TITLE: **LFI REQUIREMENTS FOR RFQM PATTERN MEASUREMENTS**

DOC. TYPE: TECHNICAL NOTE

PROJECT REF.: PL-LFI-PST-TN-045 **PAGE:** I of IV, 10

ISSUE/REV.: 1.0 **DATE:** July 2003

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CHANGE RECORD

Issue	Date	Sheet	Description of Change	Release
1.0	Jul 24, 2003	All	First Issue of the Document	===

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1 INTRODUCTION AND SCOPE

Scope of this document is to define LFI requirements for the beam pattern measurements will be performed on the Planck RFQM telescope / FPU assembly by the Planck Industry contractor. The requirements specifically on polarization measurements will be addressed in a forthcoming technical note.
The LFI Focal Plane layout for the RFQM test campaign is reported in Figure 1.

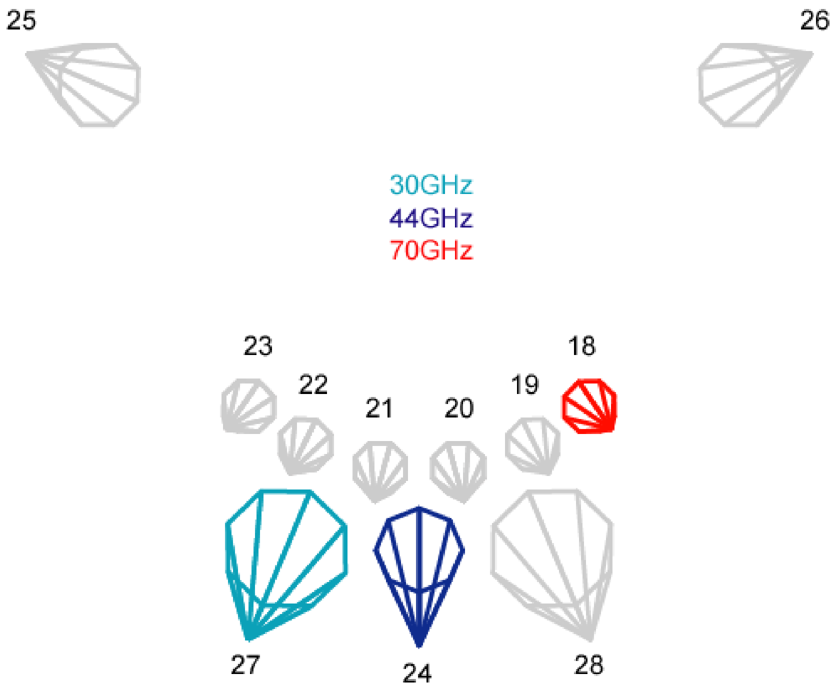

Figure 1: LFI focal plane layout. The horn will be used for RFQM test are in colour.

2 APPLICABLE DOCUMENTS

3 REFERENCE DOCUMENTS

[RD 1] Planck/LFI: Main Beam Locations and Polarization Alignment for the LFI Baseline FPU, PL-LFI-PST-TN-027

[RD 2] LFI Pointing Requirements Issue/Rev. 1.2, PL-LFI-PST-TN-023_1.2

[RD 3] LFI Optical Interfaces, PL–LFI -

[RD 4] C. Burigana, P. Natoli, N. Vittorio, N. Mandolesi, M. Bersanelli, Straylight Contamination from Internal Solar System Bodies in PLANCK/LFI Observations, Int. Rep. ITeSRE 272/2000, April 2000

[RD 5] M. Sandri, F. Villa, R. Nesti, C. Burigana, M. Bersanelli, N. Mandolesi, 2003, Trade-off between angular resolution and straylight contamination in CMB anisotropy experiments. I. Pattern simulations, A&A, submitted, astro-ph/0305152

[RD 6] C. Burigana, M. Sandri, F. Villa, D. Maino, R. Paladini, C. Baccigalupi, M. Bersanelli, N. Mandolesi, 2003, Trade-off between angular resolution and straylight contamination in CMB anisotropy experiments. II. Straylight evaluation, A&A, submitted, astro-ph/0303645

[RD 7] C. Burigana, P. Natoli, N. Vittorio, N. Mandolesi, M. Bersanelli, In-flight main beam reconstruction for PLANCK/LFI, (2002), Experimental Astronomy, 12/2, 87-106, 2001

[RD 8] K. Pontoppidan, Technical description of GRASP8, TICRA, March 2002

4 MAIN BEAMS

Main beam will be measured in co–polar and cross–polar components in amplitude and phase (TBC).

4.1 REFERENCE FRAME, ANGULAR REGION, AND ANGULAR STEP

Each main beam shall be measured in a regular (u,v)–grid[1] defined in its own coordinate system. The main beam coordinate systems are defined in **Table 1**, starting from the LOS coordinate system. Three angles are given, according to the GRASP8 coordinate system definition. The centre of each beam in the LOS coordinate system is reported in the following table as calculated with GRASP8. The angular region is defined in **Table 2**.

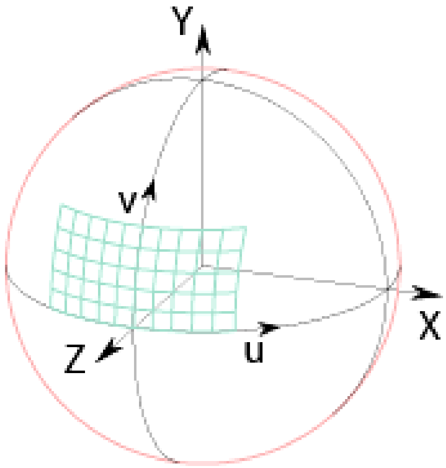

Figure 2: (u,v) coordinate system adopted for the main beam measurements. The beam peak is in the +Z direction (adopted form the GRASP8 technical description).

Main Beam	$\theta_{(MB)}$ (°)	$\varphi_{(MB)}$ (°)	$\psi_{(MB)}$ (°)	U	V
LFI 27	4.3466	153.6074	-22.5000	-0.06789	0.03369
LFI 24	4.0536	180.0000	0.0000	-0.07069	0.00000
LFI 18	3.2975	-131.8147	22.3000	-0.03835	-0.04287

Table 1: Definition of the main beam coordinate system.

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

Beam	theta range	phi range	*u* range	*v* range	delta *u*	delta *v*
LFI 27	[0°, 1.5°]	0° – 360°	[–0.026,+0.026]	[–0.026,+0.026]	1.7E–04	1.7E–04
LFI 24	[0°, 1.5°]	0° – 360°	[–0.026,+0.026]	[–0.026,+0.026]	1.7E–04	1.7E–04
LFI 18	[0°, 1.0°]	0° – 360°	[–0.017,+0.017]	[–0.017,+0.017]	1.7E–04	1.7E–04

Table 2: Angular region and angular step for main beam measurements.

4.2 dB – Level Accuracy

In order to assess the accuracy for main beam measurements three considerations are needed. First of all the uncertainty on the measurements will reflects in the uncertainty on the FWHM estimation or equivalently on the estimation of the beamwidth, σ, if Gaussian profile is assumed. Secondly the uncertainty on σ will reflect on the error on the power spectrum reconstruction, specially at high multipoles. Finally the requirement on the beamwidth shall not exceed the uncertainty derived from the in–flight beam reconstruction for which the pointing accuracy impacts substantially (see [RD 2] and [RD 4]).

A 0.5’ of pointing requirement permits to measure the beamwidth with an accuracy of ±6 arcsec. This gives directly the requirement. At 70 GHz (13’ of FWHM or σ = 5.52) means an error of 1.8%.

In order to translate this error in accuracy of iso–dB levels, we use the approximation that the beam can be model by a symmetric Gaussian function:

$$R(\theta) = e^{-\frac{1}{2}\frac{\theta^2}{\sigma^2}}$$

In decibel (dB) the response can be written as

$$R^{(dB)}(\theta) = -\frac{5}{\ln(10)} \cdot \frac{\theta^2}{\sigma^2}$$

We can estimate the uncertainty on R by

$$\delta R^{(dB)} = \sqrt{\left(\frac{\partial R^{(dB)}}{\partial \sigma}\right)^2 \delta\sigma^2} = 2 \cdot \frac{R^{(dB)}(\theta)}{\sigma}\delta\sigma$$

we used also

$$\theta^2 = -\frac{\ln(10)}{5} R^{(dB)}(\theta) \cdot \sigma^2$$

Then, we obtain that

$$\frac{\delta R^{(dB)}}{R^{(dB)}} = 2 \cdot \frac{\delta\sigma}{\sigma} = 2 \cdot 1.8\% = 3.6\%$$

In Table 3 the accuracy we require for the main beam measurements is reported. The accuracy is given in dB for each iso–dB level of interest below the main beam peak. The values in table shall be applied to all the LFI channels.

Iso–Level dB	Accuracy dB
–3	± 0.1
–5	± 0.2
–10	± 0.4
–15	± 0.5
–20	± 0.7
–40	± 1.4
–60	± 2.2
–80	± 3.0

Table 3: Accuracy requirements for main beam measurements.

5 STRAY LIGHT ZONE

Stray light zone is defined as the angular region of the pattern within a cone of ±32° of angle toward the -Xsc axis. The cone vertex in Figure 3 is at the Telescope reference frame origin.

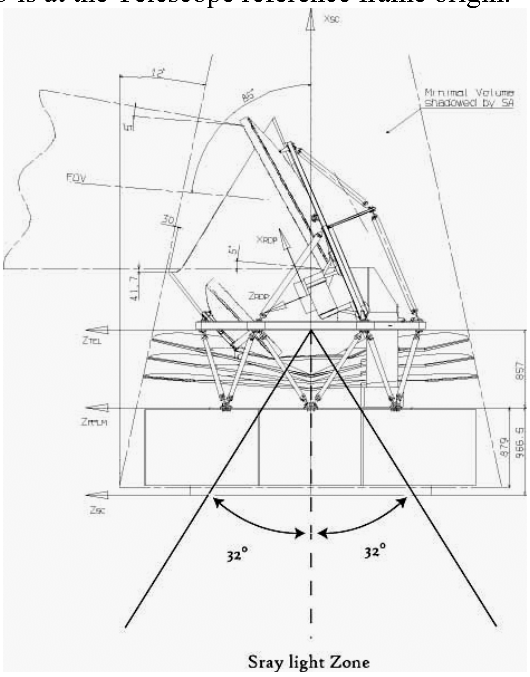

Figure 3: Stray light zone definition.

5.1 REFERENCE FRAME AND ANGULAR STEP

Two coordinate systems and then two different setup are proposed for the stray light pattern measurements.

[S1] Regular spherical grid (theta,phi) centred in the main beam peak (left panel of **Figure 4**). The same system is defined in GRASP8 as Elevation over Azimuth regular grid (see left panel of **Figure 5**).

Elevation Range	Azimuth Range	Elevation Step	Azimuth Step
from –32° to +32°	from –32° to +32°	0.7°	0.7°

[S2] Regular (theta,phi) coordinate system centred in the anti–spin axis (right panel of **Figure 4** and **Figure 5**).

θ Range	ϕ Range	θ Step	θ Step
from 0° to +32°	from 0° to +180°	1°	1°

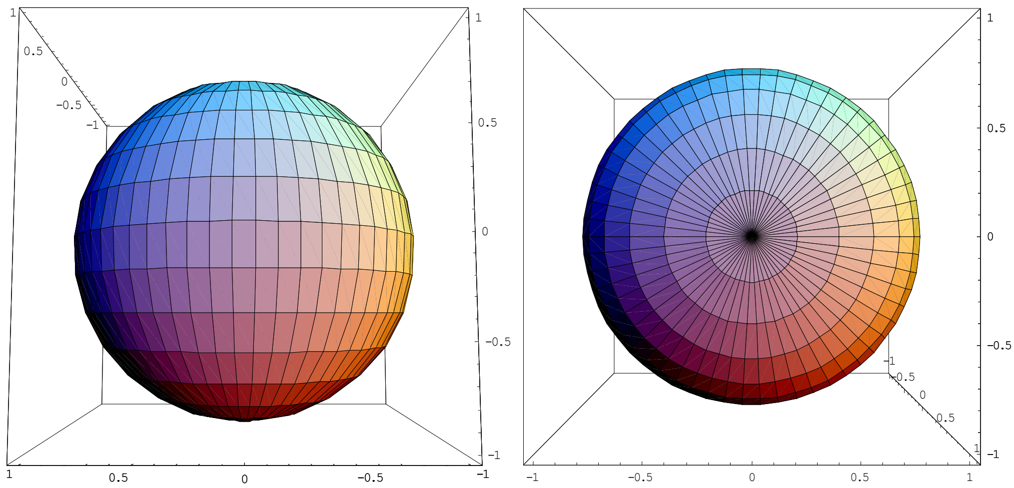

Figure 4: The two reference frames as seen by the Sun

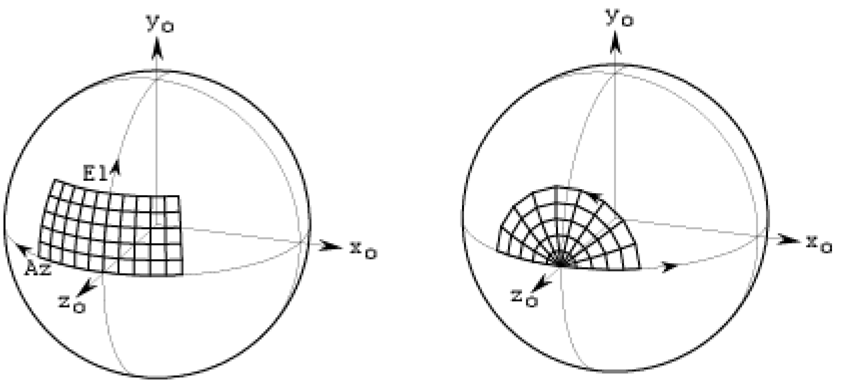

Figure 5: Definition of the two reference frames (from GRASP Technical Description)

5.2 ACCURACY

At a certain dB level (dB below the main beam peak) the measurement (dB) ± error (δdB) shall not exceed the LFI straylight rejection requirement from Sun .
When the measured dB level is approaching the requirement, the maximum error shall not exceed 1dB.

$$\delta \mathrm{dB} \le Max(\mathrm{dB} - \mathrm{Req}, 1\mathrm{dB})$$

dB and Req are defined as positive numbers.

For simplicity we report in **Table 4** with the accuracies at various dB levels. However, with the formula above, it is possible to calculate the error at any dB level.

Channel	Rejection from Sun dB	dB level below the peak	accuracy dB
LFI 27	94	94	1
		96	2
		98	4
		100	6
		110	16
LFI 24	96	96	1
		98	2
		100	4
		110	14
LFI 18	101	101	1
		104	3
		107	6
		110	9
		120	19

Table 4: Accuracy required for stray light zone measurements

6 SPILLOVER ZONE

The spillover zone is defined by imposing a threshold at 80 dB down to the beam peak for each channel. The resulting patterns are shown in the Figure 6, Figure 7, and Figure 8, from which the angular regions have been extracted (yellow rectangles) and reported in Table 5.

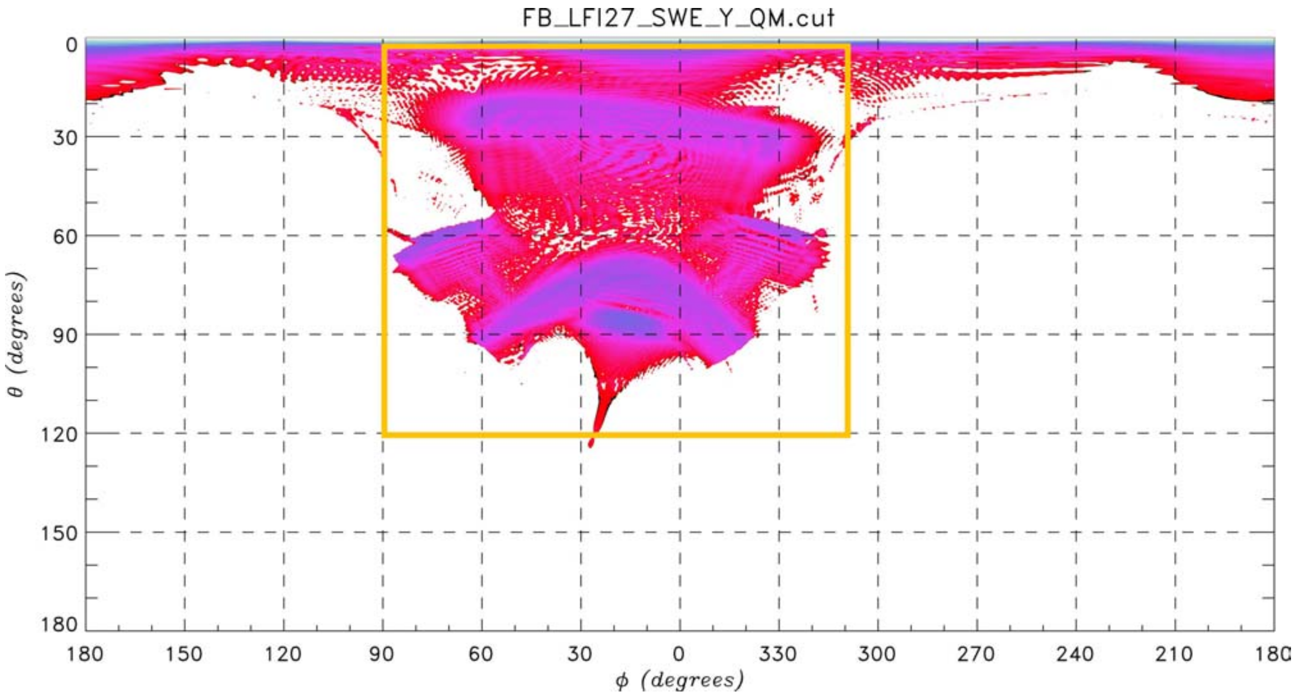

Figure 6: Spillover zone identified for the LFI 27 beam pattern

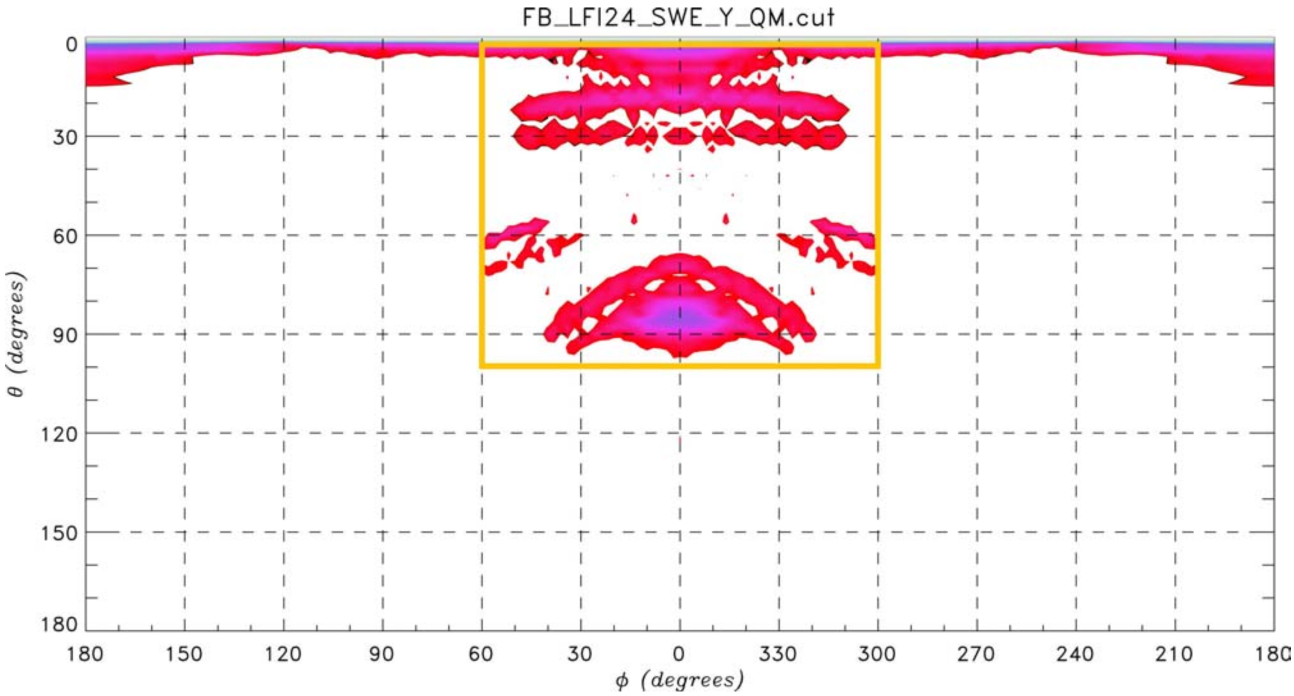

Figure 7: Spillover zone identified for the LFI 24 beam pattern

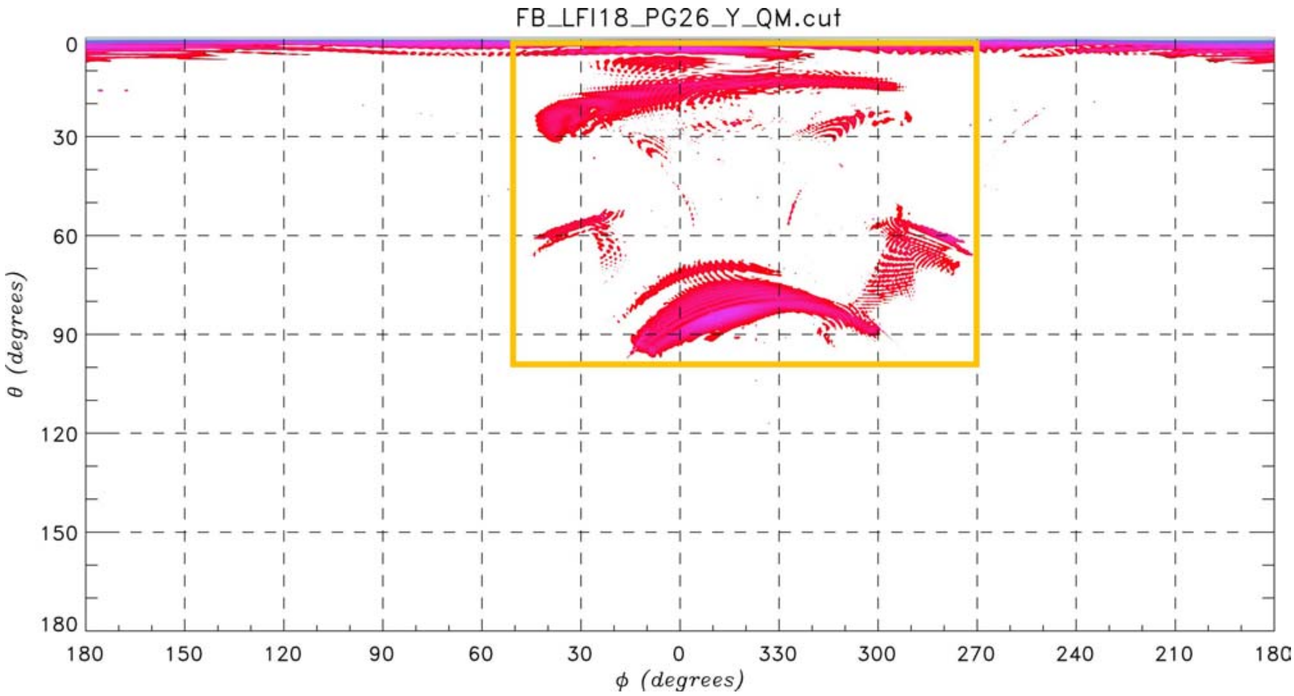

Figure 8: Spillover zone identified for the LFI 18 beam pattern

6.1 REFERENCE FRAME AND ANGULAR STEP

The coordinate system is the main beam coordinate system as defined in **Table 1**.

Beam	θ range	Δθ	ϕ range	Δϕ
LFI 27	$0° < \theta < 120°$	2°	$310° < \phi < 360° \cup 0° < \phi < 90°$	2°
LFI 24	$0° < \theta < 100°$	2°	$300° < \phi < 360° \cup 0° < \phi < 60°$	2°
LFI 18	$0° < \theta < 100°$	2°	$270° < \phi < 360° \cup 0° < \phi < 50°$	2°

Table 5: Angular region and step for the spillover zone of each beam

6.2 ACCURACY

For each spillover zone the maximum has been found. The requirement on the accuracy of the spillover zone measurements is motivated by the necessity to provide a reasonably accurate check of optical simulations to be able to reliably subtract the Galactic straylight contamination
in the time ordered data during the data analysis. From recent accurate studies [RD 5][RD 6] and very recent simulations and 70 GHz, the expected peak-to-peak (rms) Galactic straylight contamination is of about 6–7 μK (0.3–1.3 μK) both from the intermediate pattern region and the far sidelobes at 30 GHz, and of about 3μK (0.3 μK) at 70 GHz. Of course, only if the beam pattern is accurately known this spurious signal can be reduced in the data analysis by simulating the effect on the sky maps derived from Planck. An uncertainty of

3dB (a factor 2) on the pattern measurement in the spillover zone would imply in practice that the correction for this effect will be affected by an uncertainty level similar to level of the effect that has to be subtracted. Our requirements should be then significantly better, particularly close to the maximum spillover zone.
The accuracy is set to be 1dB maximum at the maximum level of the spillover reported in Table 6. At various dB – isolevel the accuracy requirements are listed in Table 7.

This requirements assure that, assuming the same pattern in flight, the straylight effect can be reduced during the data analysis to about 25% of the unsubtracted one, i.e. in terms of peak-to-peak signal to few uK at 30 GHz and to less than 1 μK at 70 GHz, which is the best cosmological channel for LFI.

Beam	Max dBi	Max dB below the peak	(θ,ϕ) coordinates	Accuracy at this level
LFI 27	–3.52	–54.45	(85.0°,16.5°)	1 dB
LFI 24	–5.59	–59.65	(86.0°,0.0°)	1 dB
LFI 18	–5.33	–63.71	(–84.5°,170.0°)	1 dB

Table 6: Maximum spillover signal and accuracy at maximum for each beam.

Channel	dB level below the peak	accuracy dB
LFI 27	54 ÷ 66	1
	67 ÷ 70	2
	71 ÷ 80	3
LFI 24	60 ÷ 66	1
	67 ÷ 70	2
	71 ÷ 80	3
LFI 18	64 ÷ 66	1
	67 ÷ 70	2
	71 ÷ 80	3

Table 7: Accuracy requirements at various dB – isolevels for spillover zone measurements.

Of course, an accuracy of 1dB is required in each spillover region where, possibly, the measured response is larger than 54, 60, 64 dB respectively for LFI 27, 25, 18.