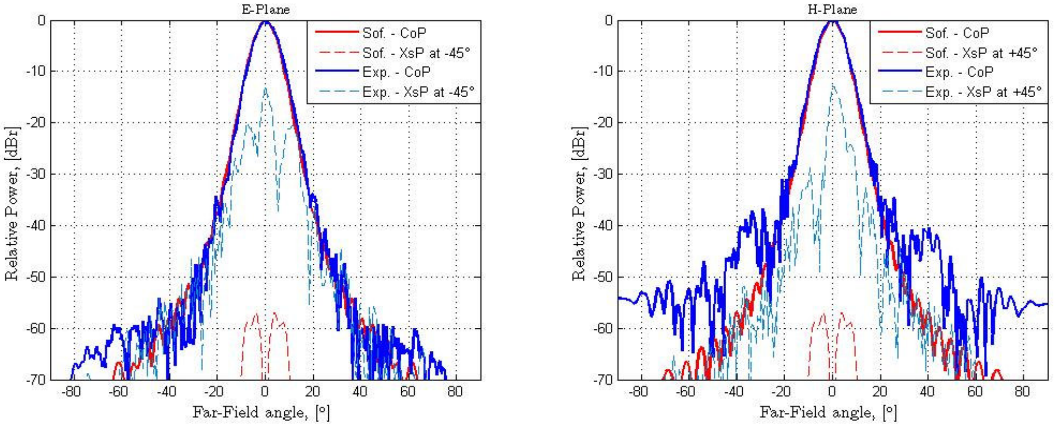
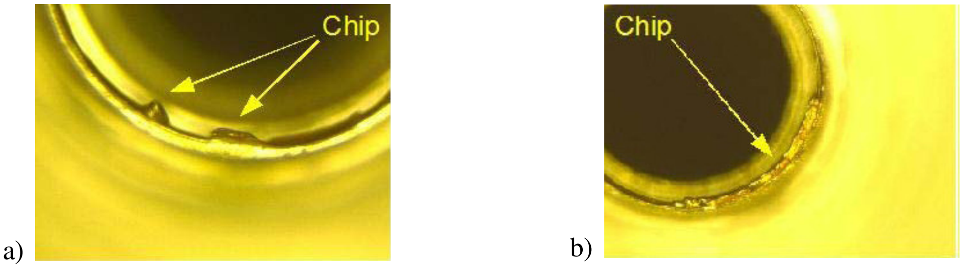


Figure 5. E-Plane and H-Plane far field intensity pattern of the KB horn at 868GHz.

6. Corrugation damage

Detailed pictures taken with a microscope of the first corrugations at the horn input section are shown in Fig. 6 for the KA and KB horn. It is shown that chips are formed during the machining of the corrugations with the spinning tool. The bigger the chips and the closer they are at the horn input section the higher the content of high order modes that are getting excited increasing the level of cross-polarisation.



a)

b)

Figure 6. Corrugation damage caused by milling chip formations. a) is KA, b) is KB.

7. Conclusions

A direct machined corrugated horn for the frequencies of 787-950GHz has been realised and tested at 868GHz. Near field measurements have been used to directly compute the far field pattern. Good agreement with theory is shown for the co-polar field, but high deterioration of the cross-polar is believed being related to milling damage of the corrugations close to the horn throat. In order to achieve cross-polarisation levels close to -28dB measured for a similar horn but electro-formed made, improvements of the direct machining technique must be attained.

References

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