Verification of the optical design for Band 9 of the ALMA receiver

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Abstract

In this paper, we report on a comprehensive verification of the quasi-optical design of the ALMA band 9 optics. Accurate nearfield (phase and amplitude measurements) are compared to detailed electromagnetic modelling of the optical system using GRASP8 for complete validation of the design.

Introduction

ALMA (Atacama Large Millimeter Array) is an ESO (European Southern Observatory) project run by an international collaboration including groups from North America (US & Canada) and Europe (the 10 member states of ESO and Spain). Japan will also become a partner, making this a truly global collaboration.

ALMA, to be located in the Chilean Andes, is planned to be the most complex and ambitious ground-based astronomy project of the next decade. The facility will consist of 64 separate 12-m diameter antennas ,with each with a 0.75m diameter secondary mirror and will each will operate over 10 separate channels. The 64 antennas will work together as an interferometer with baselines of up to 10 km. It will give unparalleled resolution at the very highest frequencies of operation possible from the ground (70 to 900 GHz). The ALMA bandwidth is divided to coincide with regions where the atmosphere is relatively transparent. This paper reports on the analysis and verification of the Band 9 (602-720GHz).

All of these receivers are dual polarization and have sideband separation or double sideband Superconductor–Isolator–Superconductor (SIS) tunnel junction mixers. The chosen mixer technology requires cryogenictemperatures of liquid Helium level (4K) and high vacuum. With the large number of systems to be produced for the 64 antennas, special high standards of quality and reliability are required [1,2,3].

ALMA Band 9 Optical Design

The ALMA antenna is a classical Cassegrain system with the distance from the secondary mirror to the focal plane being 6m. The band 9-receiver optics has a design criteria where all optics is mounted in a specific cryogenic cartridge with various levels of thermal isolation (e.g. the LO power source is located on the 90K stage and the SIS mixer is located in a 4K stage). Also the receiver should detect two orthogonal linear polarizations from the sky and the secondary mirror edge illumination taper should be -12 dB and should be frequency independent over the band. In addition, the design should only use mirrors and the cross polarization signal level should not more than –20 dB normalized to the main polarization.

The mirrors are to have manufactured tolerances, which can be machined on standard CNC machines. Since the wavelength is much longer than optical wavelengths in band 9, only 7 micron RMS mirror roughness is required, and the tightest tolerance for this particular design is about 40 microns.

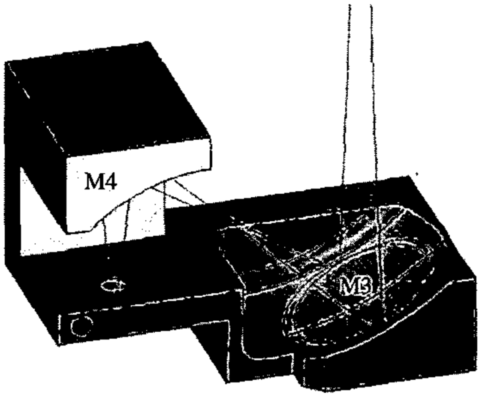

Figure 1: The two-mirror block configuration used to experimentally verify the optical design of the band 9 optics.

In order to verify the design concept of using direct CNC machining for these frequencies and the optical design itself, a simple model for a signal chain – a two-mirror block has been built, together with a mixer horn, which was tested and the output beams compared to simulated data. This is illustrated in figure 1 above and the equivalent simulated optical set-up is shown in figure 2 below, taken from GRASP8.

A near field measurement system (described in more detail in [4] & [5]) was used to measure the quality of the output beam at a plane 125.5mm from the chief ray intercept on the M3 mirror at various frequencies over the band 9 bandwidth – 612GHz 654GHz and 672GHz.

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This optical configuration was also modelled in the software package GRASP8 and the equivalent simulated beam at output plane is compared to the measured beam at the equivalent plane. In the simulations a truncated Bessel model of the corrugated aperture plane was used of the form

$$E_{ch} = J_0\left(\frac{2.405r}{a}\right)\exp\left(\frac{-j\pi r^2}{\lambda L}\right) \quad r \le a'$$

where J_0 is a Bessel function and a is the aperture radius and L is the slant length of the horn[6]. Below in figures 3 & 4 a sample comparison at 672GHz is illustrated showing good agreement between the measured and simulated data.

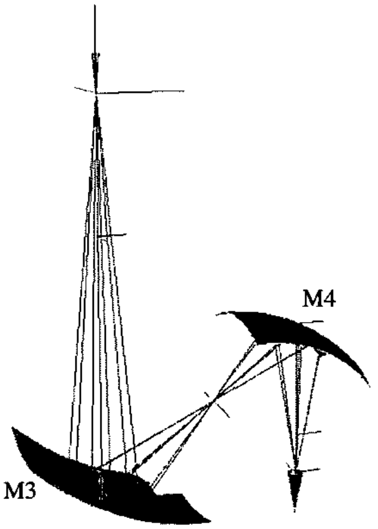

Figure 2: GRASP8 simulation of the two-mirror configuration used to experimentally verify the optical design of the band 9 optics.

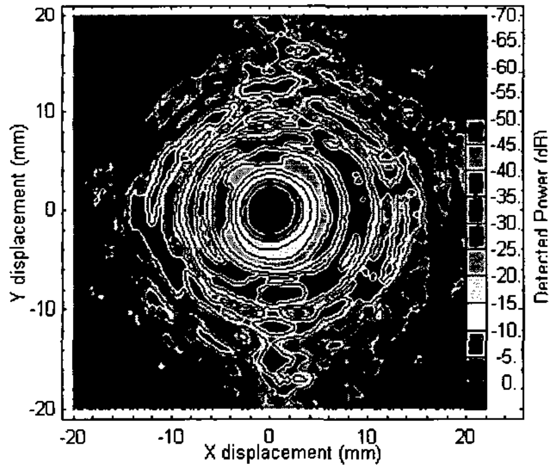

Figure 3: 672GHz Measured Intensity pattern close to the focal plane of the Cassegrain system.

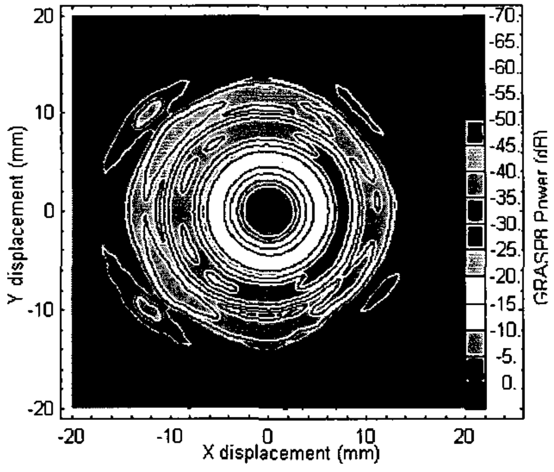

Figure 4: 672GHz Simulated Intensity pattern close to the focal plane of the Cassegrain system.

Present activities and plans

In the near future, further detailed analysis is required. A complete description of the corrugated aperture field will be calculated using a mode matching technique and this exact aperture distribution will be used instead of the simple truncated Bessel model to represent the horn in the analysis. This will allow the bandwidth effects of the corrugated horn to be simulated fully. Further experimental testing of the configuration is also planned.

Acknowledgements:

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