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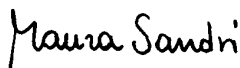
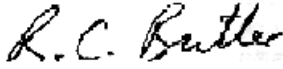
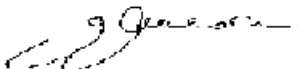
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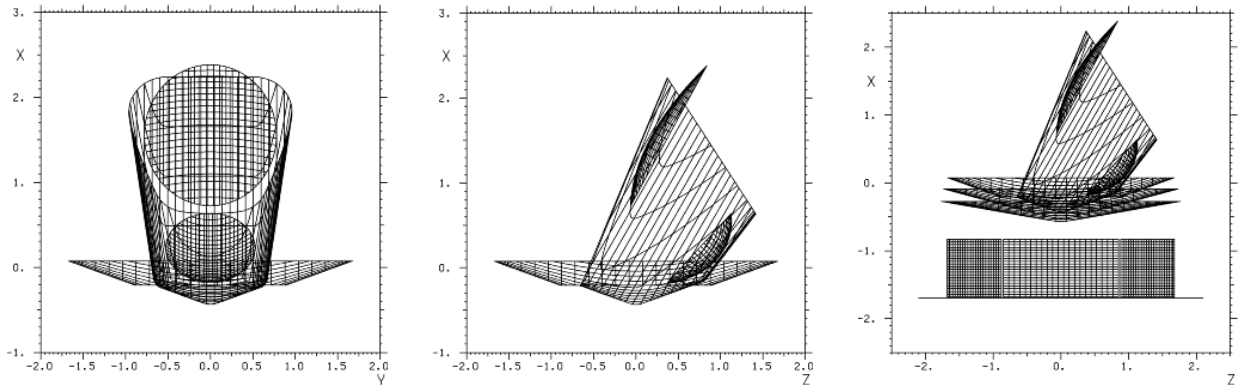
## 1 INTRODUCTION

This note is to present the results of  $4\pi$  beam optical simulations carried out for the LFI dual profiled corrugated feed horns at 30 GHz. Both polarizations have been considered for each feed. The simulations have been carried out in the transmitting mode using GRASP8 software package [1] coupled with the MrGTD add-on package [2]. In Section 2 the optical layout considered in the simulations is described. The  $4\pi$  maps are reported in Section 3 whereas in Appendix some details of the simulation method are explained for completeness.

## 2 THE OPTICS

### 2.1 Telescope and shields

The PLANCK Telescope geometry is reported in [3], together with details of the coordinate systems defined to represent the telescope in GRASP8. The blocking structures considered in these simulations consist of the baffle and the upper V-groove, which is directly in view of the telescope and instrument. Fig. 1 shows the simulated optics (left and central panels) and the complete satellite geometry (right panel).



**Fig. 1** Telescope and shields geometry in  $(XY)_{\text{TEL}}$  (*left*) and  $(XZ)_{\text{TEL}}$  (*centre*) planes; spacecraft geometry (*right*).

### 2.2 Focal Plane Layout

The location and orientation of the two LFI feed horns at 30 GHz are reported in Tab. 1, in the Reference Detector Plane Coordinate System [4]. The UV- location of the power peak of the corresponding beams on the sky are listed in Tab. 2, together with the orientation (with respect to the telescope line of sight) of the coordinate systems in which the beams have been computed [5]. The feed model used in the simulations is a Y- axis polarized dual profiled feed horn specified by its spherical wave expansion provided by Alcatel Space Industries, since the sub reflector is in the near field of the corrugated horn and near field effects cannot be neglected. The feed horn directivity is about 22 dBi and the ET is 30 dB at  $22^\circ$ . The X- axis polarized model has been obtained rotating each feed horn around its axis of 90 degrees.

**Tab. 1** 30 GHz LFI feed horn locations in the Focal Plane Unit (in the Reference Detector Plane coordinate system).

| FH<br># | Location<br>( $X_{RDP}, Y_{RDP}, Z_{RDP}$ )<br>[mm,mm,mm] |        |       | Orientation<br>( $\theta_{RDP}, \phi_{RDP}, \psi_{RDP}$ )<br>[deg,deg,deg] |        |        |
|---------|-----------------------------------------------------------|--------|-------|----------------------------------------------------------------------------|--------|--------|
|         |                                                           |        |       |                                                                            |        |        |
| 27      | -136.95                                                   | 54.94  | 18.60 | 15.56                                                                      | -23.01 | -19.22 |
| 28      | -136.95                                                   | -54.94 | 18.60 | 15.56                                                                      | 23.01  | 19.22  |

**Tab. 2** Main beam locations on the sky ( $u = \sin\theta \cdot \cos\phi$ ,  $v = \sin\theta \cdot \sin\phi$ ) and polarization angle,  $\psi$ .

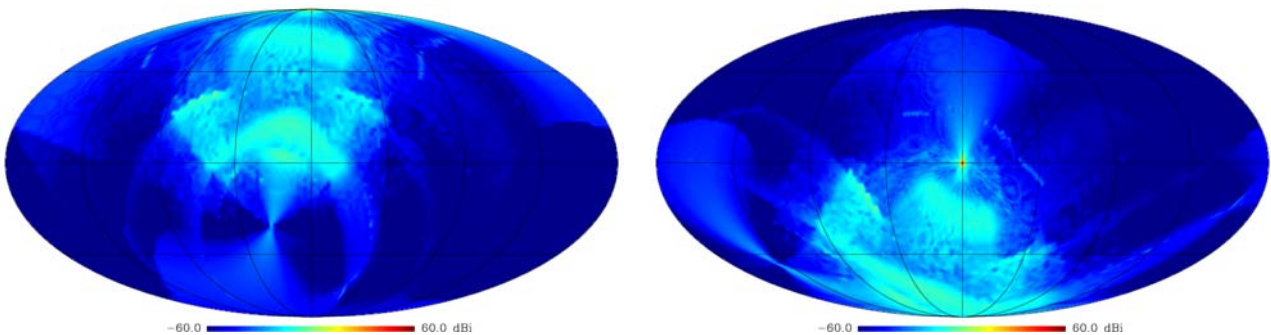
| MB<br># | Location |          | Orientation<br>( $\theta_{LOS}, \phi_{LOS}, \psi_{LOS}$ )<br>[deg,deg,deg] |           |          |
|---------|----------|----------|----------------------------------------------------------------------------|-----------|----------|
|         | U        | V        |                                                                            |           |          |
| 27      | -0.06789 | 0.03369  | 4.3466                                                                     | 153.6074  | -22.5000 |
| 28      | -0.06789 | -0.03369 | 4.3466                                                                     | -153.6074 | 22.5000  |

### 3 4 $\pi$ BEAMS

Each beam has been computed in the co- and x- polar basis according to the Ludwig's third definition [6], in spherical polar cuts in which  $\theta \in [-180^\circ, +180^\circ]$  and  $\phi \in [0^\circ, +178^\circ]$ , with  $\Delta\theta = \Delta\phi = 2^\circ$ . The 4 $\pi$  maps are shown in Fig. 2 ÷ Fig. 5. In the left panel of each figure, the beam boresight direction is at the top of the map. Each polar cut with a constant  $\phi$  value is a meridian of the map. The  $\theta$  angle runs, on each meridian, from  $\theta = 0^\circ$  (towards the main beam direction) to  $\theta = 180^\circ$  ( $-180^\circ$ ) sweeping the map on its left (right) side. The  $\phi$  angle goes from  $\phi = 0^\circ$  (centre of the map) to  $\phi = 180^\circ$  (left side of the map) on the left side of the map, and from  $\phi = 0^\circ$  (right side of the map) to  $\theta \rightarrow 180^\circ$  (centre of the map) on the right side of the map. Therefore the centre of the map has  $\theta = 90^\circ$  and  $\phi = 0^\circ$ . Whereas in the right panel of each figure the main beam pointing direction is in the centre of the map, at  $\theta = \phi = 0^\circ$ .

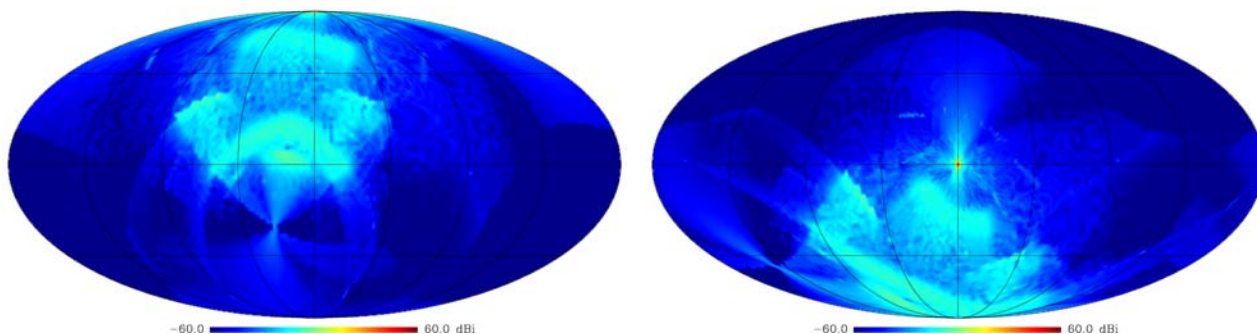
#### 3.1 4 $\pi$ Beam #27

##### 3.1.1 X- polarized

**Fig. 2** Full Pattern of the LFI27 SWE X- axis polarized at 30 GHz (*power*). *Left*: the boresight direction is at the top of the map; *Right*: the boresight direction is in the centre of the map.



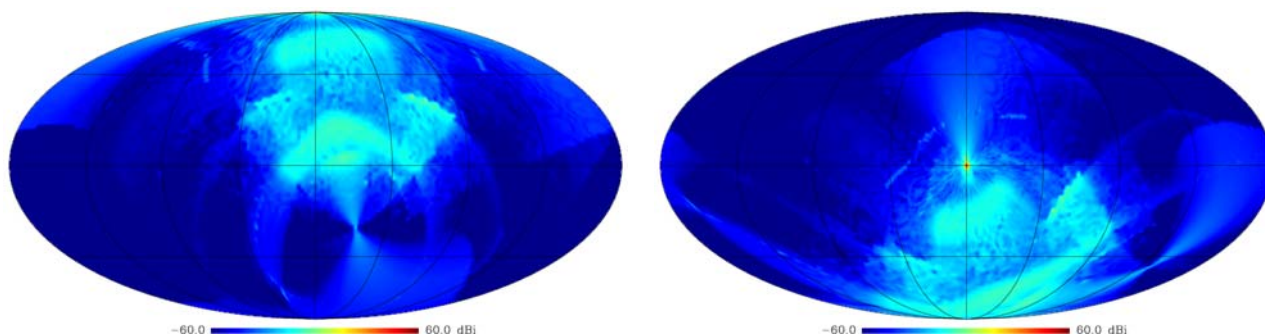
### 3.1.2 Y– polarized



**Fig. 3** Full Pattern of the LFI27 SWE Y– axis polarized at 30 GHz (power). *Left*: the boresight direction is at the top of the map; *Right*: the boresight direction is in the centre of the map.

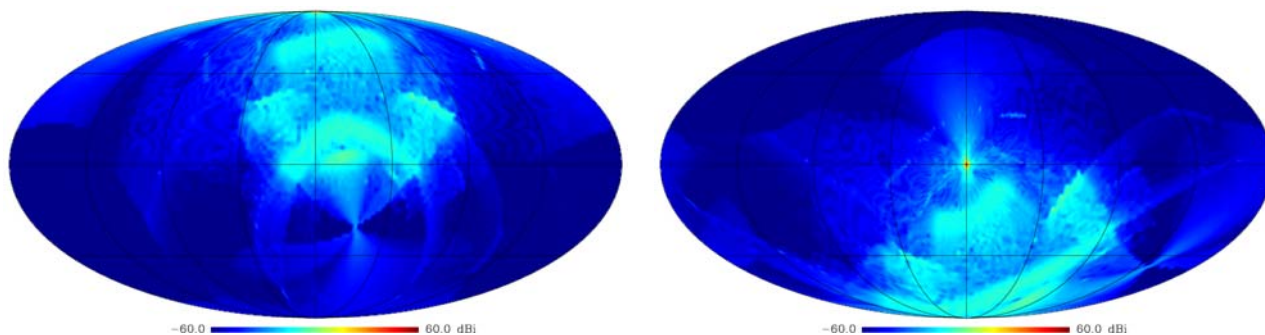
## 3.2 4 $\pi$ Beam #28

### 3.2.1 X– polarized



**Fig. 4** Full Pattern of the LFI28 SWE X– axis polarized at 30 GHz (power). *Left*: the boresight direction is at the top of the map; *Right*: the boresight direction is in the centre of the map.

### 3.2.2 Y– polarized



**Fig. 5** Full Pattern of the LFI28 SWE Y– axis polarized at 30 GHz (power). *Left*: the boresight direction is at the top of the map; *Right*: the boresight direction is in the centre of the map.



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## 5 ACKNOWLEDGMENTS

We wish to thank people of the Herschel/Planck Project, ALCATEL Space Industries, and the LFI Consortium that are involved in activities related to optical simulations.

Some of the results in this paper have been derived using the HEALPix [11] (see also the HEALPix home page at <http://www.eso.org/science/healpix/>).

## 6 APPENDIX

### 6.1 Simulation methods

Full pattern simulations have been performed using GRASP8 MrGTD, an advanced GTD method developed by TICRA. It computes GTD fields from any number of reflectors sequentially illuminated starting from a given source. MrGTD is a ray-optical method in which the computational time is frequency independent and produces accurate results in about one week per beam, as it has been verified for the LFI 30 GHz channel comparing the results with those obtained using the Physical Optics approach [7]. The contributions (that are, bundles of rays defined by a sequence of scatterers and by the type of interaction – reflection or diffraction – occurred on each of them) taken into account in the simulations presented, are those which power level is greater than  $-50$  dBi ( $-100$  dB) in at least one point of the map. This threshold level represents the required straylight rejection level in the LFI frequency channel. Lower power levels not produce significant straylight contamination from the diffuse Galactic emission, as reported in [8]. Only the 2<sup>nd</sup> order optical contributions



have been considered since neglecting the 3<sup>rd</sup> order interactions involve only few % errors on the straylight evaluation [9] [10]. In this framework, we have not considered reflections or diffractions on the V- groove, as well as higher order contributions, since we expect them at very low levels (less than -100 dB).

The computed contributions for the X- axis polarized feed horns are:

- 1) feed  $\Rightarrow$  far field
- 2) feed  $\Rightarrow$  reflection on sub reflector  $\Rightarrow$  far field
- 3) feed  $\Rightarrow$  reflection on main reflector  $\Rightarrow$  far field
- 4) feed  $\Rightarrow$  reflection on baffle  $\Rightarrow$  far field
- 5) feed  $\Rightarrow$  diffraction on sub reflector  $\Rightarrow$  far field
- 6) feed  $\Rightarrow$  diffraction on main reflector  $\Rightarrow$  far field
- 7) feed  $\Rightarrow$  diffraction on baffle  $\Rightarrow$  far field
- 8) feed  $\Rightarrow$  reflection on sub reflector  $\Rightarrow$  diffraction on main reflector  $\Rightarrow$  far field
- 9) feed  $\Rightarrow$  diffraction on sub reflector  $\Rightarrow$  reflection on main reflector  $\Rightarrow$  far field
- 10) feed  $\Rightarrow$  diffraction on sub reflector  $\Rightarrow$  diffraction on main reflector  $\Rightarrow$  far field
- 11) feed  $\Rightarrow$  diffraction on sub reflector  $\Rightarrow$  diffraction on sub reflector  $\Rightarrow$  far field
- 12) feed  $\Rightarrow$  diffraction on main reflector  $\Rightarrow$  diffraction on main reflector  $\Rightarrow$  far field
- 13) feed  $\Rightarrow$  reflection on main reflector  $\Rightarrow$  diffraction on main reflector  $\Rightarrow$  far field
- 14) feed  $\Rightarrow$  diffraction on main reflector  $\Rightarrow$  reflection on main reflector  $\Rightarrow$  far field
- 15) feed  $\Rightarrow$  diffraction on baffle  $\Rightarrow$  reflection on main reflector  $\Rightarrow$  far field
- 16) feed  $\Rightarrow$  reflection on baffle  $\Rightarrow$  diffraction on baffle  $\Rightarrow$  far field
- 17) feed  $\Rightarrow$  diffraction on baffle  $\Rightarrow$  diffraction on main reflector  $\Rightarrow$  far field
- 18) feed  $\Rightarrow$  diffraction on sub reflector  $\Rightarrow$  diffraction on baffle  $\Rightarrow$  far field
- 19) feed  $\Rightarrow$  reflection on baffle  $\Rightarrow$  diffraction on sub reflector  $\Rightarrow$  far field
- 20) feed  $\Rightarrow$  reflection on baffle  $\Rightarrow$  diffraction on main reflector  $\Rightarrow$  far field
- 21) feed  $\Rightarrow$  reflection on baffle  $\Rightarrow$  reflection on main reflector  $\Rightarrow$  far field
- 22) feed  $\Rightarrow$  reflection on baffle  $\Rightarrow$  reflection on sub reflector  $\Rightarrow$  far field
- 23) feed  $\Rightarrow$  diffraction on main reflector  $\Rightarrow$  reflection on baffle  $\Rightarrow$  far field
- 24) feed  $\Rightarrow$  reflection on sub reflector  $\Rightarrow$  diffraction on baffle
- 25) feed  $\Rightarrow$  reflection on main reflector  $\Rightarrow$  diffraction on baffle  $\Rightarrow$  far field
- 26) feed  $\Rightarrow$  diffraction on sub reflector  $\Rightarrow$  reflection on baffle  $\Rightarrow$  far field
- 27) feed  $\Rightarrow$  diffraction on main reflector  $\Rightarrow$  diffraction on baffle  $\Rightarrow$  far field
- 28) feed  $\Rightarrow$  reflection on main reflector  $\Rightarrow$  reflection on baffle  $\Rightarrow$  far field
- 29) feed  $\Rightarrow$  reflection on sub reflector  $\Rightarrow$  reflection on baffle  $\Rightarrow$  far field

The same contributions have been considered for the Y- axis polarized feed horns, and also the latter one:

- 30) feed  $\Rightarrow$  diffraction on sub reflector  $\Rightarrow$  reflection on sub reflector  $\Rightarrow$  far field

The main beam region of each map has been opportunely replaced with a computation carried out using a PO/PTD analysis in order to avoid caustic artefacts originated by the GTD approach.