TESRE

LFI Project System Team

Planck LFI

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CHANGE RECORD

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1.0	March '01	All	First Issue of the Document	

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1 Introduction

In order to optimise the angular resolution (10 arcmin at 100GHz as a goal, 12 arcmin as a requirement) and at the same time to minimise all the systematics coming from the side lobes of the radiation pattern, it is necessary to carry out a detailed study of the optical interfaces. The side lobes level is driven by the so called Edge Taper, which is defined as the ratio between the power incident at the centre of the reflector and the power incident at the reflector edges. A strong taper (or an high value of the Edge Taper) means a strong under–illumination of the reflector which implies a degradation of the angular resolution. On the contrary, increasing the illumination of the telescope (low values of the Edge Taper) improves the angular resolution and degrades the stray light rejection of the telescope. The Edge Taper can be modified by changing the feed horn design, and thus how the horn illuminates the telescope can be controlled.

A preliminary study of the primary mirror Edge Taper of the Planck telescope baseline configuration (CASE1 design) is reported here. Because of the symmetry of the Planck Focal Plane Unit, this study has been limited to 15 LFI feed horns.

The simulations have been carried out in the transmitting mode using GRASP8 software package.

2 Focal Plane Unit Configuration and Feed Locations

The location of the LFI feed horns on the Planck Focal Plane is reported in Fig. 2-1. The axes are the X– and Y– axes of the Reference Detector Plane System. Because of the Planck/LFI Focal Plane Layout, the illumination of the telescope is depending on the feed location. Due to the symmetry of the Focal Plane and of the Telescope, fifteen horns illuminate the telescope in different ways. Moreover, for the same feed the edge taper is not a constant value but varies along the mirror contour.

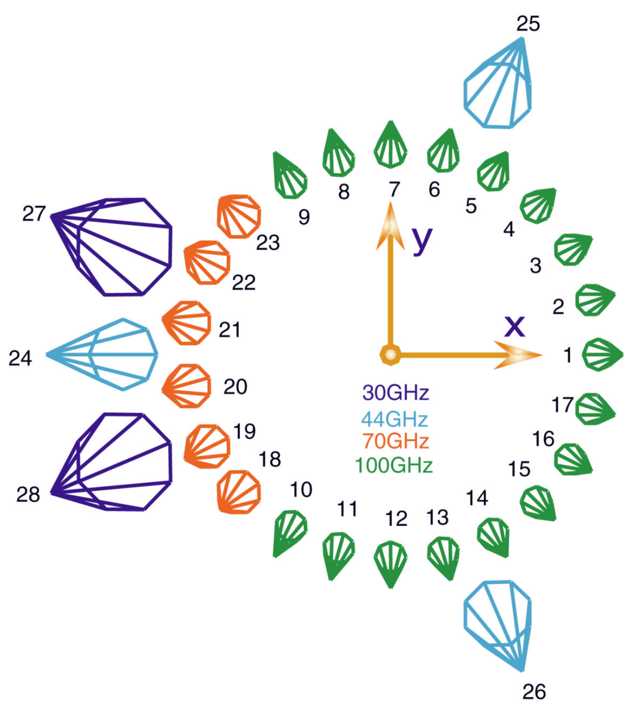

Fig. 2-1: *Planck/LFI Focal Plane Unit configuration.*

The feed horns listed in Table 2-1 have been considered for the calculations.

Name	Frequency [GHz]	Location (X_{RDP},Y_{RDP},Z_{RDP}) [mm,mm,mm]			Orientation (θ,φ,ψ) [°,°,°]		
FH1	100	104,41	0,00	-19,58	12,48	180,00	-180,00
FH2	100	100,77	27,23	-19,06	12,42	-165,81	-157,16
FH3	100	90,12	52,43	-17,56	12,26	-151,26	-156,78
FH4	100	73,22	73,69	-14,72	12,09	-136,19	-133,79
FH5	100	51,46	89,57	-11,19	11,96	-120,75	-109,64
FH6	100	26,42	98,97	-6,80	11,92	-105,32	-109,00
FH7	100	-0,08	101,32	-1,47	11,91	-90,24	-90,24
FH8	100	-26,15	96,77	3,98	11,87	-75,61	-70,99
FH9	100	-50,03	85,77	9,67	11,74	-61,23	-70,31
FH21	70	-101,46	15,79	20,91	11,38	-9,72	-22,69
FH22	70	-91,82	46,04	18,36	11,63	-28,71	-23,14
FH23	70	-76,44	69,10	13,98	11,93	-44,31	-23,82
FH24	44	-136,32	0,00	21,37	14,89	0,00	0,00
FH25	44	54,44	131,24	-17,48	16,20	-113,38	-113,38
FH27	30	-134,91	54,09	19,39	15,56	-23,01	-22,61

Table 2-1: *LFI Horns locations in the Focal Plane Unit in the Reference Detector Plane coordinate system. The pointing direction of each feed horn has been reported in the last three columns (the definition of the angles follows the GRASP8 notation)*

3 Field Distribution on Primary Mirror

The contour plots of the amplitude field incident on the main reflector have been calculated for the feed horns reported in Table 2-1. The field distribution has been computed in a surface grid with 301 x 301 points. The model of the feed we used is a X– axis polarised gaussian with an edge taper of 30 dB at 22° of angle (this feed illumination function has been used as the baseline for the Carrier Telescope Configuration). The axes of the contour plot are the X– and Y– axis in which the telescope is defined in GRASP software. The X– axis runs on the symmetry plane of the telescope while the Y– axis is on the asymmetry plane. The +Z direction, which corresponds to the main beam direction, is pointing orthogonal and then outward to the plane XY. As a conseguence, the top edge of the main reflector is at X ~ 750mm and Y~ 0mm on the contour plot coordinate system. We used the Geometrical Optics (GO) and the Geometrical Theory of Diffraction[1] (GTD) on the sub reflector to calculate the total amplitude[2] of the field incident on the surface of the primary mirror, in the reference system of the main beam (the system has the Z– axis along the direction of the main beam peak and the XY– plane perpendicular to this direction).

Figures from Fig. 3-1 to Fig. 3-15 show that, as expected, the illumination of the primary mirror is roughly elliptical. As a consequence the field amplitude on the primary mirror rim is not constant.

[1] A detailed description of these methods is reported in the *Technical Description of GRASP8* (TICRA.Doc. No. S-894-02, Knud Pontoppidan, 1999).

[2] The total amplitude in dB is defined as $E_{tot}^{dB} = 20 \cdot \log \sqrt{E_x^2 + E_y^2 + E_z^2}$

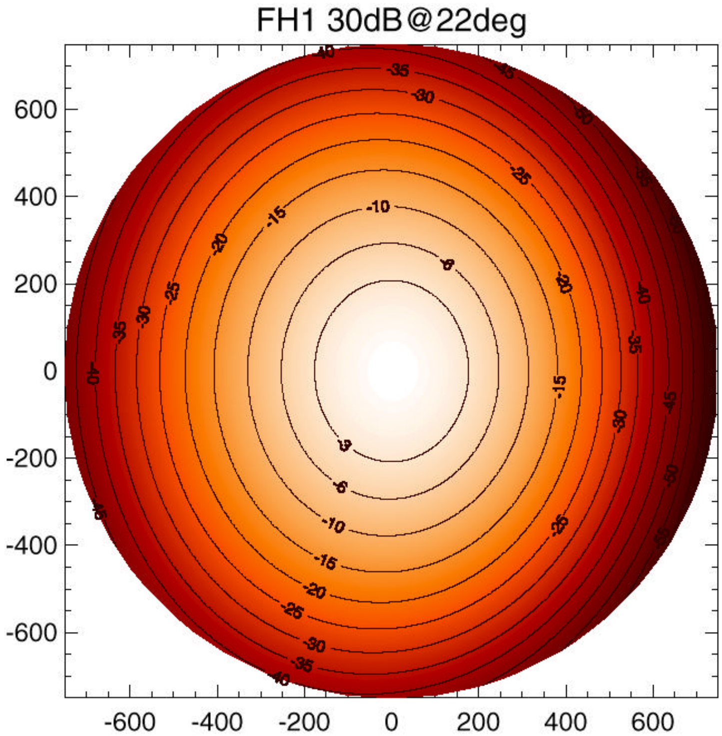

Fig. 3-1: *Feed Horn # 1: Field Distribution on the main reflector*

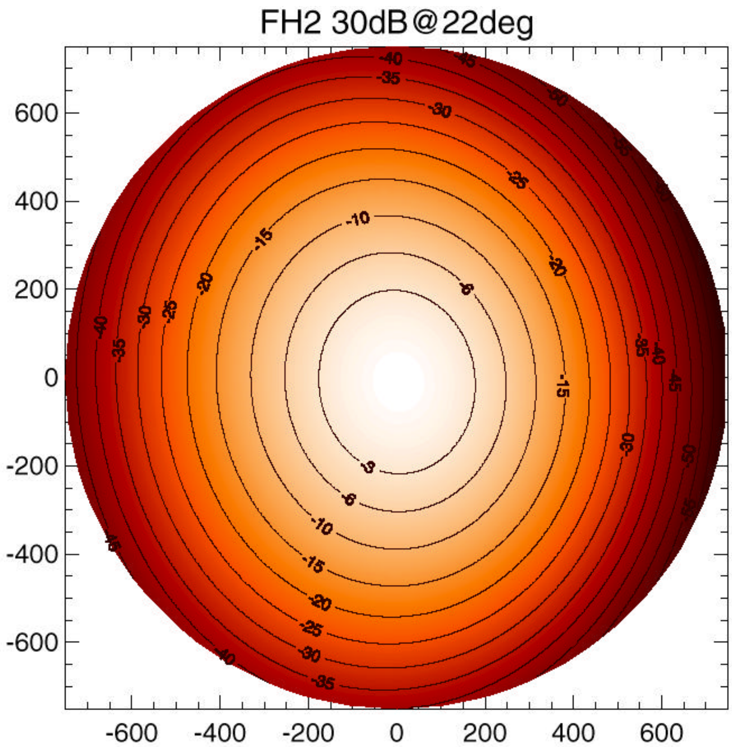

Fig. 3-2: *Feed Horn # 2: Field Distribution on the main reflector*

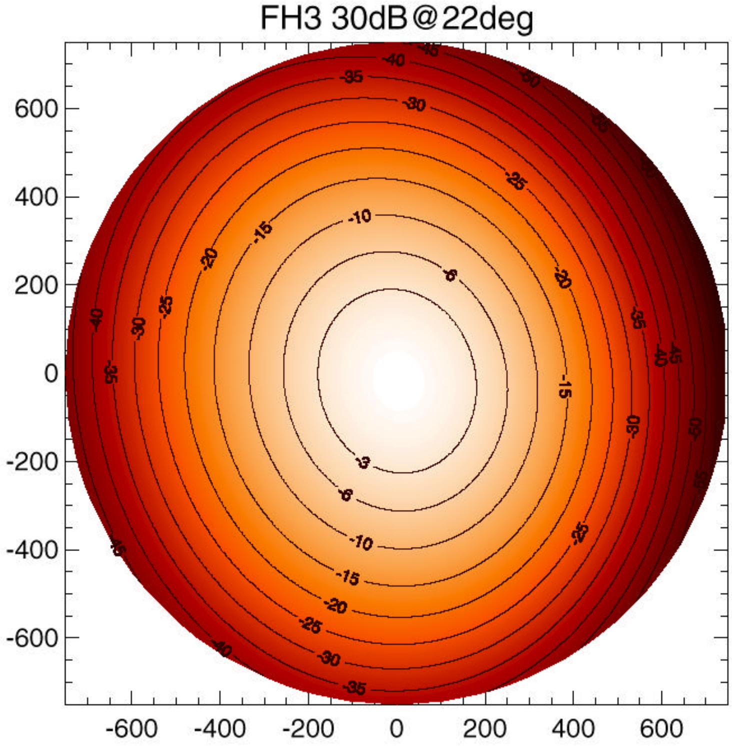

Fig. 3-3: *Feed Horn # 3: Field Distribution on the main reflector*

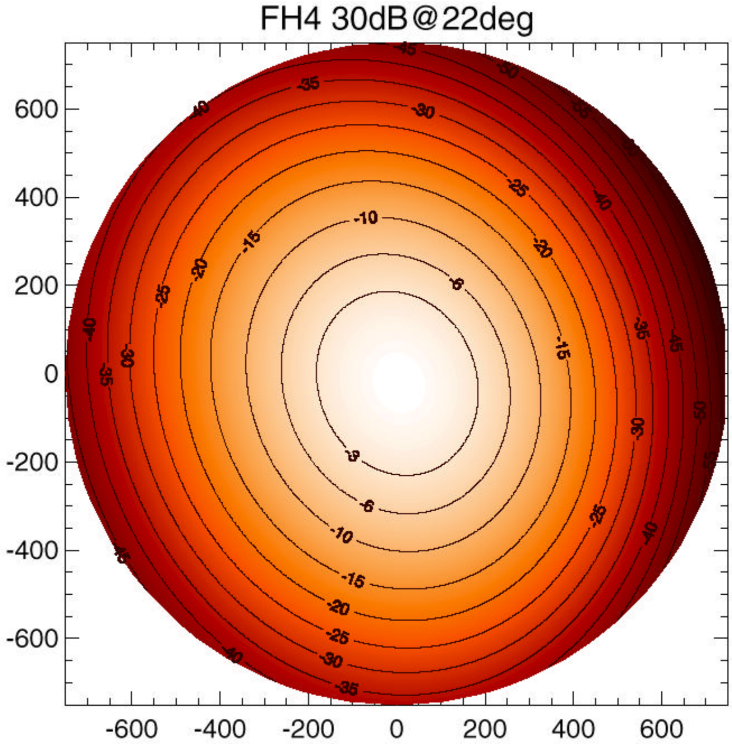

Fig. 3-4: *Feed Horn # 4: Field Distribution on the main reflector*

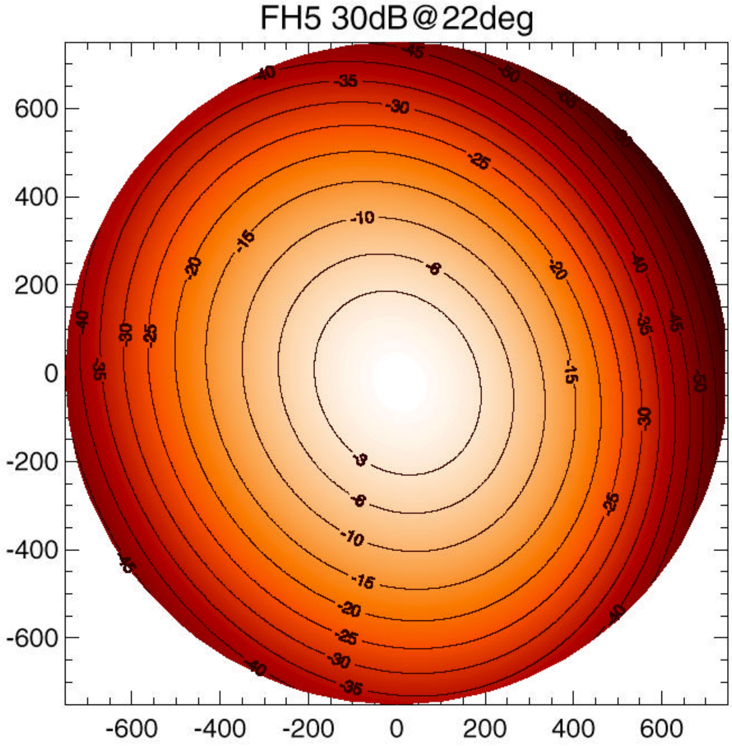

Fig. 3-5: *Feed Horn # 5: Field Distribution on the main reflector*

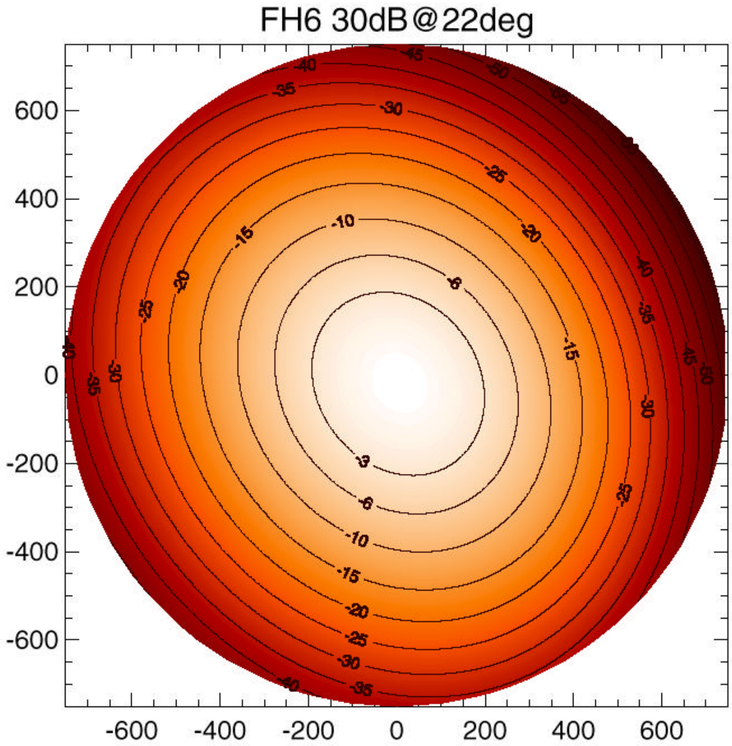

Fig. 3-6: *Feed Horn # 6: Field Distribution on the main reflector*

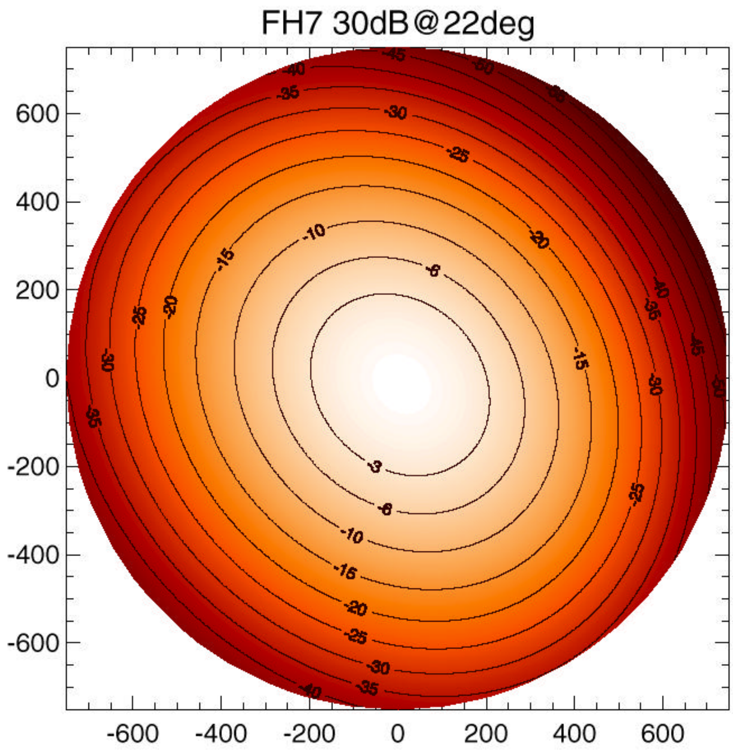

Fig. 3-7: *Feed Horn # 7: Field Distribution on the main reflector*

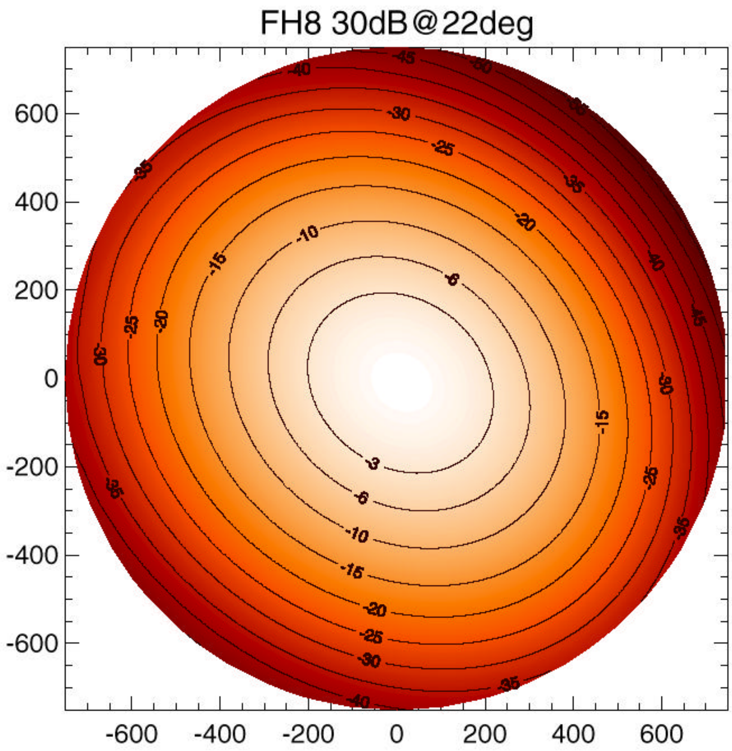

Fig. 3-8: *Feed Horn # 8: Field Distribution on the main reflector*

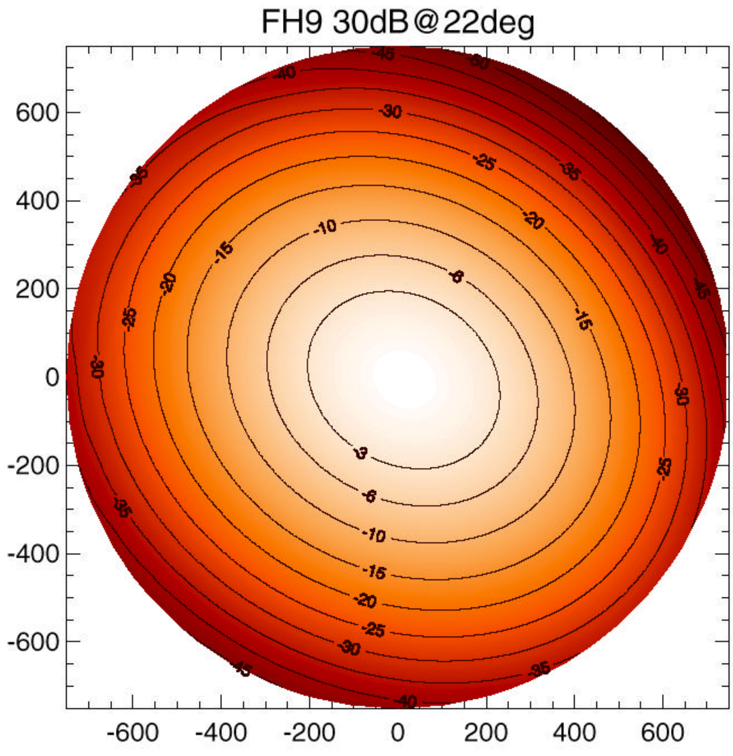

Fig. 3-9: *Feed Horn # 9: Field Distribution on the main reflector*

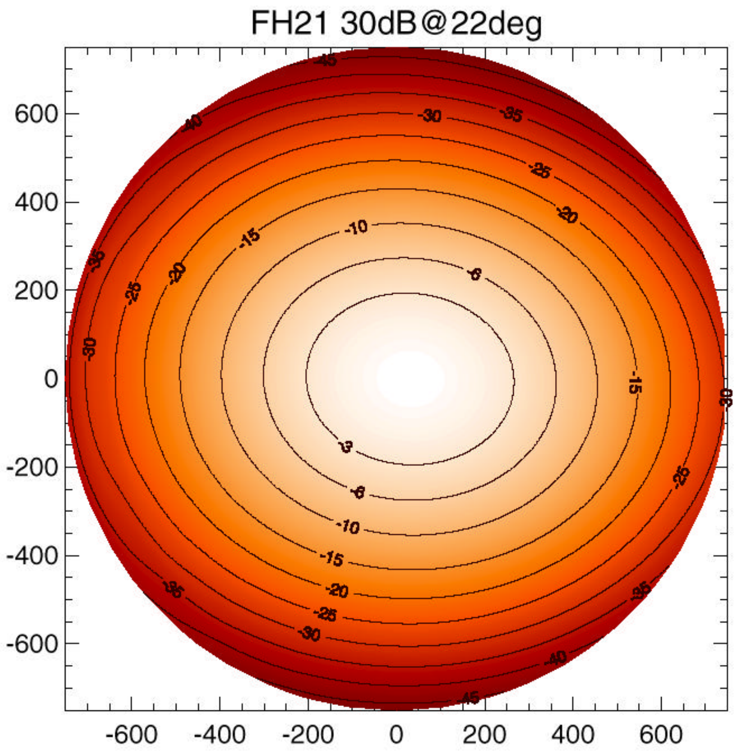

Fig. 3-10: *Feed Horn # 21: Field Distribution on the main reflector*

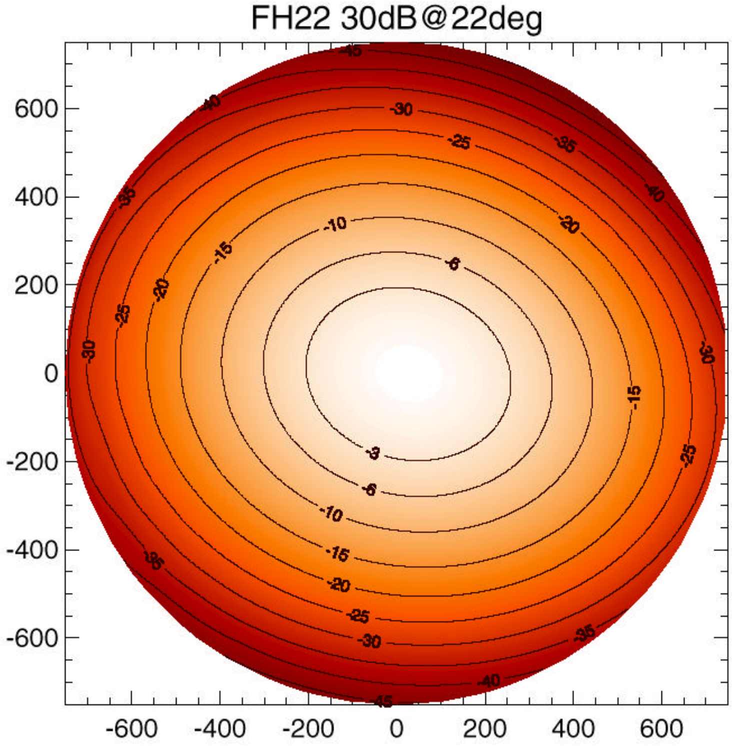

Fig. 3-11: *Feed Horn # 22: Field Distribution on the main reflector*

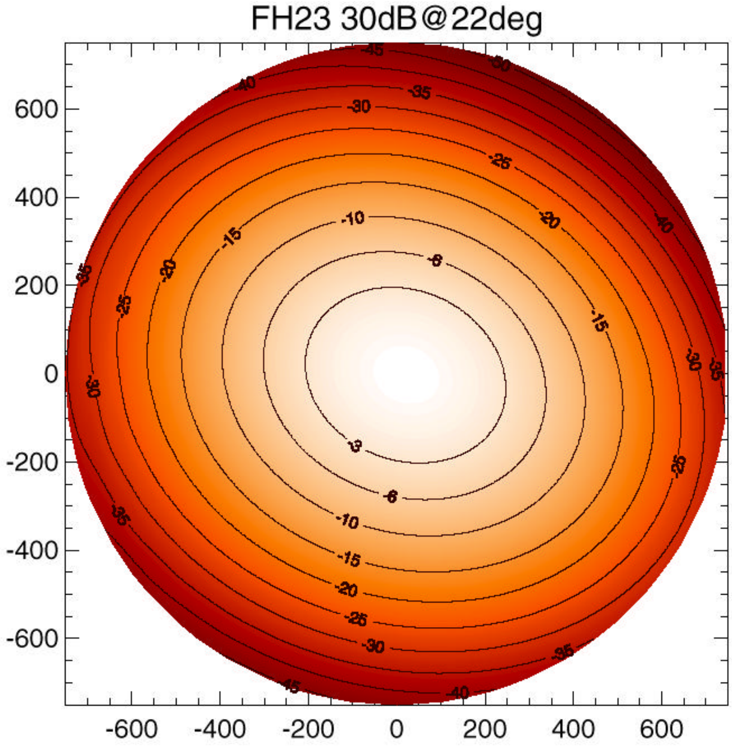

Fig. 3-12: *Feed Horn # 23: Field Distribution on the main reflector*

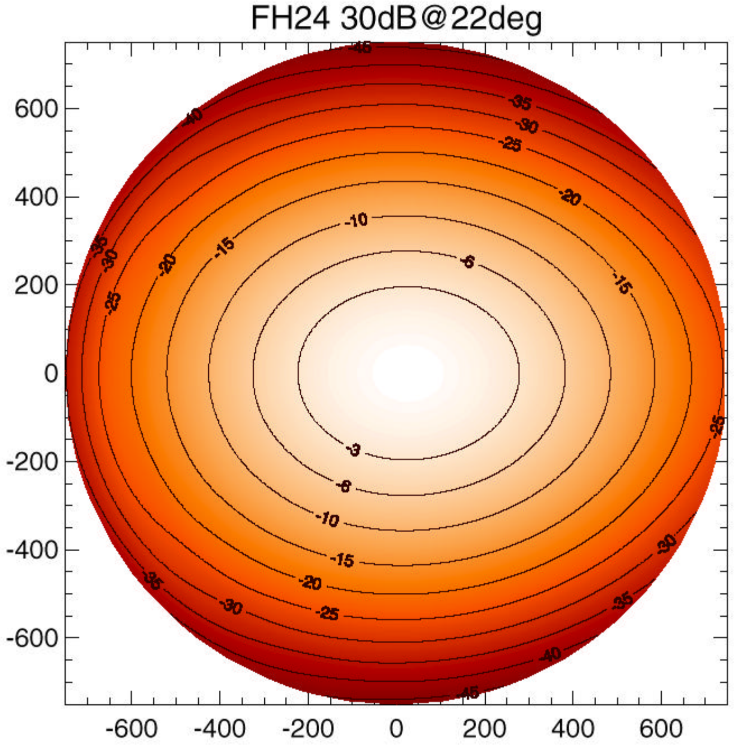

Fig. 3-13: *Feed Horn # 24: Field Distribution on the main reflector*

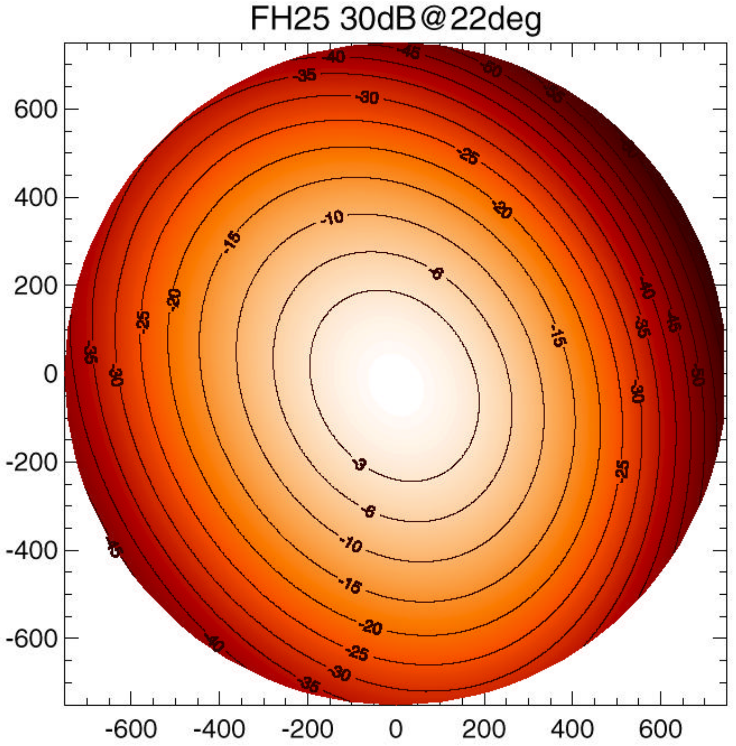

Fig. 3-14: *Feed Horn # 25: Field Distribution on the main reflector*

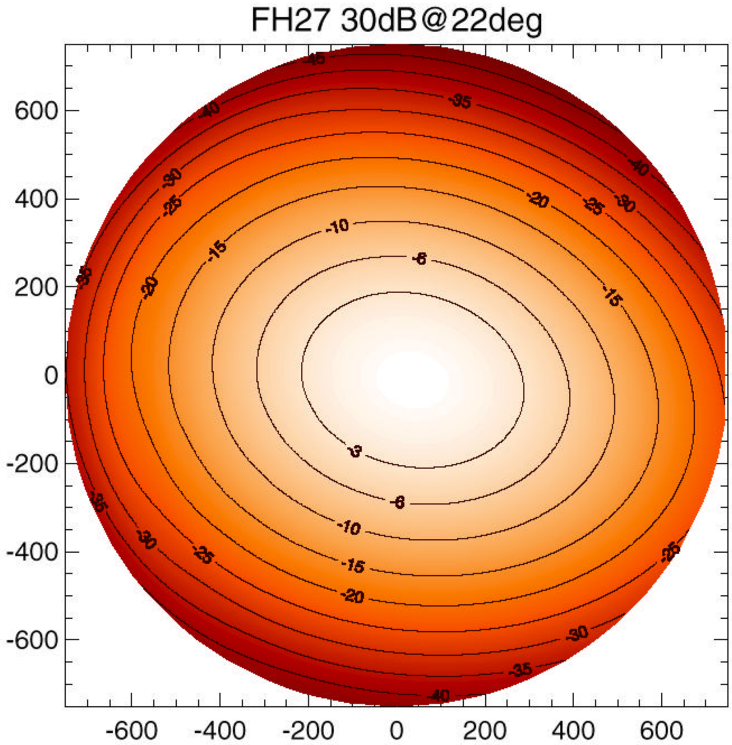

Fig. 3-15: *Feed Horn # 27: Field Distribution on the main reflector*

4 Edge Taper Values evaluation

It is readily seen that a taper of 30 dB @ 22 degree means a strong under–illumination of the primary mirror for the CASE1 configuration for almost all the LFI feeds. In order to improve the angular resolution some relaxation of the edge taper can be accepted.

The required edge taper has been evaluated by comparing the main reflector power distribution of each feed horn and that of the LFI feed #27 of the Carrier Configuration[3] hereafter "Reference Feed". The degradation assumed has been evaluated by obtaining an edge taper around the primary mirror rim such that in each point of the rim the edge taper is at least as large as the Reference Feed. In Table 4-1 we report, for each feed, the lowest edge taper value along the rim after optimisation. These values are calculated assuming gaussian illumination.

# FH	REFERENCE dB @ deg	EDGE TAPER dB @ deg
27	30dB @ 22	23.64 @ 19.73
25	30dB @ 22	27,79 @ 22,58
24	30dB @ 22	25.20 @ 19.73
23	30dB @ 22	21.52 @ 22.49
22	30dB @ 22	23.56 @ 22.18
21	30dB @ 22	25.11 @ 22.04
9	30dB @ 22	23.27 @ 23.05
8	30dB @ 22	25.10 @ 23.31
7	30dB @ 22	26.50 @ 23.57
6	30dB @ 22	27.03 @ 23.74
5	30dB @ 22	27.27 @ 23.95
4	30dB @ 22	28.78 @ 24.25
3	30dB @ 22	29.71 @ 24.51
2	30dB @ 22	30.13 @ 24.77
1	30dB @ 22	30.50 @ 25.01

Table 4-1: *Reference values of the taper and updated values of the edge taper for the LFI feed horns. The values reported are the worst edge taper around the primary reflector rim. For the FH#27, FH#25 and FH#24 the edge tapers have been simply reported at different angles, since the gaussian illumination function has not been modified (30dB @ 22 degree).*

[3] The Carrier Configuration has been used for calculating extensively the stray light contamination at 30 GHz. The Stray light Induced Noise (SIN) of this configuration has been derived both by ESA and LFI team. The SIN contribution resulted few micro Kelvin at 30 GHz.

5 Main Beam Response

The main beam pattern has been simulated for each feed horn, with the edge taper values found. The contour plots normalized at peak gain are shown in Figures 5.1 – 5.15 . Each beam is centred on the relative beam axis. The contour lines plotted are -3, -6, -10, -15, -20, -25, -30, -35, -40, -45 dB. In Table 5-1 are shown the corresponding angular resolution.

Feed Horn	Frequency (GHz)	HWHM Min (°)	HWHM Max (°)	HWHM Average (°)	FWHM (arcmin)	Ellipticity	Directivity (dBi)
FH27	30	0.243	0.336	0.290	34.74	1.38	50.55
FH25	44	0.204	0.251	0.228	27.30	1.23	52.46
FH24	44	0.170	0.235	0.203	24.30	1.38	53.62
FH23	70	0.103	0.130	0.117	13.98	1.26	58.38
FH22	70	0.103	0.134	0.119	14.22	1.30	58.21
FH21	70	0.105	0.137	0.121	14.52	1.30	58.08
FH9	100	0.077	0.097	0.087	10.44	1.26	60.74
FH8	100	0.082	0.101	0.092	10.98	1.23	60.31
FH7	100	0.086	0.105	0.096	11.46	1.22	59.92
FH6	100	0.091	0.108	0.100	11.94	1.19	59.63
FH5	100	0.093	0.110	0.102	12.18	1.18	59.41
FH4	100	0.097	0.114	0.106	12.66	1.18	59.20
FH3	100	0.099	0.114	0.107	12.78	1.15	59.09
FH2	100	0.101	0.114	0.108	12.90	1.13	59.05
FH1	100	0.099	0.114	0.107	12.78	1.15	59.05

Table 5-1: *Maximum, minimum and average Half Width Half Maximum (HWHM), the average FHWM (in arcmin), the ellipticity for the LFI feed horns. The last column is the directivity in dBi of the calculated beams.*

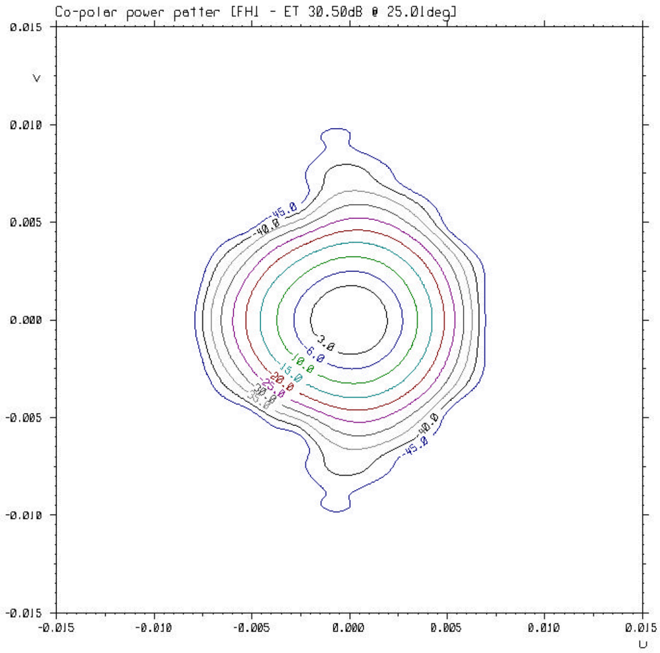

Fig. 5-1: *UV – plot of the beam at 100 GHz Feed Horn 1, ET 30.50 dB @ 25.01°*

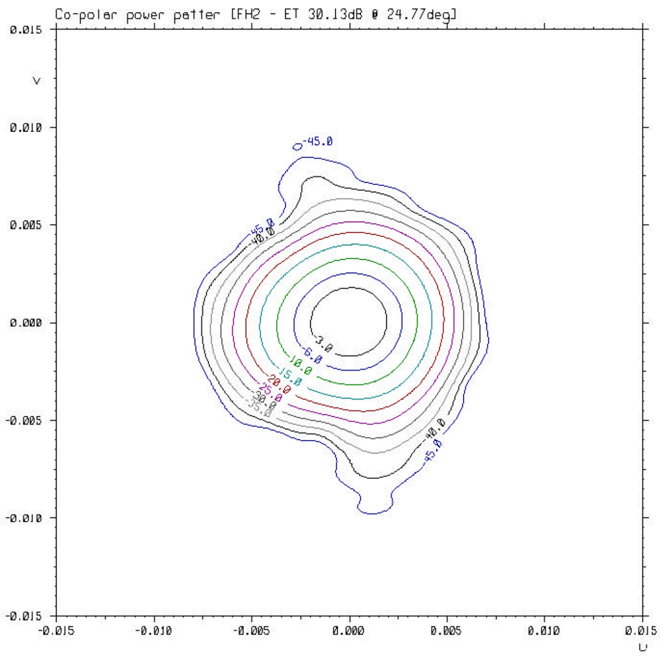

Fig. 5-2: *UV – plot of the beam at 100 GHz Feed Horn 2, ET 30.13 dB @ 24.77°*

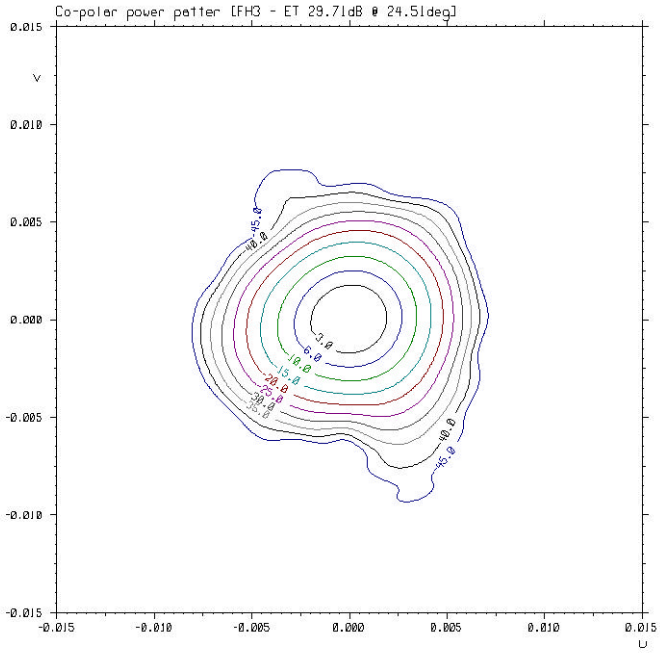

Fig. 5-3: *UV – plot of the beam at 100 GHz Feed Horn 3, ET 29.71 dB @ 24.51°*

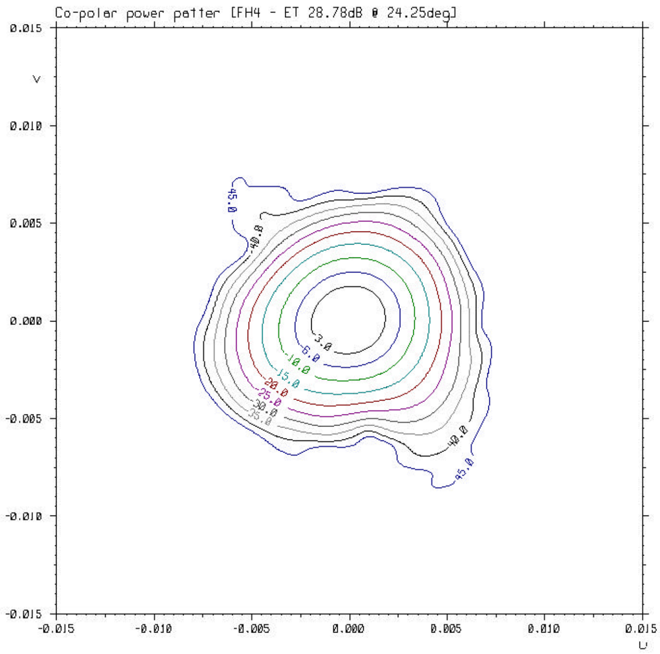

Fig. 5-4: *UV – plot of the beam at 100 GHz Feed Horn 4, ET 28.78 dB @ 24.25°*

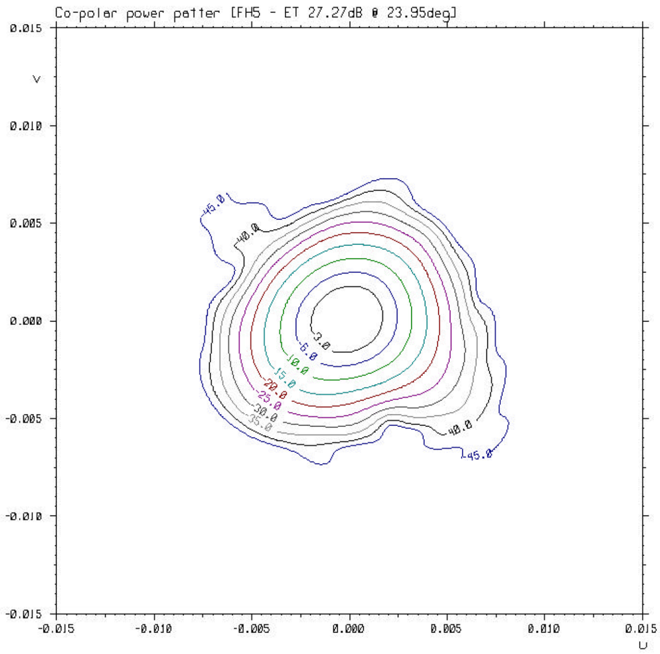

Fig. 5-5: *UV – plot of the beam at 100 GHz Feed Horn 5, ET 27.27 dB @ 23.95°*

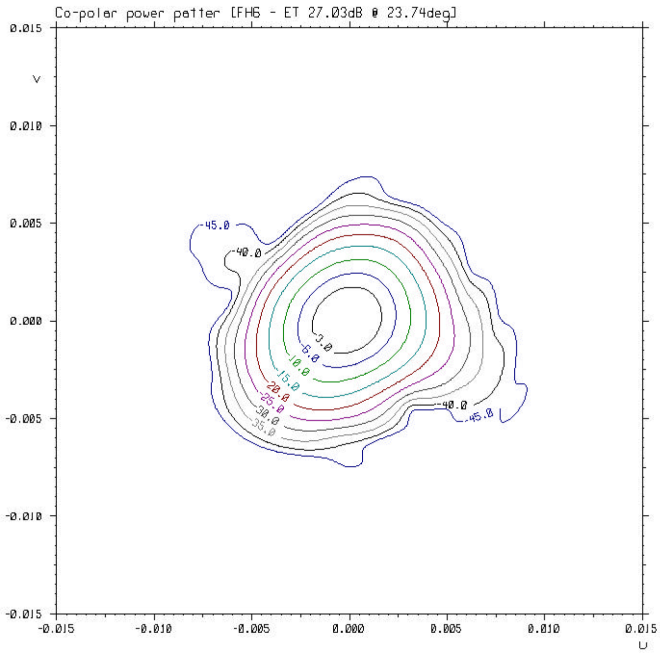

Fig. 5-6: *UV – plot of the beam at 100 GHz Feed Horn 6, ET 27.03 dB @ 23.74°*

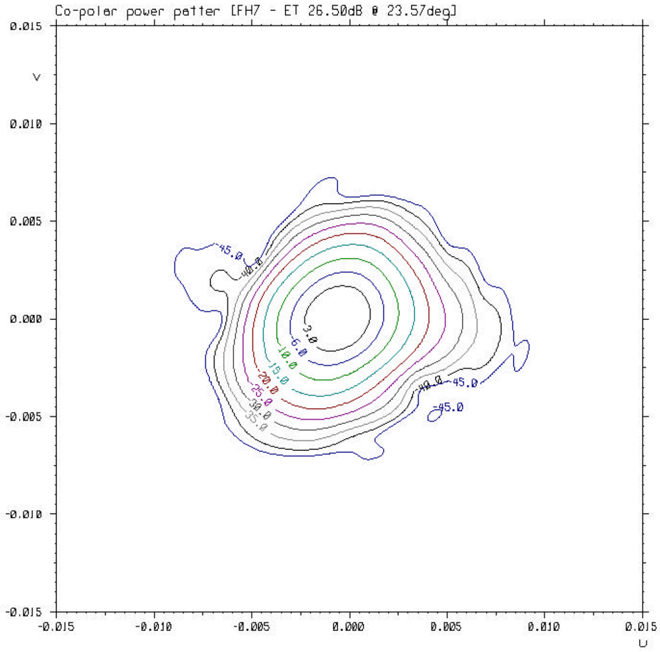

Fig. 5-7: *UV – plot of the beam at 100 GHz Feed Horn 7, ET 26.50 dB @ 23.57°*

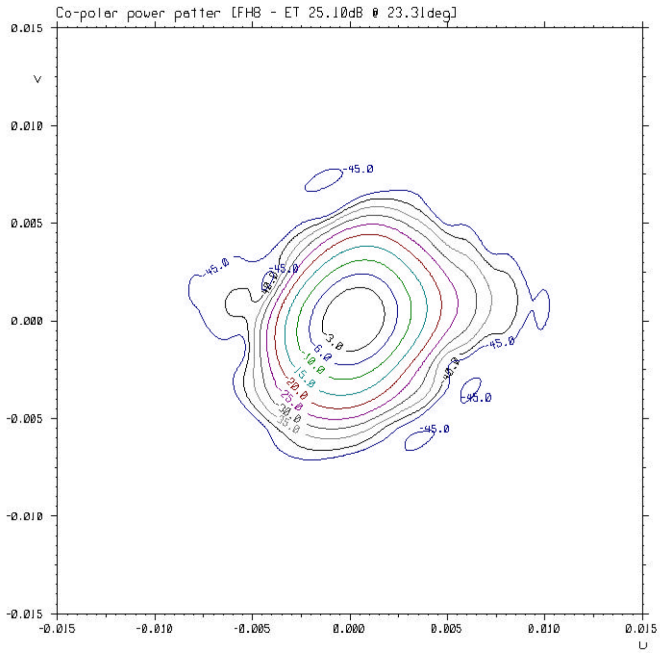

Fig. 5-8: *UV – plot of the beam at 100 GHz Feed Horn 8, ET 25.10 dB @ 23.31°*

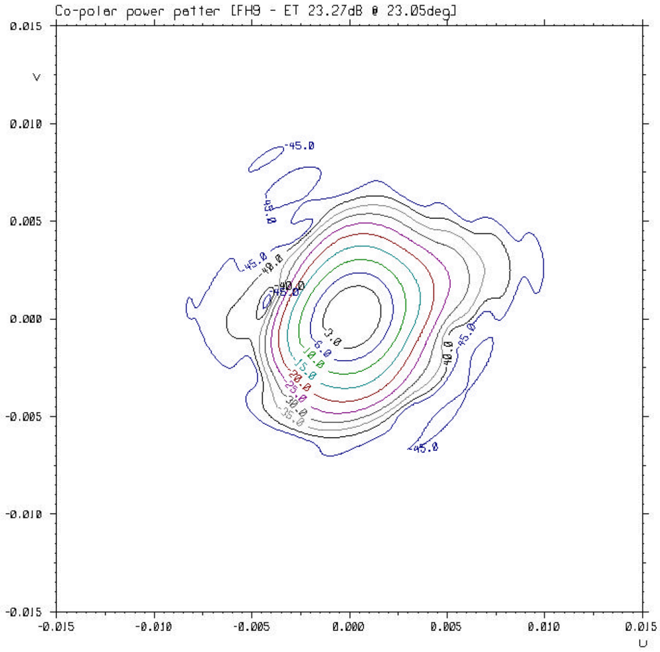

Fig. 5-9: *UV – plot of the beam at 100 GHz Feed Horn 9, ET 23.27 dB @ 23.05°*

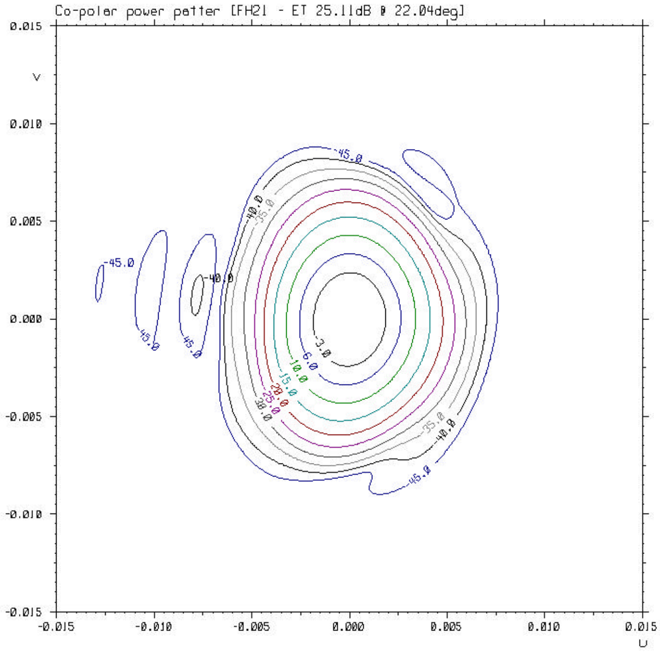

Fig. 5-10: *UV – plot of the beam at 70 GHz Feed Horn 9, ET 25.11 dB @ 22.04°*

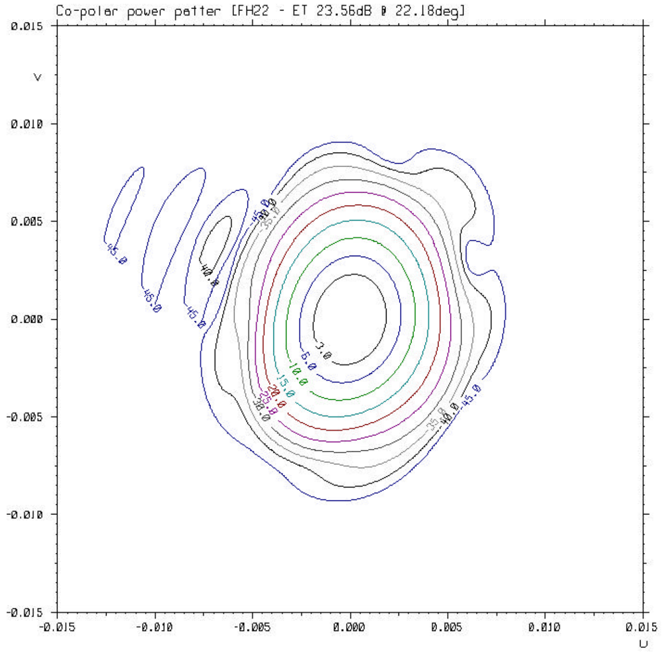

Fig. 5-11: *UV – plot of the beam at 70 GHz Feed Horn 22, ET 23.56 dB @ 22.18°*

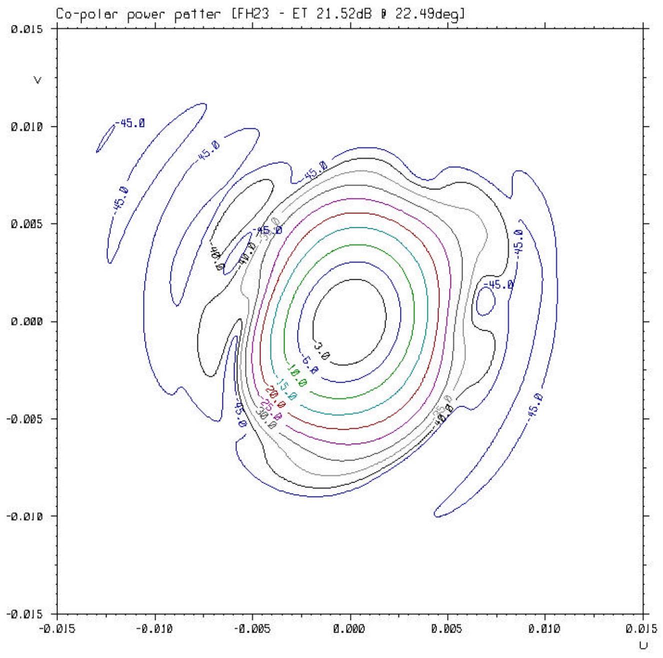

Fig. 5-12: *UV – plot of the beam at 70 GHz Feed Horn 23, ET 21.52 dB @ 22.49°*

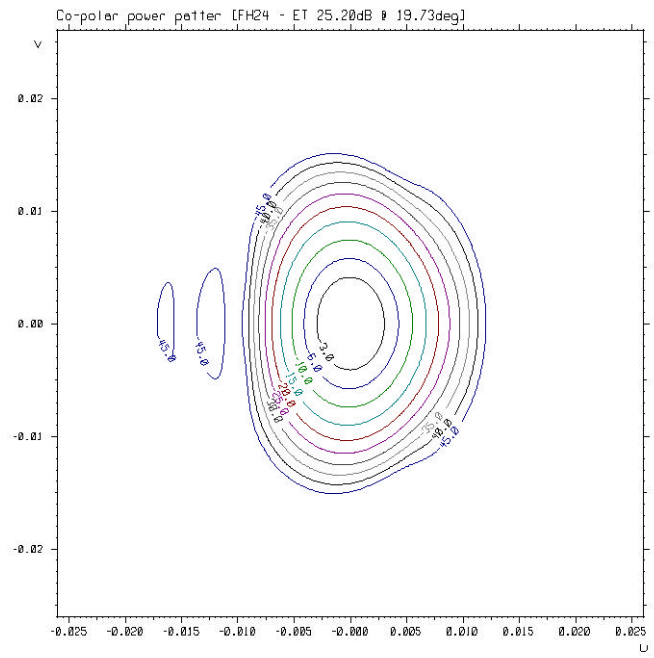

Fig. 5-13: *UV – plot of the beam at 44 GHz Feed Horn 24, ET 25.20 dB @ 19.73°*

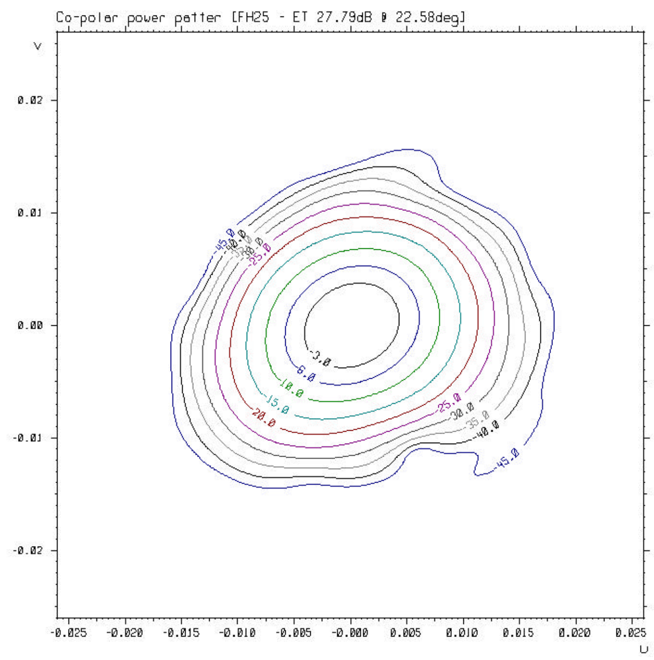

Fig. 5-14: *UV – plot of the beam at 44 GHz Feed Horn 25, ET 27.79 dB @ 22.58°*

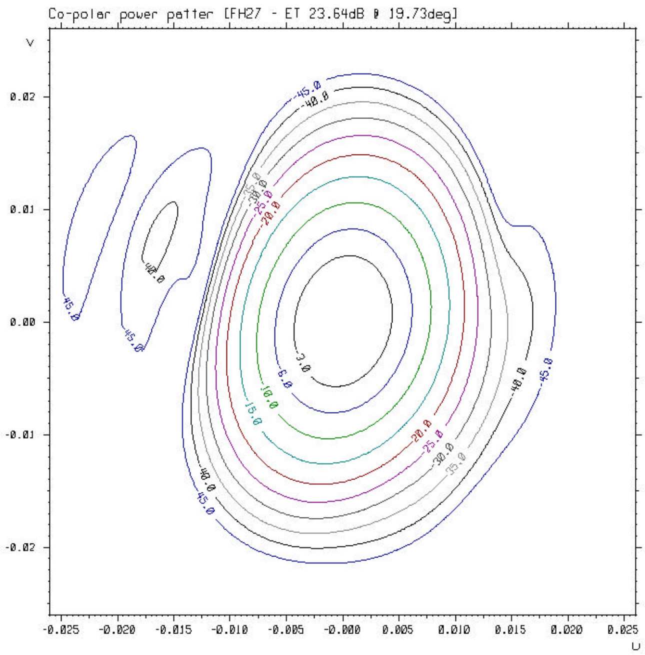

Fig. 5-15: *UV – plot of the beam at 30 GHz Feed Horn 27, ET 23.64 dB @ 19.73*

6 Conclusions

The amplitude field distribution on the primary mirror of the Planck baseline telescope has been calculated and reported assuming a feed illumination of 30 dB at 22 degree from axis as a reference.

By comparing the field power level on the primary mirror rim of the Carrier Configuration at 30GHz, new values of the edge taper have been obtained for the LFI feed horns coupled to the baseline telescope configuration (CASE1).

These updated values of the illumination function (feed horn pattern taper), reported in Table 4-1, give an edge taper equal or higher than the edge taper that the LFI feed horn #27 has with the Telescope Carrier Configuration.

The resulting main beam shapes and angular resolutions have been calculated using GRASP8.