Characterization of ALMA Calibration Targets

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***Abstract*—This paper describes active and radiometric reflection measurements of blackbody calibration targets for ALMA.**

I. Introduction

The Atacama Large Millimeter Array (ALMA) has the challenging goal to achieve an absolute radiometric accuracy better than 5% at frequencies between 30 - 950 GHz. For the calibration of the receivers ambient and hot blackbody calibration target will be used, which can be inserted in the optical path using a robotic arm (Fig. 1). These targets need to have a high emissivity, which is equivalent to a low value of integrated scattering into all possible directions. Even more critical is the coherent backscatter of the target, since it will lead to frequency dependent standing waves between the target and the receiver. In addition the targets have to be held at a uniform temperature to ensure that the surface brightness temperature corresponds to the reading of the thermometers in their body.

The ALMA specifications for the calibration targets [1] require an emissivity >99.8% and temperature gradients below ±0.5K (ambient) and ±1K (hot target at 70°C). The required accuracy for the effective brightness temperature of the targets is specified with ±0.3K and ±0.5K for ambient and hot, respectively.

In this paper we present detailed active backscatter measurements between 30-700GHz of different target prototypes, passive radiometric measurements of their integrated scattering, and thermal IR images of the temperature gradients of a prototype of the hot target. The complete test series is described in more details in [2].

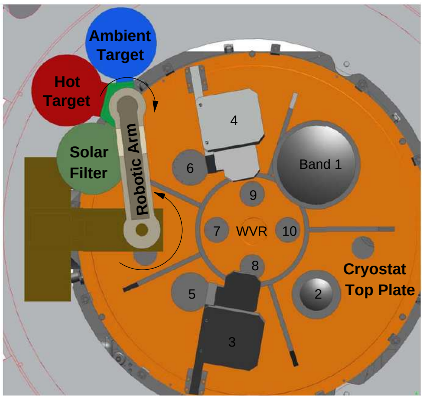

Fig. 1. Schematic design of the ALMA calibration unit.

TABLE I

TARGET PROTOTYPES.

Pyramids (RAL)	Array of Aluminum pyramids (10×10×40mm) covered with 0.7mm casted Eccosorb MF114 absorber.
Tiles (TK)	Carbon loaded polypropylene absorber with 10mm thickness and pyramidal surface (4×4×6mm).
Cone (TK)	Conical target with 0.14m aperture, 0.5m length and 10mm thickness made of carbon loaded polypropylene absorber.

Table I shows the target prototypes that were used for the comparison. Only the pyramidal design with a relative thin layer of epoxy based absorber on a metal backing is suitable for the hot target. The other two are made of a thermoplastic absorber with a low thermal conductivity, which makes it more difficult to heat them uniformly to an elevated temperature. Their main advantage is that they can be mass produced by injection molding, which could make them a cost efficient solution for the ambient target.

II. Active Backscatter Measurements

The coherent backscatter at the target results in a standing wave to the receiver, which should be as small as possible for spectroscopic observations. We measured this backscatter performance of the prototypes using an AB-Millimetre vector network analyzer and a quasi-optical reflectometer (Fig. 2). Since the results depend also on the beam parameters of the test setup we used similar beam waists and target distances as in the ALMA optics. For Band 1 and 2 prototypes of the ALMA feeds and lenses were used together with directional waveguide couplers (Fig. 3).

The targets under test were mounted on a translation and rotation stage to allow a sliding load calibration and measurements at different angles of incidence. The axial translation of the target under test leads to a phase change of the reflected signal, whereas the phase of the spurious signals, e.g. from the crosstalk in the directional coupler, remains constant. As a result the data points move on a circle in the complex measurement plane (Fig 4). Fitting the radius and the offset of this circle allows to determine the target reflectivity and the directivity of the setup, respectively.

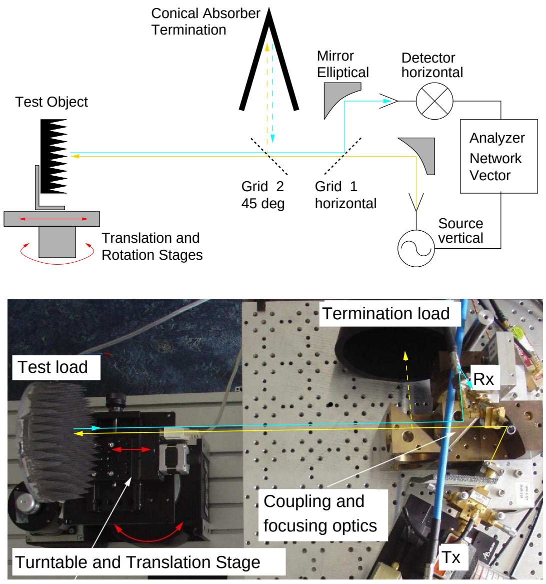

Fig. 2. S11 test setup for Band 6 (211–275GHz) using a quasi-optical reflectometer setup.

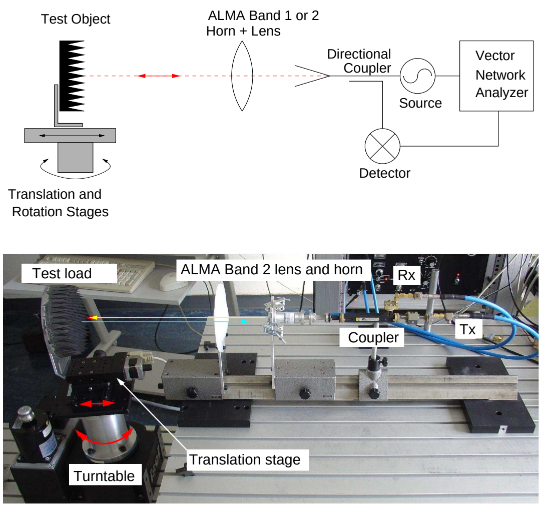

Fig. 3. S11 test setup for Band 2 (67–90GHz) using a wwaveguidecoupler and the actual ALMA lens antenna.

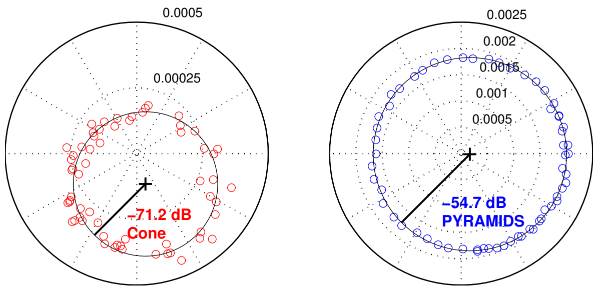

Fig. 4. Measurement examples of the conical (left) and the pyramidal target (right) in polar coordinates recorded during an axial $\lambda/2$ shift.

The periodic surface of the pyramidal targets acts as a diffraction grating and causes an angular dependence of the backscatter signal. For that reason the measurements were repeated with varying angles of incidence. Figure 5 gives examples for such angular resolved measurements for a few spot frequencies. The worst case values over the complete frequency range of the test series are shown in figure 6.

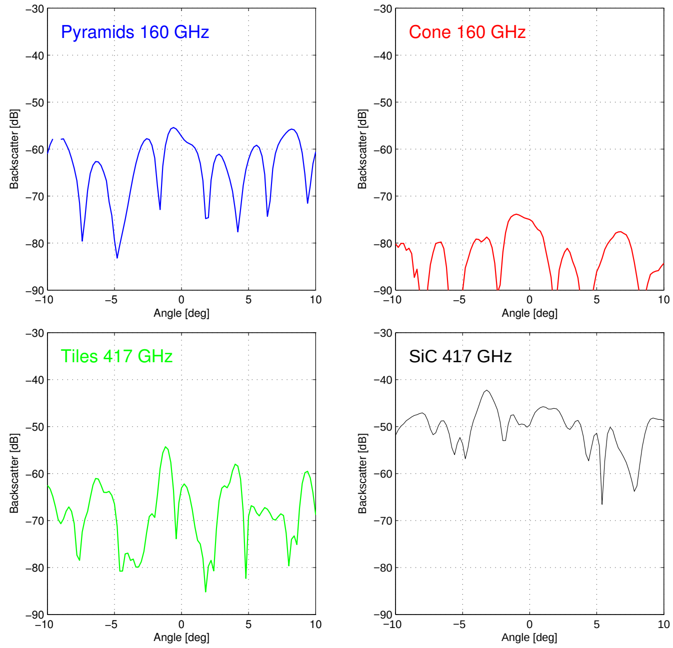

Fig. 5. Calibrated S11 results for different incidence angles with distinct Bragg reflections for the pyramidal and TK-RAM targets. The plot labeled SiC is a sample with the Stycast/SiC absorber coating used in ttheHIFI instrument, which acts as an almost isotropic scatterer.

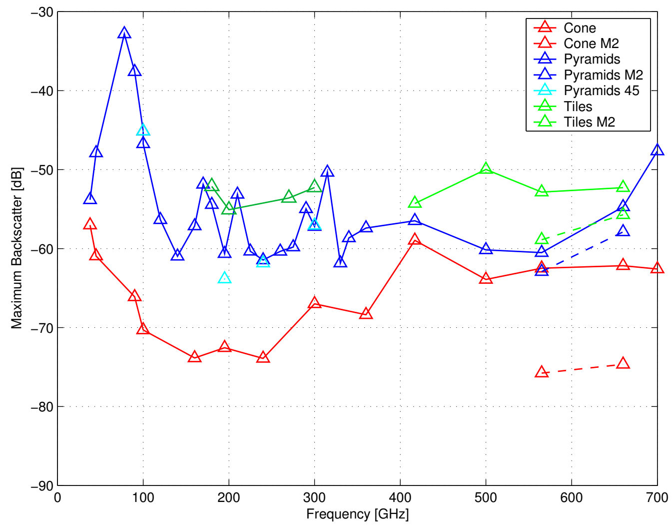

Fig. 6. Summary of the active backscatter measurements between 30 and 700GHz.

III. Radiometric Tests

The integrated scattering of the targets is always significantly higher than their coherent backscatter, but this parameter cannot be measured easily with active reflection measurements. For that reason we performed radiometric tests with a 90GHz and a 323 GHz SIS receiver which were available at IRAM. In our test setup a chopper wheel switches at about 80Hz between two ambient temperature targets, and the modulation on the IF signal is analyzed with a power detector and a Lock-In amplifier. The target under test is mounted in a metal enclosure above an extended LN2 background target, which can be covered by a another ambient temperature absorber (Fig. 7). When this ambient background is removed, almost the complete field of view of the target under tests becomes exposed to the cold background signal. The background signal reflected at the reference target remains unchanged. For that reason any change of the Lock-In signal corresponds to the integrated scattering of the target under test. To normalize the results an additional measurement has been made in the same setup where the target under test is replaced by a 45 degree reflector pointing to the cold background.

The normalized results in Fig. 8 indicate at 90GHz emissivities of the different targets between 0.997 and 0.999. At 323GHz the pyramidal and the tile target show an emissivity of about 0.9994, whereas the conical target is better than 0.9999.

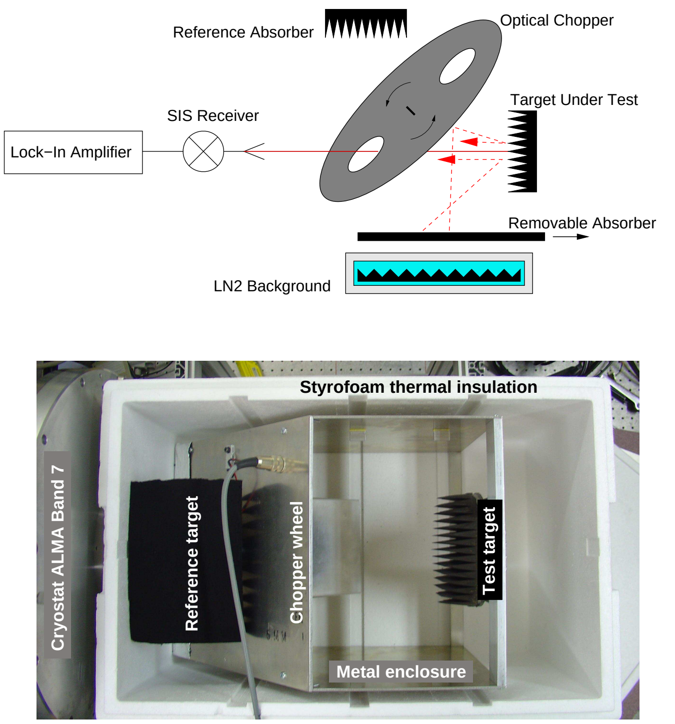

Fig. 7. Measurement setup for the radiometric tests with an ALMA Band 6 receiver at IRAM.

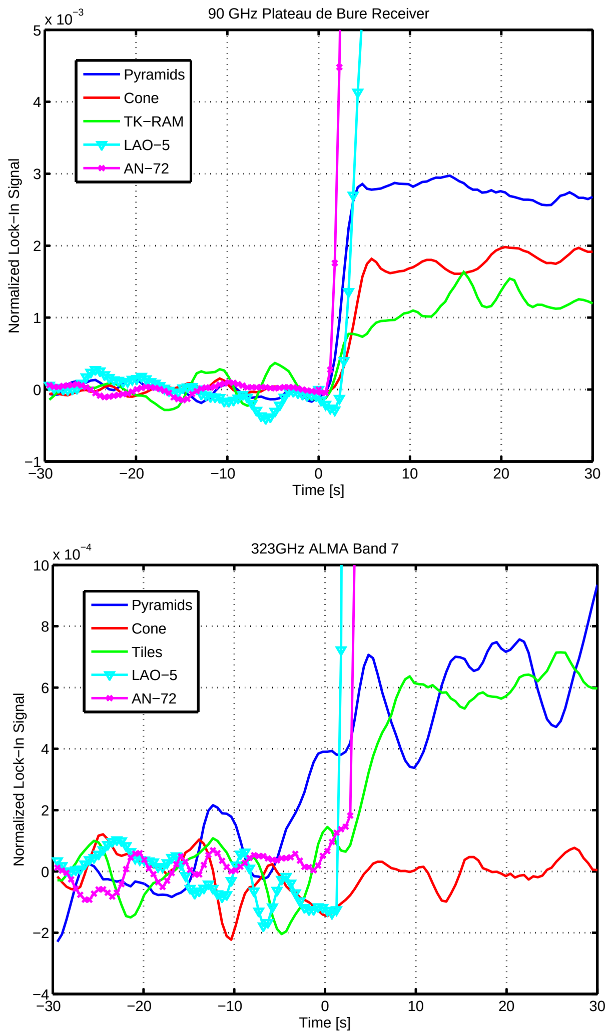

Fig. 8. Normalized results or the radiometric tests. LAO-5 and AN-72 are flat foam absorbers, which resulted in reflections between 0.5 and 4%, respectively.

IV. Thermal Gradients

Thermal gradients within the target lead to a difference between its effective brightness temperature and the readout of the temperature sensors. This effect is difficult correct because it depends on the changing environmental conditions and the orientation of target. We used an IR camera to measure the gradients of the surface temperature of the hot pyramidal target. Figure 9 shows that the tips of the pyramids are significantly colder than their base. These gradients depend on the orientation of the target, which has a significant influence on the convective cooling rate. This becomes evident in the linear temperature profiles of IR images with different target orientations in Fig. 10.

The polymer absorbers TK-RAM and Cone are not suited for the hot target because of their low thermal conductivity. Thermal simulations for this material showed that even for the ambient target an air temperature change in the receiver cabin can result in unacceptable gradients over their surface area.

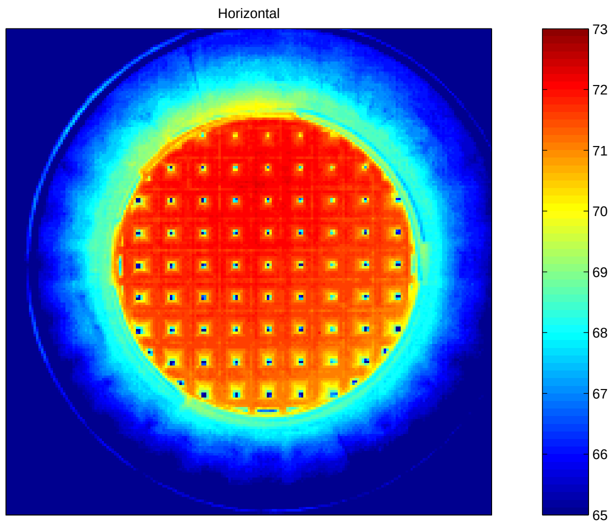

Fig. 9. Thermal images with an IR camera of the hot calibration target in horizontal orientation.

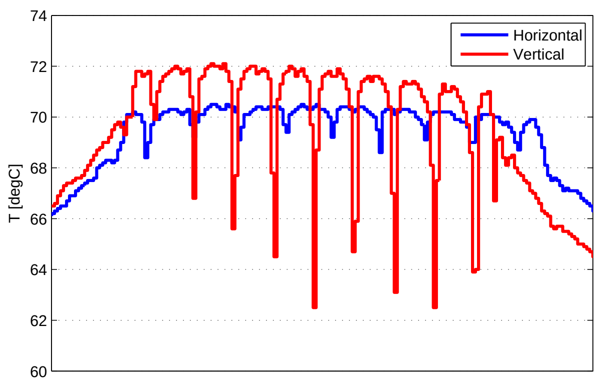

Fig. 10. Temperature profile from different IR images where the hot pyramidal target was mounted in horizontal and vertical orientation.

V. Conclusions

The pyramidal prototype showed a coherent backscatter between -50 to -60dB for most frequencies. Below 100GHz it is up to -35dB, which would result in significant standing waves. The backscatter of the TK-RAM tiles was below -50dB. They could not be used for the elevated temperatures, but for the ambient target they would be the most economical option. The total reflectivity of both targets was about 0.6E-3 at 323GHz. At 90GHz the pyramids were with 3E-3 three times worse than the tiles. The best electrical performance was achieved with the conical design. The polymer absorber of the tested version would be well suited for economic mass production, but it has severe disadvantages because of its bad thermal conductivity. None of the tested targets would be fully cocompliantith the ALMA requirements.

The best RF and thermal performance could be achieved with a conical target made of a thin layer of thermally conducting absorber on a metal backing. We have already tested similar targets for various other projects, and they achieved routinely a coherent backscatter below -60dB [3]. In order to improve the thermal accuracy we have now started to investigate different shroud geometries, which will help to decouple the target from the thermal environment and to make it a better approximation to an ideal blackbody.

References

[1] "ALMA Calibration Device: Technical Specifications," Tech. Rep. FEND-40.06.00.00-009-C-SPE, European Southern Observatory, Munich, Germany, Dec. 2007.

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[3] A. Murk, R. Wylde, R. Spurrett, P. Fürholz, and N. Kämpfer, "Blackbody Calibration Targets with Ultralow Reflectivity at Submillimeter Wavelengths," in *4th ESA Workshop on Millimetre-Wave Technology and Applications*, vol. WPP-258, pp. 359–364, Feb. 2006.