Design of an Optical Beam Combiner for Dual Band Observation with ALMA

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Abstract

The aim of this work is to improve high-frequency calibration data on long baseline observations for the ALMA antennas. A dual-frequency atmospheric phase error calibration method is proposed and will be implemented by the simultaneous observation in two ALMA Bands, specifically 6 and 9, coupled by means external optics in a few baselines. This method is envisioned to demonstrate the advantage of receiving signals simultaneously at different frequencies from the same point of the sky. It will permit an increase of accuracy in determining the phase correction needed to reduce the effects of the atmosphere. While maintaining the existing receiver optics, an optical layout that couples Bands 6 and 9 is proposed. Here we demonstrate that very limited impact on the existing ALMA system is needed. Furthermore, we present in detail the optical layout, made within the formalism of ray optics, and a detailed tolerance analysis. The initial results demonstrate the feasibility of the proposed system

1. Introduction

At present, the Atacama Large Millimeter/Submillimeter Array (ALMA) [1] represents the largest astronomical project in existence, which is composed by 66 high precision antennas with advanced technology. Despite being located in one of the best sites for performing mm and submm radio astronomy (Chajnantor plateau located at the Atacama Desert in northern Chile) ALMA is not exempt from image degradation caused by atmospheric effects or instabilities in the instruments. To ensure that it operates at its full potential during the next years and decades it is necessary to maintain a continuous development program.

As a part of this program we propose to develop a dual-frequency atmospheric phase-error calibration method using ALMA Bands 6 and 9 by means of external optics on a few ALMA baselines employing existing ALMA receivers. This method is devised to demonstrate the advantages of receiving signal simultaneously at different frequencies from the same area of the sky. When implemented, it will permit an increase of accuracy in determining phase correction due to atmosphere; improve UV coverage and image quality; double instantaneous frequency coverage for line searches and improve cross calibration between different bands. This project involves designing an optical system for combining the beams of existing Bands 6 and 9, implementing limited modifications of signal transfer at few ALMA antennas and making dual-frequency observations with ALMA. Here we demonstrate that very limited impact on the existing ALMA system is needed and present the optical layout that it will be used.

2. Optical Layout

Figure 1 shows the optical layout of the coupling system. The concept is to use a dichroic to separate Band 6 and 9 beams. The beam of Band 6 is reflected and then redirected to its respective window by an optical system. This system is composed of a dichroic filter followed by an elliptical mirror, then by a flat mirror and finally a second elliptical mirror. The incidence angle upon the dichroic filter is 12°, which guarantees a good efficiency performance for the whole system, in terms of beam distortion [2]. The idea of using two elliptical mirrors in this system is that the beam distortion (produced by each elliptical mirror) can be compensated by only adjusting their foci. Other advantage of using elliptical mirrors is that the beam shape could be easily matched, in order to change the beam features as few as possible [3].

All the optical components must be properly aligned for achieving high levels of efficiency. However, this situation is not realistic and the misalignments present in the system should be corrected. A tolerance analysis is presented in the next section in order to quantify the impact these misalignments.

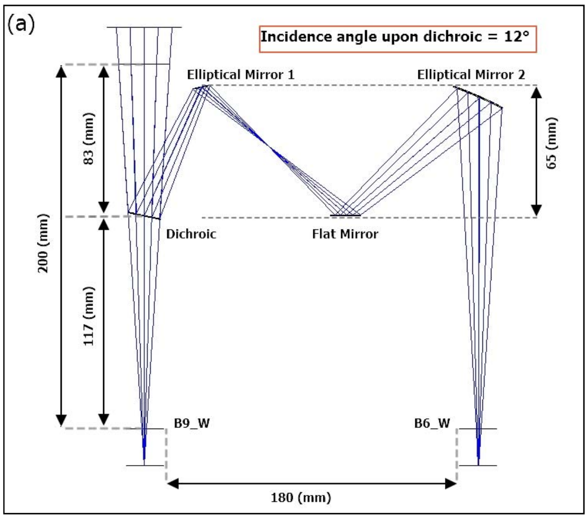

Fig. 1. Lateral view of the system under design made in Zemax software. It has been made using the sequential multi configuration Zemax option.

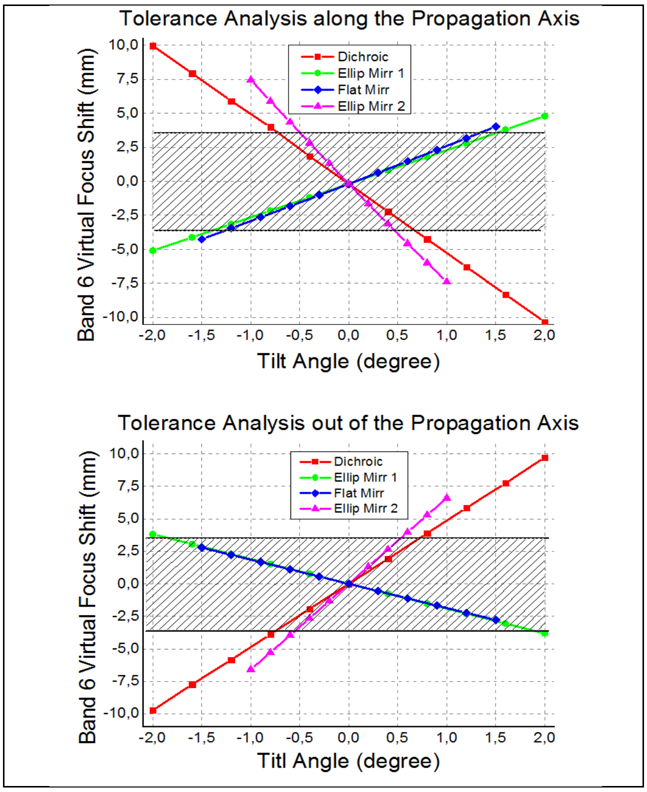

Fig. 2. Tolerance analysis for the virtual focus of the band 6. The shadowed region correspond to the allowed field of view. This region indicates the maximum misalignment angle for each component of the system.

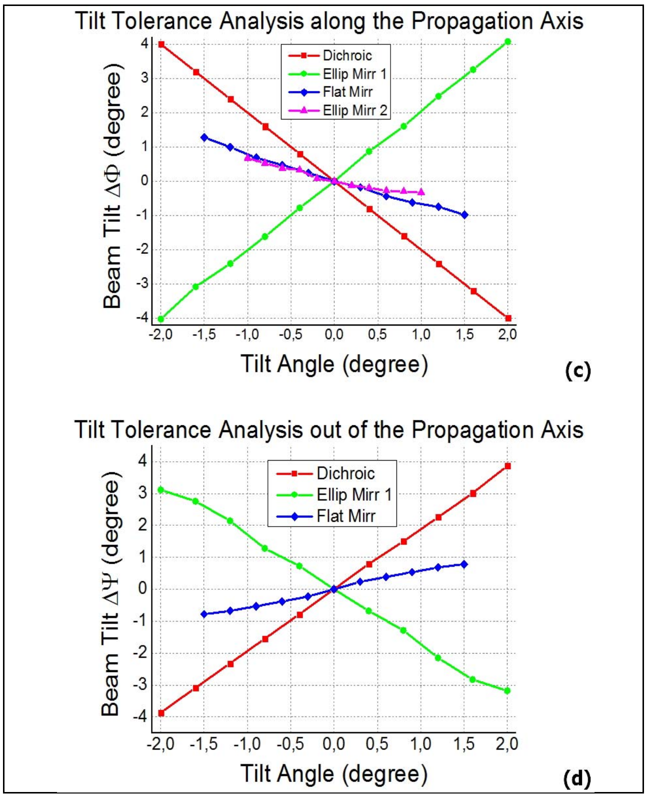

Fig. 3. Tolerance analysis for beam tilt. This graphs show us that the elliptical mirror 1 is the best candidate to keep both beams in a coaxial configuration.

3. Tolerance Analysis

Tolerance analysis has as objective to know how sensitive the proposed system is to the angle misalignment and how the focus matching between the bands 6 and 9 will change. For this purpose it is necessary to find the virtual focus of the beam reflected by the dichroic. This means quantifying the shift along the propagation axis and perpendicular to the propagation axis that the virtual focus of the band 6 will have when each reflective surface of the system is tilted in certain angle. The shift of the virtual focus is computed by simple geometry and its results are showed in the figure 2.

In order to both bands look at the same point in the sky their focus should overlap in a certain region, which defines an allowed field of view. That region is delimited by the beam waist of each band. The band 6 has a beam waist of 6,53 mm at a frequency of 275 GHz and the band 9 has a beam waist of 2,98 mm at a frequency of 602 GHz. The difference between these two beam waist is 3,55 mm and the allowed field of view is showed as shadowed area in the figure 2. Moreover, the graphs show that the more sensitive component is the elliptical mirror 2. This feature makes it the best choice to control the beam shift.

Other important tolerance parameter to consider is the coaxial match between the beam of both bands. To assure a coaxial pair of beams, the tilt between the paraxial beam of each band has to be as small as possible. In the practical case this condition is hard to fulfill. A practical solution is to find out which element is more sensitive to angle variation (tilt) and which one is less to shift variation. This feature will help us to identify which elements are better in order to assign as a control parameter in order to reduce the beam mismatch. The results of this task are showed in the figure 3, showing us that the best choice to keep both beams in a coaxial configurations corresponds to the elliptical mirror 1 due to its high sensitivity.

Additionally, we have performed the corresponding beam coupling efficiency calculations, which lead us to conclude that the power loss due to misalignment presented in the system is negligible for axially aligned beams. However, this power loss considerable increases when the beams are not in a coaxial configuration. This result show us the importance of including an alignment control device in the system in order to correct the misalignment.

4. Conclusions

An innovative and low distortion Zemax first order system, within the ray optics formalism, has been proposed. This system uses mirrors (two elliptical and one flat), which keeps the losses in a minimum level.

After an exhaustive tolerance analysis, we have concluded that any misalignment presented in the system could be corrected by tilting the elliptical mirrors. As seen in the figure 2 and 3 these mirrors present the higher sensitivity in one control parameter, either beam shift or beam tilt, and the lower in the other parameter. This feature makes them the best option to work as alignment control. Both elliptical mirrors are in top of the system under design. This detail could represent an advantage in the next stage of the project, when we focus on the mechanical design.

In the next stage of the project, a Quasi-Optical model should be developed to corroborate the feasibility of this proposed design and calculate the size of the reflecting surfaces.

7. References

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