Technical feasibility of microwave absorbers for straylight mitigation in the LiteBIRD MHFT telescopes

Andrea Occhiuzzi[1,2,3], *G. Singh*[4], *E. Battistelli*[1,2], *P. de Bernardis*[1,2], *F. Cacciotti*[1,2], *F. Columbro*[1,2], *A. Coppolecchia*[1,2], *G. D'Alessandro*[1,2], *M. De Petris*[1,2], *J.E. Gudmundsson*[4,6], *L. Lamagna*[1,2], *E. Marchitelli*[1,2], *S. Masi*[1,2], *S. Micheli*[1,2], *M. Moriconi*[1], *A. Novelli*[1,2], *A. Paiella*[1,2], *F. Piacentini*[1,2], *G. Pisano*[1,2], *G. Savini*[5] *and A. Shitov*[5]

for the LiteBIRD Collaboration.

INTRODUCTION

LiteBIRD[1] mission is dedicated to the search for primordial *B* modes in the Cosmic Microwave Background (CMB) polarization. To achieve unprecedented sensitivity and accuracy in this measurement, the control of instrument systematics is paramount. In this context, we describe the development of **microwave absorbers** needed to mitigate the straylight within the telescope tubes of the ***LiteBIRD*** **Mid- and High-Frequency Telescopes** (MHFT). A baseline solution has been designed and validated through HFSS simulations, consistently demonstrating sub-percent level specular reflectance across the entire 90-448GHz band of the MHFT under a broad variety of incidence conditions. A prototype has been manufactured and characterized in laboratory measurements, demonstrating a promising reflectance mitigation despite the deviation from the nominal geometry.

DESIGN

The ARC design consists in an impedance matching through a square-based pyramid structure with a side length of **0.6mm** and a height of **1.5mm**, built directly on the vacuum/dielectric interface. The choice of the design of our prototype is driven by the need to achieve a reflectance below 1% across the entire frequency band of MHFT.

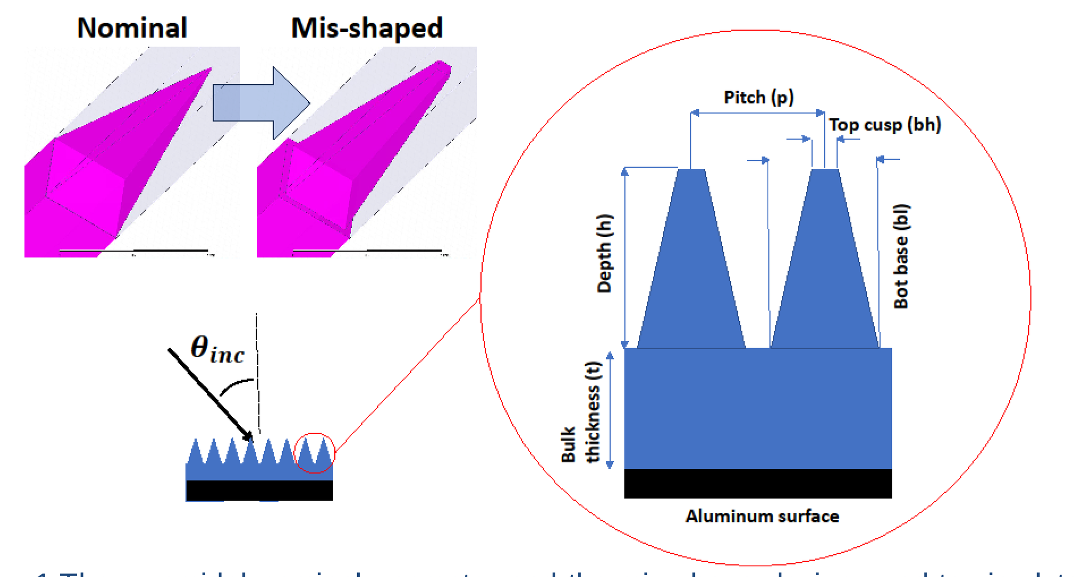

Fig. 1 The pyramidal nominal geometry and the mis-shape design used to simulate the actual prototype performance

SIMULATION

The model is validated via HFSS simulations of a periodic-cell absorbing plate for different incidence angles and polarization states of the incoming radiation. The simulated specular reflectance is below 1% over the whole MHFT frequency band.

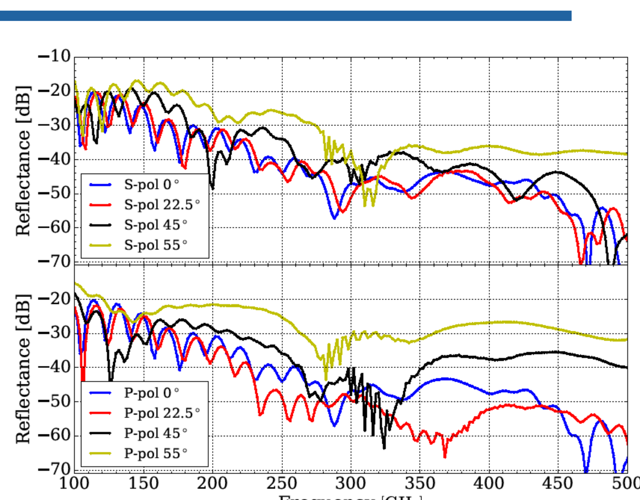

Fig.2 Simulated specular reflectance for the nominal geometry.

We have performed a simple simulation of the performance degradation with a fixed truncation of the pyramid tips and a progressive filling of the troughs at the base.

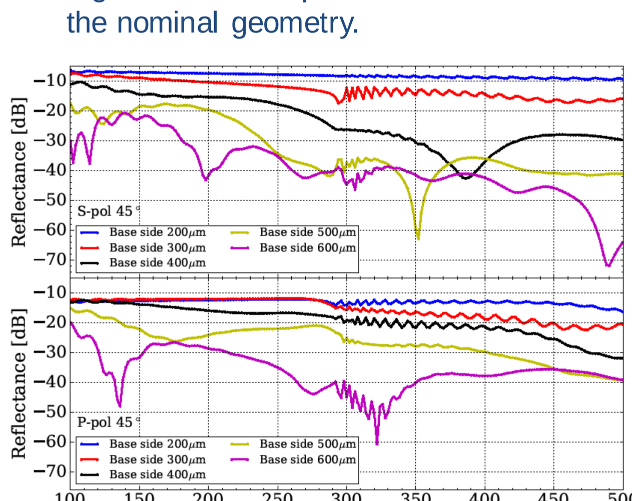

Fig.3 Simulated specular reflectance for the mis-shaped geometry.

MANUFACTURING

The fabrication of prototypes with ARC occurs in three steps: the production of a positive master using a UV 3D printer, the production of a negative silicone mold and the actual prototype production.

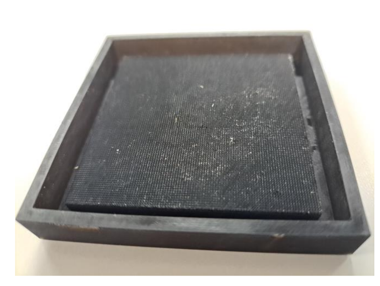

Fig.4 3D printed positive master

Fig.5 Silicone negative mold

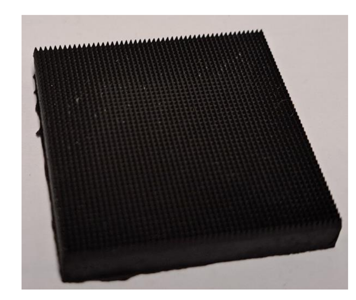

Fig.6 Actual loaded STYCAST prototype

The base materials are two epoxy resins: Eccosorb CR110 is employed to fabricate flat plates as a preliminary test for the measurement setup while the STYCAST 2850FT is employed for the actual prototype manufacturing. The recipe includes the carbon black dust (grains size 10-250μm) as loading material to increase the prototype loss.

SEM IMAGING

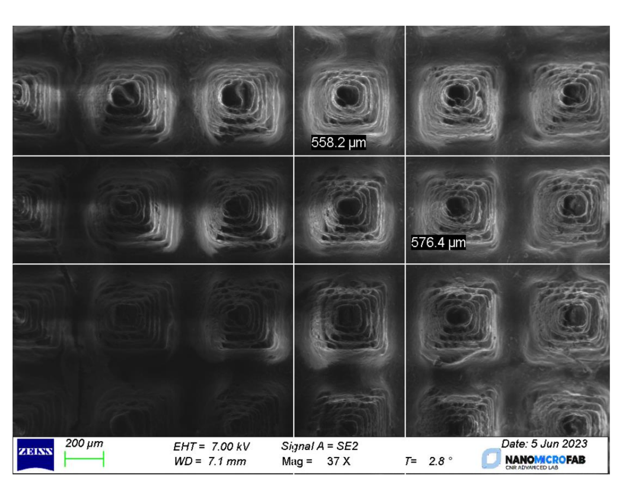

Fig.7 Top view: side size measurement.

The imaging of the prototype is performed using a scanning electron microscope (SEM). A **non-negligible deviation** of the average pyramidal profile from the nominal model is found.

Overall reduction of the height ~300μm and truncation of the pyramid tips by ~250μm, resulting in a lower total height of **~300-500μm**. Filling of troughs at the pyramid base by ~280μm.

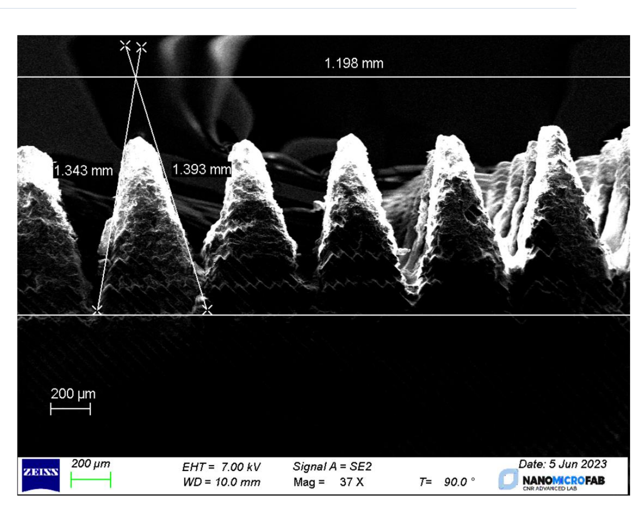

Fig.8 Lateral view: height size measurement.

DIELECTRIC PROPRIETIES

The dielectric properties of a thin layer (820μm) of **carbon-loaded (10%) STYCAST 2850FT prototype** are measured with a Fourier Transform Spectrometer (FTS)[2,3]. The transmittance is measured at 0° incidence angle and fitted in the 175-500GHz range with the model to estimate the loss tangent (**tanδ=0.151±0.010**). The refractive index (**n=2.07±0.16**) is estimated measuring the interferograms ZPD shift when the thin sample is inserted in the one of the two arms of the FTS.

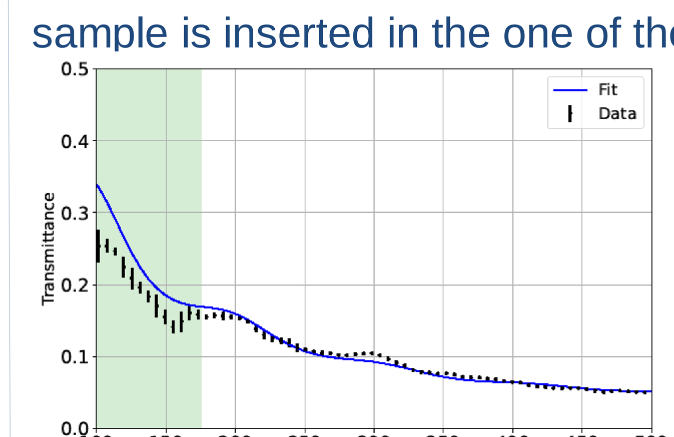

Fig. 9 The measured transmittance (black curve) and best fit (blue curve)

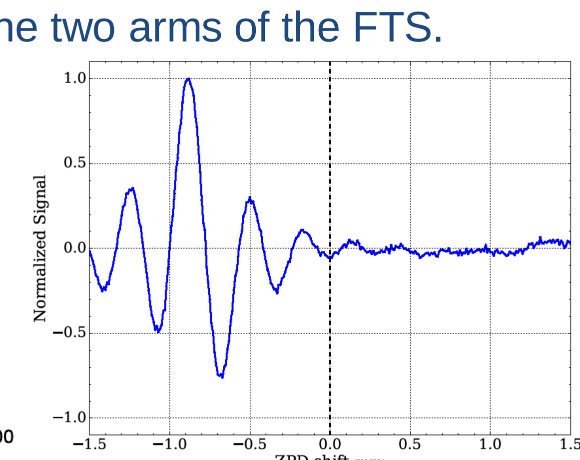

Fig.10 The normalized shifted interferogram.

RESULTS

The test prototype is a 60 × 60mm² plate based on a mixture of STYCAST 2850FT (90%) and carbon black (10%). The specular reflectance at 22,5° and 45° incidence angle is measured using an FTS. The measured reflectance is below 1% for frequencies above 200GHz. However, it does not meet the requirement at lower frequencies due to the general deformation of the pyramidal shape.

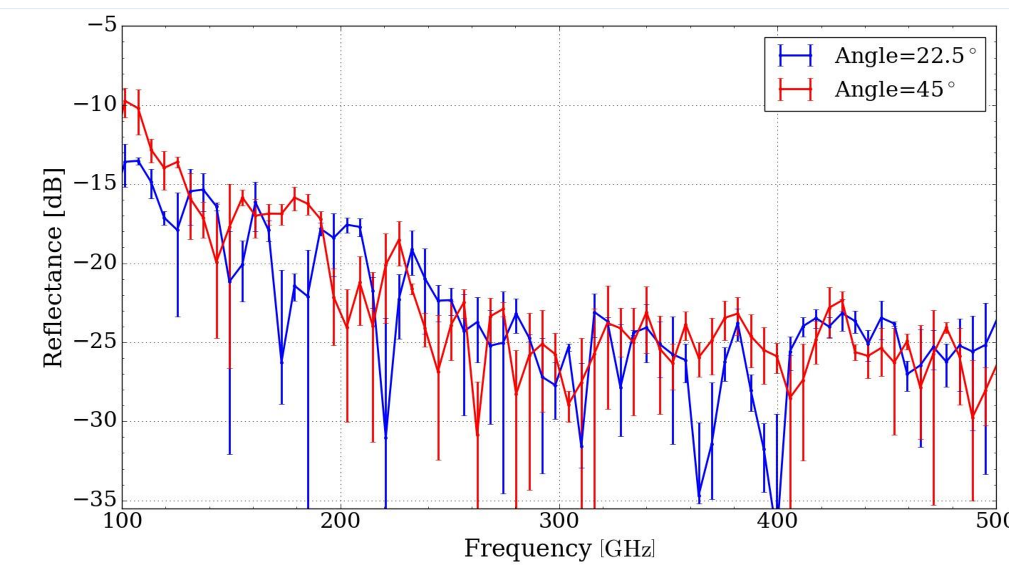

Fig. 11 The measured specular reflectance for 22.5° and 45° incidence angles.

An independent coherent setup is employed to measure the specular and diffuse reflectance of the prototype in comparison with some commercial alternative like AN72, HR10 and TKRAM.

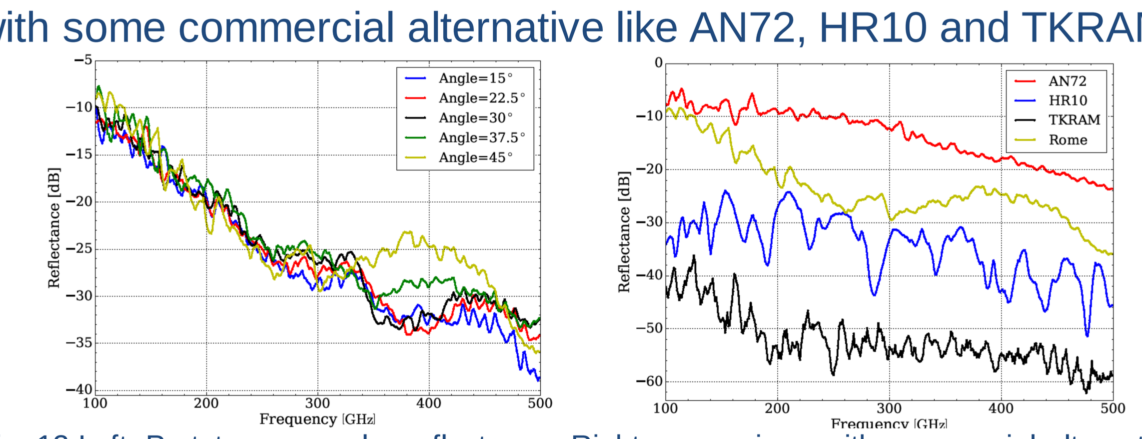

Fig. 12 Left: Prototype specular reflectance. Right: comparison with commercial alternatives

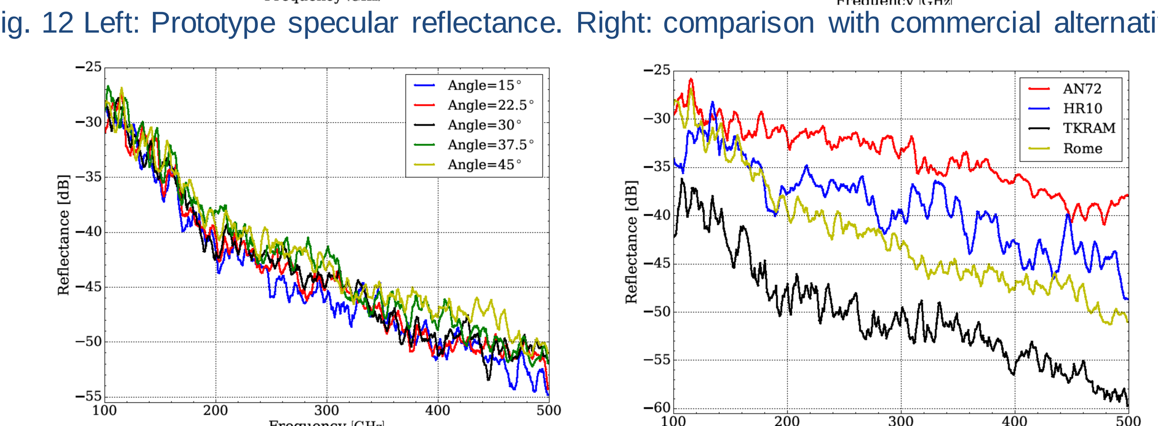

Fig. 13 Left: Prototype diffuse reflectance. Right: comparison with commercial alternatives

CONCLUSIONS

1. A **suitable design** for the MHFT microwave absorber is identified and validated using HFSS simulations.
2. A **preliminary manufacturing process** is developed and qualified trough SEM imaging.
3. **Dielectric properties** of the mixture are subsequently measured and employed to refine the simulation.
4. **Electromagnetic performance** are measured using two independent setup, confirming the **sub-percent** reflection level above 200GHz.

FUTURE WORK:

- **Addition of silica powder or alumina to the recipe in order to match the thermal expansion coefficient to that of the aluminum substrate.**
- **Thermo-mechanical characterization of the prototypes and the definition of an attachment strategy on the optical tube wall.**

REFERENCES

1. LiteBIRD Collaboration et al., "Probing cosmic inflation with the LiteBIRD cosmic microwave background polarization survey," Progress of Theoretical and Experimental Physics 2023(4), 042F01 (2023)

2. F. Columbro et al., "Broadband spectral characterization of lossy dielectrics for mm/submm optical applications," in Space Telescopes and Instrumentation 2022: Optical, Infrared, and Millimeter Wave, SPIE, vol. 12180, 2022, pp. 861–871.

3. L. Lamagna et al, "A testbed for modeling validation and characterization of quasi-optical elements in microwave receivers", in Journal of Low Temperature Physics 209(5), 1272–1279 (2022)

SPIE Astronomical Telescopes + Instrumentation 2024
AS24-AS111-73

andrea.occhiuzzi@roma1.infn.it

[1]*Department of Physics, Sapienza University of Rome, Rome, Italy*
[2]*INFN-Sezione Roma1, Rome, Italy*
[3]*Department of Physics, University of Rome Tor Vergata, Rome, Italy*
[4]*Department of Physics, Stockholm University, Stockholm, Sweden*
[5]*Physics and Astronomy Dept., University College London, London UK*
[6]*Science Institute, University of Iceland, Reykjavik, Iceland*