Study of ALMA Band 2 receiver optical design of ACA 7-m antenna

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***Abstract*—ALMA Band 2 receiver optical designs for ACA 7-m antenna are studied with ray-tracing software prior to heavy electromagnetic full-wave simulation. We have obtained good candidates for our application.**

Keywords—optical design, ray tracing, EM simulation

I. Introduction

The ALMA Band 2 receiver is being developed [1]. ESO leads the development project with NAOJ, whose activity covers the receiver optical designs for the 12-m antennas and the 7-m antennas. We have made the component designs for the 12-m antennas. The poster shows the receiver optical design study to the corrugated horn.

The requirements are as follows:

- Aperture efficiency at sub-reflector: > 0.8,
- Polarization efficiency at sub-reflector: > 0.995,
- Forward efficiency: > 0.95,
- Focus efficiency: > 0.98.

The specific constraints for the Band 2 receiver optical system in the 7-m antenna are as follows:

- Same horn position as in 12-m antenna,
- Same lens (shape and material),
- Same IR filter (shape, material, and position).

II. Methods

We employed ray tracing to obtain designs. The goals of ray tracing were 1) to image the sub-reflector on the horn aperture and 2) to make rays converge on the phase center of a horn beam. Point 1) ensures that the electric field on the sub-reflector is copied on the horn aperture geometrically [2]. Point 2) achieves the phase matching between the beams from the sky and the receiver. The phase center of the horn beam seems located around 100 mm from the horn aperture (Fig. 1). Once we obtained a design candidate that satisfied those points, PO+MOM simulation was carried out to see its performance. The efficiencies were calculated with the following equations:

$$\eta_{\rm ap} = \frac{G}{D_{\rm std}}, \quad \text{ap. eff. at sky (PO+MoM)}$$

$$\eta_{\rm ap,sub} = \frac{\eta_{\rm ap}\eta_{\rm spill,rec,sub}}{\eta_{\rm spill,ent}\eta_{\rm spill,rec,pri}}, \quad \text{ap. eff. at subref. (PO+MoM)}$$

$$\eta_{\rm spill,ent} = \frac{\pi\left(R_{\rm ent}^2 - R_{\rm cas}^2\right)\cos\theta_{\rm inc}}{\pi R_{\rm pri}^2}, \quad \text{ent. spill. eff. (geometrically)}$$

$$\eta_{\rm pol} = \frac{\iint_{\Omega_{\rm sub}} |E_{\rm co}(\theta,\phi)|^2 \,{\rm d}\Omega}{\iint_{\Omega_{\rm sub}} \left(|E_{\rm co}(\theta,\phi)|^2 + |E_{\rm cx}(\theta,\phi)|^2\right) {\rm d}\Omega}, \quad \text{pol. eff. (PO+MoM)}$$

$$\eta_{\rm fwd} = \frac{\eta_{\rm spill,rec,pri}}{\eta_{\rm spill,rec,sub}}, \quad \text{fwd eff. (PO+MoM)}$$

$$\eta_{\rm foc} = \frac{\left|\iint_S E_{\rm horn} E_{\rm inc}^* {\rm d}S\right|^2}{\left(\iint_S |E_{\rm horn}|\,|E_{\rm inc}|\,{\rm d}S\right)^2}. \quad \text{focus eff. (MoM+ray tracing)}$$

The right column describes each efficiency with calculation methods.

III. Results

We made two designs: only the lens was adjusted (Fig. 2), and both the lens and sub-reflector were adjusted (Fig. 3). The coma aberration dominates the lens-only case performance. On the other hand, the spherical aberration by the sub-reflector dominates the lens + sub-reflector case performance. Both cases show the entrance pupil spillover efficiency [3] of 0.89 and 0.98, respectively. Interestingly, the aperture efficiency at the sub-reflector does not necessarily ensure maximum antenna gain, or aperture efficiency at the sky. Fig. 4 shows the lens-only case satisfies the requirements on the aperture, polarization, and forward efficiencies. Fig. 5 shows the focus efficiency for the lens-only case, which also satisfies the requirement. Fig. 6 demonstrates the beam patterns on the sky just for reference.

IV. Conclusion

We made receiver optical designs for the ALMA Band 2 with ray tracing simulation. Electromagnetic simulations confirmed that adjusting the sub-reflector position achieves the requirements. We also found that aperture efficiency at the sub-reflector does not necessarily reflect the antenna gain on the sky, or aperture efficiency on the sky.

References

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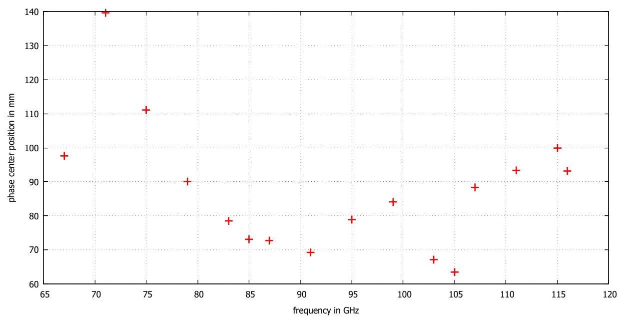

Fig. 1. Phase center position from the horn aperture.

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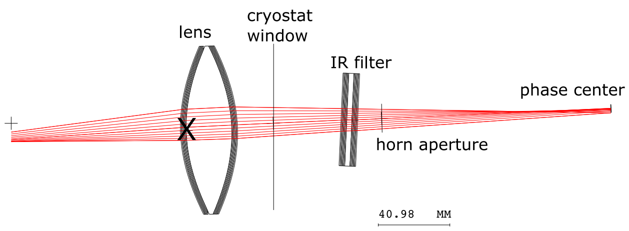

Fig. 2. Adjusting lens case.

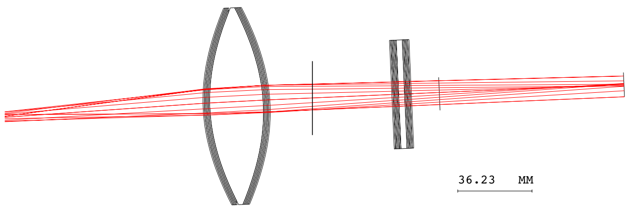

Fig. 3. Adjusting lens and sub-reflector case.

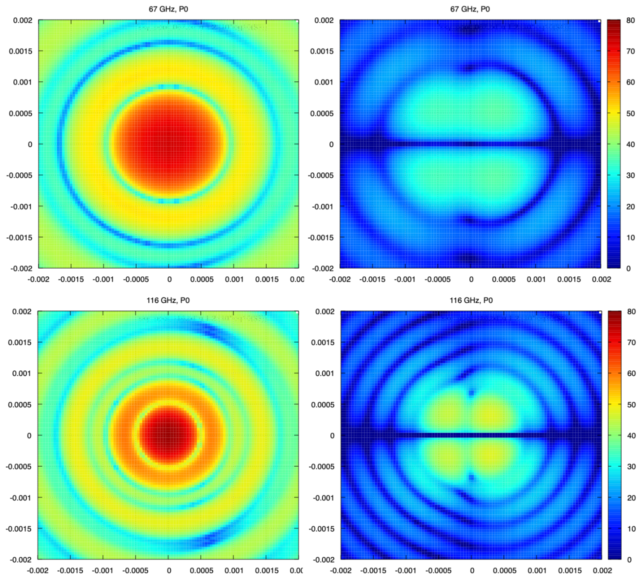

Fig. 6 Beam patterns on the sky for the lens-only case. Upper panels show the 67-GHz results and the lower the 116-GHz ones.

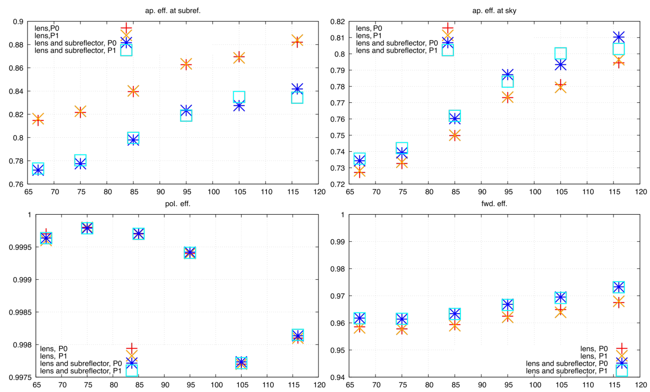

Fig. 4. Efficiencies.

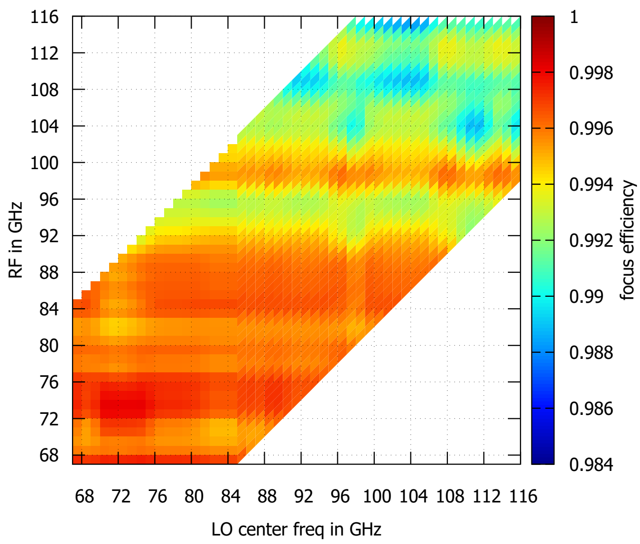

Fig. 5 Focus efficiency for the lens-only case.