Effects of cryostat infrared filters on the performance of ALMA band 1 (35-52 GHz) receiver optics

A. Gonzalez, S. Asayama
National Astronomical Observatory of Japan (NAOJ)
Mitaka, Tokyo, Japan
Alvaro.Gonzalez@nao.ac.jp, shinichiro.asayama@nao.ac.jp

V. Tapia, R. Finger, D. Monasterio, N. Reyes
Universidad de Chile (UdC)
Santiago, Chile
valeria.tapia@raig.uchile.cl, rfinger@das.uchile.cl, dmonaste@ing.uchile.cl, nireyes@u.uchile.cl

***Abstract*— The ALMA telescope is one of the largest on-ground astronomical projects in the world. It will perform astronomical observations in all the atmospheric windows from 35 to 950 GHz when completed. The ALMA band 1 (35-52 GHz) receiver is in an advanced development state and production may start soon. As for other bands, the receiver is enclosed in a cryostat, where electronics are cooled down for minimum noise temperature operation. However, in the case of band 1, components are large in comparison with cryostat dimensions and aperture sizes. This makes that the best receiver optics designs have the corrugated feed horn very close to the cryostat infrared (IR) filters. This paper discusses the effects of the IR filters on the performance of the ALMA band 1 receiver optics.**

Keywords—ALMA, radio astronomy receivers, lens optics, mutual coupling

I. INTRODUCTION

The Atacama Large Millimeter-submillimeter Array (ALMA) [1] is currently the largest operative radio astronomical observatory on ground. It has been built as a collaboration between Europe, North America, East Asia and Chile. The telescope is composed of 66 12-m and 7-m diameter antennas located at 5000 m altitude in the Atacama Desert, Northern Chile. It covers all atmospheric windows from 35 to 950 GHz. Such a large frequency range has been divided into 10 different bands for practical implementation, of which band 1 (35-50 GHz) is the lowest frequency band. Each antenna is equipped with a large cryostat which will house one cartridge receiver for each of the 10 bands and will cool them down to cryogenic temperatures for maximum sensitivity operation. The incoming beam from the large reflector antenna goes through the apertures in the cryostat before reaching the receiver optics. In the case of band 1, components are relatively large in comparison with cryostat apertures and distances. This makes that the beam potentially suffers from truncation, and at the same time, makes that the feed horn is close to the infrared (IR) filters which cover the cryostat inner apertures. IR filters have been reported to cause performance degradations for other ALMA receivers. In particular, they degrade the polarization efficiency performance of the ALMA band 4 receiver optics at certain frequencies. This effect was identified as the impedance loading effect of the IR filters on the feed horn aperture currents [2]. This paper describes similar effects for the case of the ALMA band 1 receiver optics, together with some other effects which are new for this optics and which are reported for the first time within the scope of ALMA, and probably, of radio astronomy. In particular, in the case of band 1, the effects on aperture efficiency are noticeable, and the impedance coupling is not only due to the dielectric layer in the IR filters, but also due to the metallic support structures of those dielectrics.

II. ALMA BAND 1 RECEIVER OPTICS

The ALMA band 1 receiver is currently in the latest stages of prototyping. The final receiver optics design has been described in [3], whereas the measured performance has been recently reported in [4]. Basically, the optics consists of a profiled corrugated feed horn attached to the receiver cartridge, and a modified Fresnel dielectric lens mounted on top of the cryostat, which refocuses the fields coming from the secondary mirror of the ALMA antennas onto the feed horn. In order to avoid truncation in the 15K filter aperture, the feed horn must be placed as close as possible to the 15K dielectric, which is just a 3-mm thick layer of Goretex. Fig.1 shows the schematic of the ALMA band 1 optics, together with the two IR filters.

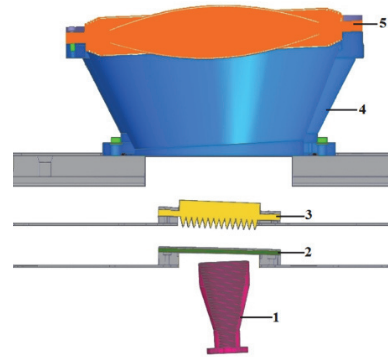

Fig. 1. Schematic of ALMA band 1 optics. The horn and lens are tilted to point at the center of the ALMA antenna secondary mirror. 1: Spline profile horn antenna, 2: 15 K infrared filter, 3: 110 K infrared filter, 4: lens holder, 5: One-zone modified Fresnel lens.

III. EFFECTS OF IR FILTERS

A. Theory

As explained in [2], when the IR filters are close to the feed horn aperture, these can effectively change the impedance seen by the horn, which produces changes in the horn co- and cross-polar radiation patterns. The impedance seen from the horn aperture will depend on the position and materials of the filters, their tilt angles, and even the distribution of magnetic and electric currents on them. In addition, this impedance will change much with small changes in any of those parameters. In the case of band 1, the situation is even more complex, due to the existence of truncation at the IR filters and lens rims. The truncated fields will generate currents on the metallic IR filter support structures, which will further load the horn aperture. Some basic equations describing the dependence of received fields on these phenomena are presented in [2]. However, in practice, the situation is too complex and must be studied by full-wave electromagnetic simulations.

B. *Study of the feed horn characteristics*

HFSS has been used to simulate the effect of IR filters on the feed horn. In the case of ALMA band 1, the horn is electrically compact thanks to its optimized profile, and IR filters are very close to it. All this allows the simulation of the geometry by the method of finite elements. Results of simulations are shown in Fig. 2. The effect of rims and dielectrics on directivity and maximum cross-polarization is clear.

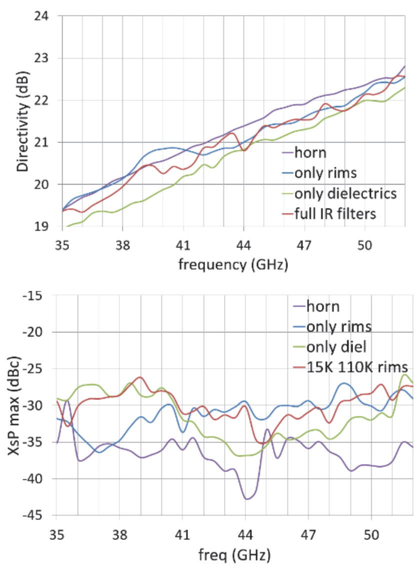

Fig. 2. Directivity and maximum XsP of the equivalent feed horn resulting of different combinations of corrugated horn and IR filters and their rims

C. *Effects on aperture and polarization efficiencies*

In order to assess the effects of IR filters on aperture and polarization efficiencies, for which there are specifications defined, the lens and its holder must be included in the simulations. However, this is not practical in HFSS, since the number of mesh elements would be too large. It could be modeled using the integral equation extension implemented in HFSS-IE, but in that case, the effects of reflections in the lens and impedance couplings would not be considered. An alternative which has been considered is the use of the hybrid mode-matching/ body-of-revolution (BOR) method of moments implemented in the commercial software WaspNet. This analysis techniques is relatively fast even for the whole optical system. The disadvantage is that the BOR geometry does not allow to consider tilt angles and offsets in the IR filters. However, important qualitative results can be obtained from this analysis. Fig. 3 shows the schematic of the simulation of the BOR model of ALMA band 1 optics. Fig. 4 shows the efficiency analysis of the performed simulations. IR filter components introduce ripples in both efficiencies, which are especially visible in the full optics aperture efficiency. As opposed to the case of the band 4 optics, large degradations in polarization efficiency are not expected. In addition, an important result is that the net effect of the filters is a reduction of the average aperture efficiency. In other words, the change in beam shape and width due to the IR filters causes that the lens cannot refocus the fields onto the sub-reflector as designed.

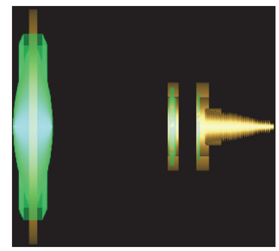

Fig. 3. WaspNET schematic for the simulation of ALMA band 1 optics including BOR IR filters

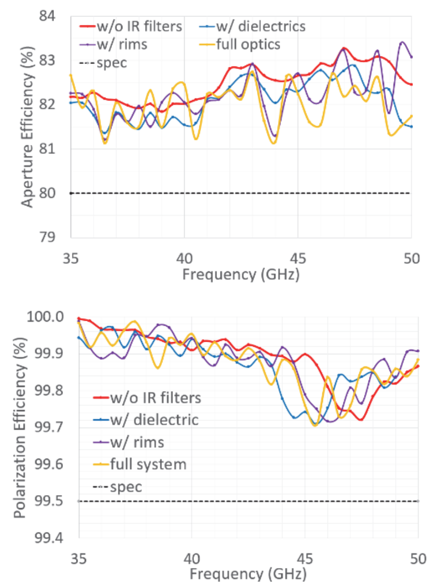

Fig. 4. Aperture and polarization efficiencies for ALMA band 1 optics with and without IR filters

Some tolerance analyses have revealed that changes in distances between IR filters changes the positions of ripples, but in general, results are qualitatively similar.

Finally, measurements performed with prototype components have shown the expected degradation of performance and validated this analysis.

References

[1] ALMA Observatory: www.almaobservatory.org

[2] A. Gonzalez, Y. Uzawa, "Investigation on ALMA Band-4 Frequency-Dependent Cross-Polarization", IEEE Trans Terahertz Science and Technology, Vol. 4, Issue 2, pp.184-192, March 2014

[3] A. Gonzalez, *et al.*, "Alternative optics design for the ALMA band 1 receiver (35–52 GHz)," in European Conference on Antennas and Propagation (EuCAP), 2015, pp. 1 – 4

[4] V. Tapia, A. Gonzalez, et al., "ALMA Band-1 optics (35-52 GHz): design, implementation and measurement results", unpublished