TITLE: # Planck/LFI: Main Beam Locations and Polarization Alignment for the LFI Baseline FPU

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TABLE OF CONTENTS

1 Introduction and Scope

This Technical Note collects the data – location on the sky, polarisation direction, FWHM and directivity – of the LFI main beams for the new LFI Baseline Focal Plane Unit.

The new baseline arrangement is shown in Figure 1 and foresees 16 horns at 100 GHz, 6 at 70 GHz, 3 at 44 GHz and 2 at 30 GHz. Each feed horn is numbered (form 2 to 28) as reported; the beams on the sky are identified with the same number of the corresponding feed horn. A picture of the main beams on the sky is shown in Figure 4.

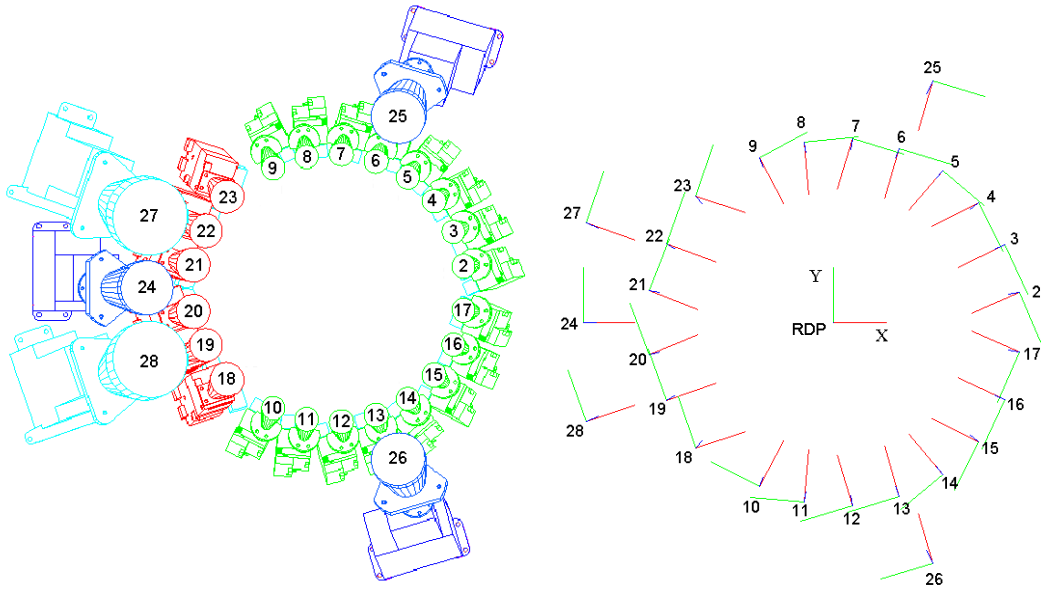

Figure 1: *Left: Planck/LFI Baseline Focal Plane Unit configuration with the adopted numbering. Right: coordinate systems for the feed horns in the FPU referred to the Reference Detector Plane Coordinate System (see [1] for details); the X– , Y–, and Z– axes are in red, green, and blue respectively.*

2 Coordinate Systems

Each of the 27 beams is identified by a local coordinate system (O_{MB}, X_{MB}, Y_{MB}, Z_{MB}). The local coordinate systems are defined starting from the Line Of Sight coordinate system (O_{LOS}, X_{LOS}, Y_{LOS}, Z_{LOS}). Z_{LOS} is tilted 85° from the spin axis (see [1]), O_{MB} coincides with $O_{LOS,}$ and Z_{MB} is the pointing direction of the power beam pattern at which the coordinate system is referring.

A detailed description of the coordinate systems used to describe the Planck Telescope, the Focal Plane Unit, and the Spacecraft is provided in [1]. However, a brief explanation of the convention used to define a coordinate system relative to another is reported here for convenience. All the coordinate systems are right-handed cartesian systems. They are defined starting from another coordinate system called in short "*reference*".

The orientation of the a new coordinate system with respect to the *reference* is defined by the three angles (θ,φ,ψ). The meaning of these angles are reported in the Figure 2.

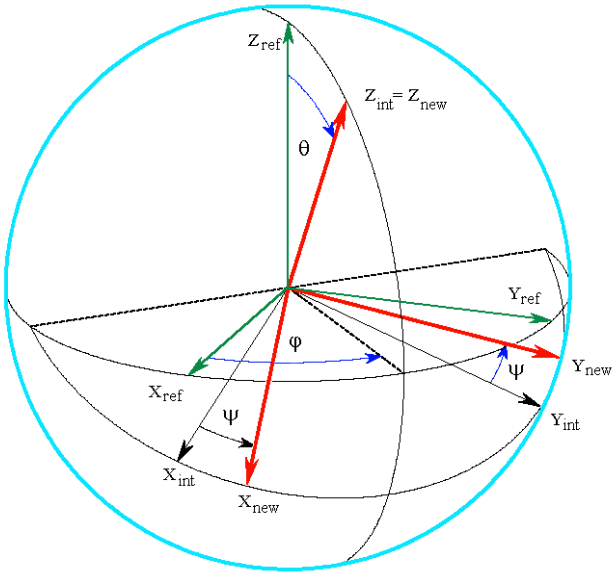

Figure 2: *The orientation of the new coordinate system relative to the reference system specified by the angles θ, φ and ψ.*

According to the Figure 2, the Z_{ref}-axis is tilted at the angle θ by rotating the $X_{ref}Y_{ref}Z_{ref}$ coordinate system around the axis – liying on the (X_{ref} Y_{ref}) plane – which is orthogonal to the line forming the angle φ with the X_{ref} vector. This rotation generates the intermediate coordinate system $X_{int}Y_{int}Z_{int}$. The desired coordinate system $X_{new}Y_{new}Z_{new}$ is then obtained rotating the angle ψ around the Z_{int}-axis. Since Z_{new} is equal to Z_{int}, the ψ angle defines the local polarisation direction.

3 Procedure and Results

The simulations have been performed considering the feed as a source and computing the pattern scattered by both reflectors on the far field using GRASP8 software package. We used the Geometrical Optics (GO) and the Geometrical Theory of Diffraction (GTD) on the sub reflector, and the Physical Optics (PO) on the main reflector. The feed modelization used is a X–axis polarized gaussian model with the optimized edge taper values defined in [2]. Far field radiation amplitude patterns have been computed in the Co– and Cross– polar basis according to the Ludwig's third definition (see [3] and [4]), in spherical grids with 301x301 points.

The LFI polarization properties have been optimised rotating the feed horns about their axis. For each pair of LFI symmetrically located feed horns, the desired relative orientation of the main beam polarization directions, β, has been obtained when the corresponding beams look at the same direction on the sky (i.e. after a rotation about the spin axis by an angle α). Obviously, for the feed horn 24 at 44 GHz no alignment has been done, since it is in the symmetry plane of the FPU and the polarization direction of the beam is already aligned with the X_{LOS} vector.

Main beam locations on the sky and polarization angles are reported in Table 2 assuming as the *reference* the LOS coordinate system. In Figure 3 all the main beam coordinate systems are shown projected in the (X_{LOS},Y_{LOS}) plane. In addition, the Table 2 reports also the beam location in (u,v) coordinates[1].

Table 3 summarizes the main beam properties: the peak values of Co– polar and Cross– polar components in dBi, the minimum, maximum and average Full Width Half Maximum (FWHM) in arcmin, the ellipticity, and the directivity in dBi. The peak of the Cross– polar component is always 25 ÷ 30 dB below the peak of the Co– polar component.

Main Beams	α	β
2 – 17	1.1036	45
3 – 16	2.8580	45
4 – 15	4.4173	45
5 – 14	5.6747	90
6 – 13	6.5436	135
7 – 12	6.9614	135
8 – 11	6.9013	180
9 – 10	6.3741	-135
18 – 23	4.9186	-45
19 – 22	3.0920	-45
20 – 21	1.2675	-45
24	N/A	N/A
25 – 26	8.8136	135
27 – 28	3.8635	-45

Table 1: *For each pair of beams, the angular distance, α, and the polarisation offset angle, β, are reported.*

[1] $u = \sin\theta\cdot\cos\varphi$, $v = \sin\theta\cdot\sin\varphi$

FH #	F (GHz)	$\theta_{(MB)}$ (°)	$\varphi_{(MB)}$ (°)	$\psi_{(MB)}$ (°)	U (rad)	V (rad)
2	100	3.6762	8.6381	-157.5000	0.06339	0.00963
3	100	3.6829	22.8367	-157.4000	0.05920	0.02493
4	100	3.6824	36.8414	-157.4000	0.05140	0.03851
5	100	3.6636	50.6904	-135.0000	0.04048	0.04944
6	100	3.6190	64.5148	-112.3000	0.02716	0.05698
7	100	3.5456	78.4902	-112.3000	0.01234	0.06060
8	100	3.4485	92.7825	-90.2000	-0.00292	0.06008
9	100	3.3393	107.6386	-67.3000	-0.01765	0.05551
10	100	3.3393	-107.6386	67.3000	-0.01765	-0.05551
11	100	3.4485	-92.8015	90.2000	-0.00294	-0.06008
12	100	3.5459	-78.4720	112.3000	0.01236	-0.06060
13	100	3.6193	-64.5066	112.3000	0.02717	-0.05698
14	100	3.6639	-50.6835	135.0000	0.04049	-0.04944
15	100	3.6829	-36.8360	157.4000	0.05141	-0.03851
16	100	3.6829	-22.8367	157.4000	0.05920	-0.02493
17	100	3.6756	-8.6395	157.5000	0.06338	-0.00963
18	70	3.2975	-131.8147	22.3000	-0.03835	-0.04287
19	70	3.1750	-150.8479	22.4000	-0.04837	-0.02698
20	70	3.1649	-168.4438	22.4000	-0.05409	-0.01106
21	70	3.1649	168.4438	-22.4000	-0.05409	0.01106
22	70	3.1747	150.8570	-22.4000	-0.04837	0.02697
23	70	3.2975	131.8147	-22.3000	-0.03835	0.04287
24	44	4.0536	180.0000	0.0000	-0.07069	0.00000
25	44	5.0186	61.1350	-113.5000	0.04223	0.07661
26	44	5.0186	-61.1350	113.5000	0.04223	-0.07661
27	30	4.3466	153.6074	-22.5000	-0.06789	0.03369
28	30	4.3466	-153.6074	22.5000	-0.06789	-0.03369

Table 2: *Main Beams locations on the sky ($u = \sin\theta \cdot \cos\varphi$, $v = \sin\theta \cdot \sin\varphi$) and polarization angle, ψ .*

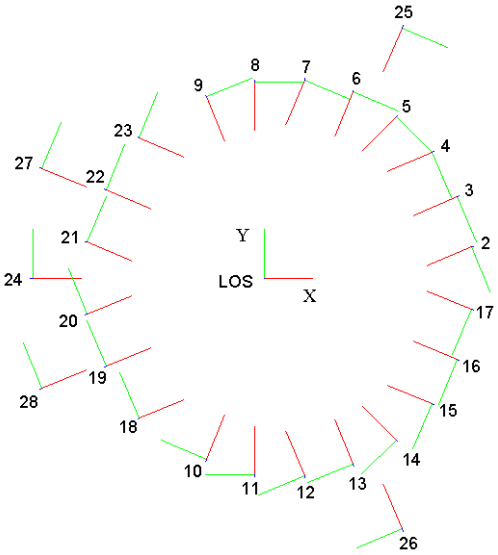

Figure 3: *Main Beams coordinate systems referred to the Line Of Sight. The blue axis is Z_{MB} axis. It should be noted that for convenience the origin of each coordinate system has been taken such as (X,Y,Z) ∝ (U,V,0).*

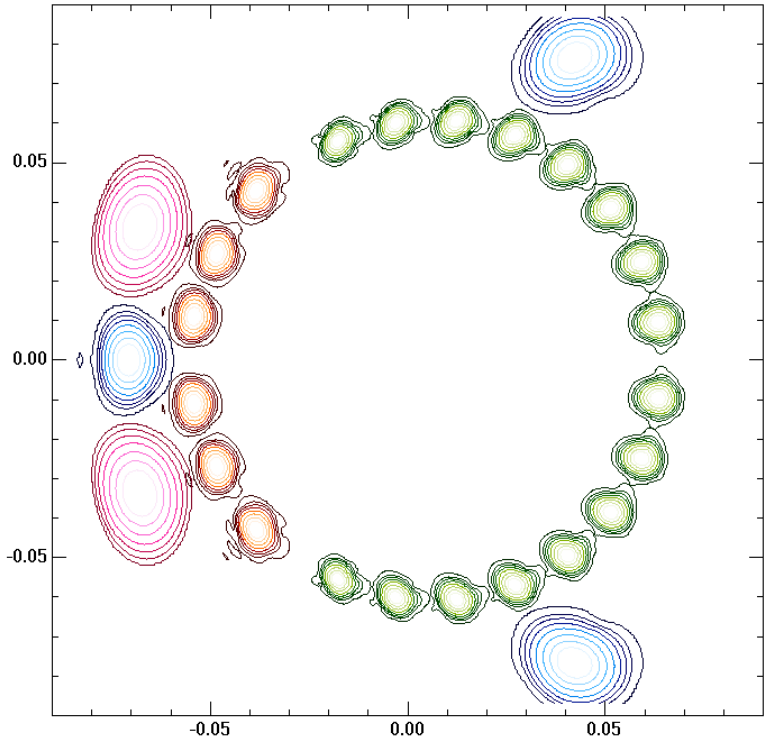

Figure 4: *UV – plots of the main beams power pattern referred to the Line Of Sight. The contours start from 44 dB below the peak for the 100 and 70 GHz feed horns, 40 dB for the 44 GHz feed horns and 30 dB for the 30 GHz feed horns.*

FH #	ET (dB @ °)	Co-polar max (dBi)	X-polar max (dBi)	FWHM (arcmin)			e	Dir (dBi)
				min	max	ave		
2	28.1 - 24	59.05	32.74	12.12	13.80	12.96	1.14	59.05
3	28.3 - 24	59.07	32.64	11.88	13.80	12.84	1.16	59.07
4	28.1 - 24	59.16	32.65	11.88	13.68	12.78	1.15	59.16
5	27.4 - 24	59.34	32.73	11.40	13.20	12.30	1.16	59.34
6	27.7 - 24	59.52	32.59	11.16	13.20	12.18	1.18	59.52
7	27.6 - 24	59.79	32.49	10.56	12.84	11.70	1.22	59.79
8	26.8 - 24	60.16	32.32	10.08	12.36	11.22	1.23	60.16
9	25.5 - 24	60.59	32.14	9.48	11.88	10.68	1.25	60.59
10	25.5 - 24	60.59	32.14	9.48	11.88	10.68	1.25	60.59
11	26.8 - 24	60.16	32.32	10.08	12.36	11.22	1.23	60.16
12	27.6 - 24	59.79	32.49	10.56	12.96	11.76	1.23	59.79
13	27.7 - 24	59.52	32.59	11.16	13.20	12.18	1.18	59.52
14	27.4 - 24	59.34	32.73	11.40	13.44	12.42	1.18	59.34
15	28.1 - 24	59.16	32.65	11.88	13.68	12.78	1.15	59.16
16	28.3 - 24	59.07	32.64	11.88	13.80	12.84	1.16	59.07
17	28.1 - 24	59.05	32.74	12.12	13.80	12.96	1.14	59.05
18	20.5 - 22	58.37	28.87	12.36	15.72	14.04	1.27	58.37
19	23.1 - 22	58.23	26.80	12.60	16.08	14.34	1.28	58.23
20	25.0 - 22	58.07	25.22	12.60	16.44	14.52	1.30	58.07
21	25.0 - 22	58.07	25.22	12.60	16.44	14.52	1.30	58.07
22	23.1 - 22	58.23	26.80	12.60	16.08	14.34	1.28	58.23
23	20.5 - 22	58.37	28.87	12.36	15.72	14.04	1.27	58.37
24	30.0 - 22	53.77	23.12	20.04	27.84	23.94	1.39	53.77
25	30.0 - 22	52.08	26.80	25.32	31.68	28.50	1.25	52.08
26	30.0 - 22	52.08	26.80	25.32	31.68	28.50	1.25	52.08
27	30.0 - 22	50.49	21.31	29.16	40.68	34.92	1.40	50.47
28	30.0 - 22	50.49	21.31	29.16	40.68	34.92	1.40	50.47

Table 3: *Main Beams characteristics.*

4 References

1. *Planck Telescope Design Specification*, SCI-PT-RS-07024

2. *Planck/LFI: Field Distribution on Primary Mirror for the Baseline Telescope*, PL-LFI-PST-TN-017

3. A.C. Ludwig, *The Definition of Cross Polarization*, IEEE Transactions on Antennas and Propagation, Jan 1973.

4. A.D. Olver, P.J.B. Clarricoats, A.A. Kishk and L. Shafai, *Microwave Horns and Feeds*, IEE Electromagnetics Waves Series 39.