PSF Calculation

Establish a symmetrical biconvex lens with a focal length of f = 100 mm made of SF1 for a wavelength of λ= 1μm. The diameter of the incoming beam should be 15 mm.

a) Calculate the spot diagram and the cross section of a point spread function (128 sampling points). Discuss the sizes of these two representations. Calculate and compare the Strehl ratio in the exact and the Marechal approximation.

b) Fix the plot window size of the PSF to 80 μm and produce a plot with the normalized PSF in the best plane and the two planes defocussed by +0.5 mm and -0.5 mm respectively. Discuss the result.

c) If now the aperture is enlarged to a diameter of 35 mm and the final distance is re-optimized, the PSF with 128 points calculation begins to show sampling problems. How can this be seen in the cross section representation ? How can this be seen in the 2D-plot ?

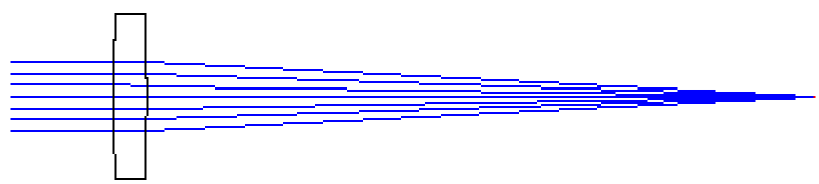
Solution:

System

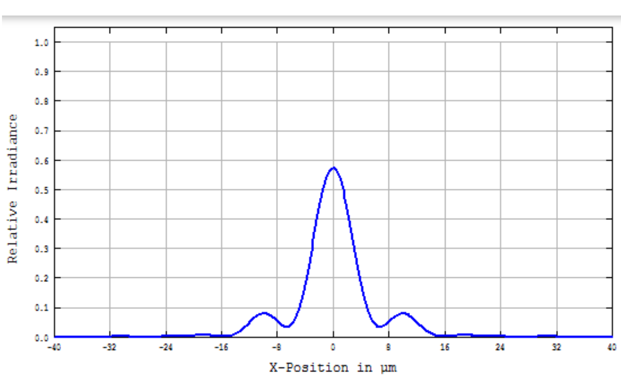
Lens Data Editor

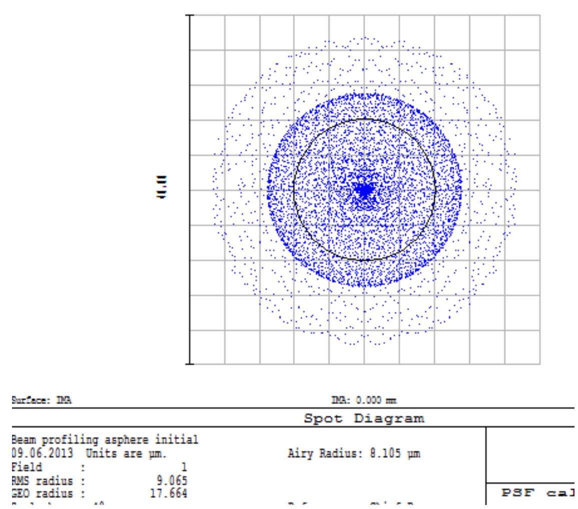
Edit Solves View Help

		Comment	Radius		Thickness	Glass		Semi-Diameter
OBJ	Standard		Infinity		Infinity			0.0000000
1	Standard		Infinity		15.0000000			7.5000000
STO	Standard		137.7828627	V	5.0000000	SF1		7.5000000
3	Standard		-137.782863	P	98.0455342			7.3973633
4	Standard		Infinity		0.0000000			0.0176669
IMA	Standard		Infinity		-			0.0176669

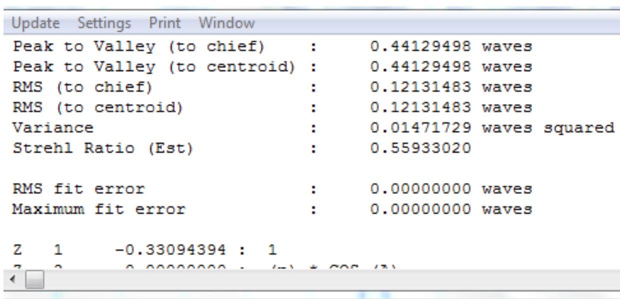


a) The spot has a rms radius of 9.1 μm, the Airy radius is 8.1 μm. The spot diagram is broadened to a radius of approximately 16 μm corresponding to the geometrical radius of the spot.





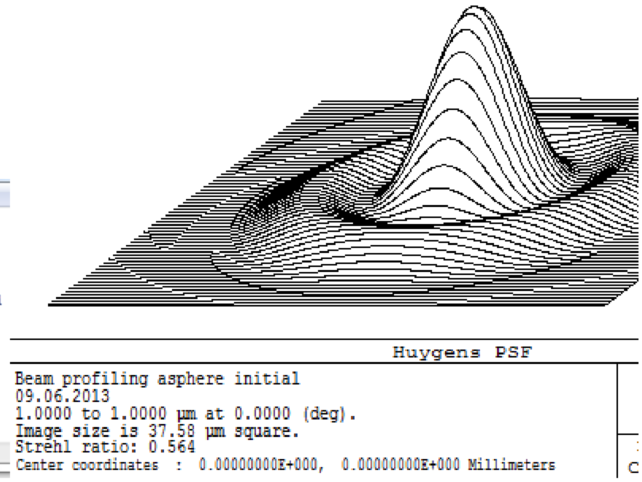
The exact Strehl ratio is 56.4%, the estimated value 55.9%. Therefore the error is in the range of 1%.



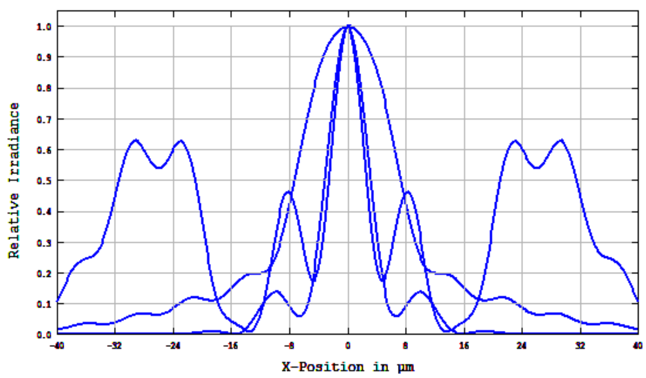
Update Settings Print Window

Peak to Valley (to chief)	:	0.44129498 waves
Peak to Valley (to centroid)	:	0.44129498 waves
RMS (to chief)	:	0.12131483 waves
RMS (to centroid)	:	0.12131483 waves
Variance	:	0.01471729 waves squared
Strehl Ratio (Est)	:	0.55933020
RMS fit error	:	0.00000000 waves
Maximum fit error	:	0.00000000 waves

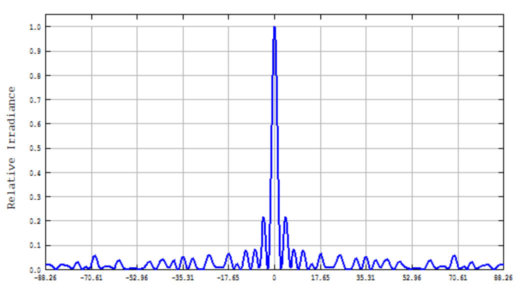
Z 1 -0.33094394 : 1

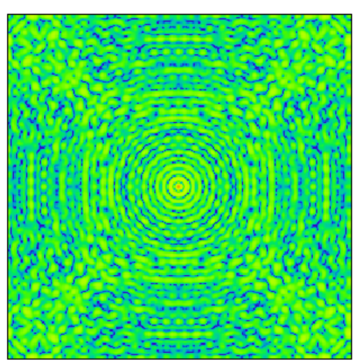


b) The plot looks like the following figure.
The PSF is broadened and has a smooth one-peak-shape for the positive defocus +0.5 mm and a ring shaped strongly modulated profile for -0.5 mm.



c) If the cross section PSF is calculated, the energy is spreaded out until the outer points of the grid. This means, that the signal is not bandlimited and shows aliasing.





In the 2D representation it can be seen, that the rotational symmetry is no longer fulfilled. This comes from the fact, that the effective spectral extend is larger along the diagonal directions and shows, that there is already an inaccuracy in the x- and y-direction.

Transfer function

a) Load the Cooke triplet 40° from the sample files of Zemax. Restrict to the center wavelength and reduce the field to 12° at one off axis field point only. Locate the stop 20 mm in front of the system. What is the residual power transmitted in the field position ? Fix the vignetting in the field menu. Calculate the distortion.

b) What is the Airy radius in the field point ? Estimate the diameter at 10 % intensity of the PSF in the field in x and y respectively. Calculate the modulation transfer function and discuss the three curves. Estimate the contrast in the case, that the PSF diameter is approximately of half the width of a grating period.

c) Determine the location and the size of the exit pupil. Calculate the phase transfer function in the field position. Discuss the green curve of the tangential orientation. If the green curve is extrapolated to a contrast reversal of 180°, what is the corresponding spatial frequency ? What is the corresponding feature size ? Explain the difference of this number with the distortion calculated above.

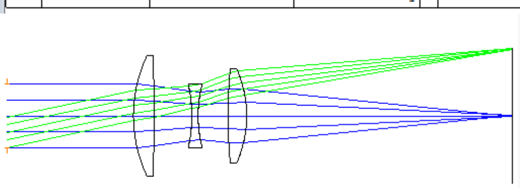
Solution:

a)

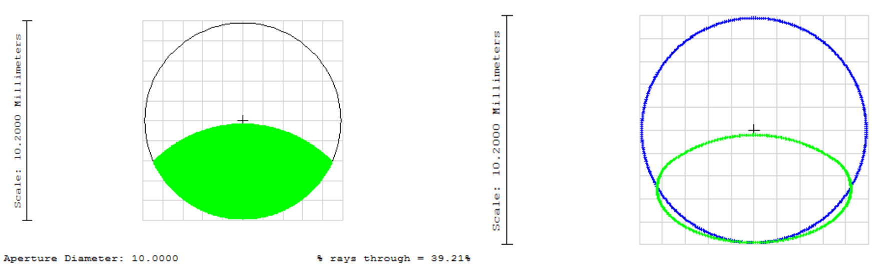
Lens Data Editor

Edit Solves View Help

	Surf:Type	Comment	Radius		Thickness		Glass		Semi-Diameter	
OBJ	Standard		Infinity		Infinity				Infinity	
STO	Standard		Infinity		20.00000				5.00000	
2*	Standard		22.01359	V	3.25896	V	SK16		9.50000	U
3*	Standard		-435.76044	V	6.00755	V			9.50000	U
4*	Standard		-22.21328	V	0.99997	V	F2		5.00000	U
5*	Standard		20.29192	V	4.75041	V			5.00000	U
6*	Standard		79.68360	V	2.95208	V	SK16		7.50000	U
7*	Standard		-18.39533	M	42.20778	V			7.50000	U
IMA	Standard		Infinity		-				13.92856	



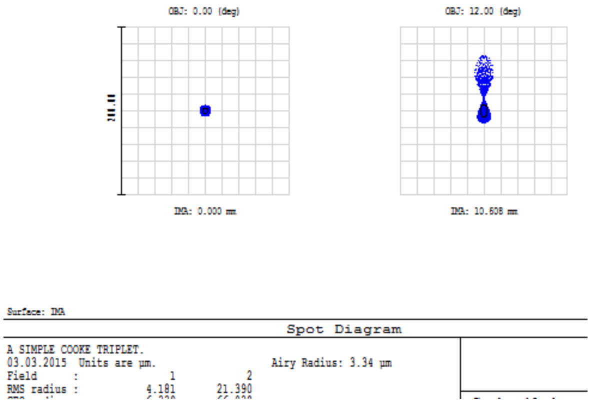
Only 40% of the energy is transmitted. Footprint at the pupil position without / with setting the vignetting:

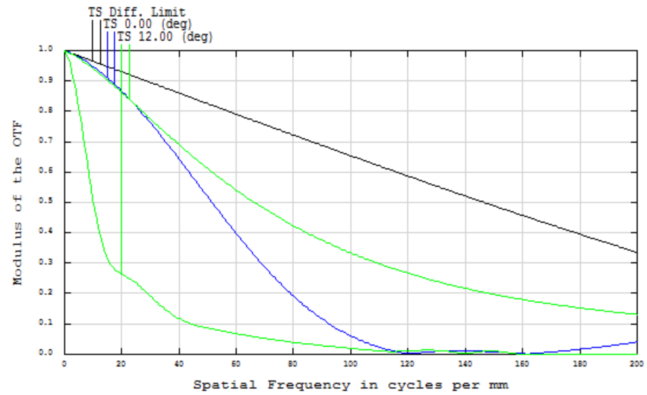


Due to the remote pupil position, there is a distortion of 0.711 % corresponding to a height difference of 75.5 μm.

11.28000000	2.59771423	0.17138867	10.00472766	9.95849275	0.46427613 %
11.40000000	2.78171195	0.18972763	10.11766549	10.06726756	0.50061181 %
11.52000000	2.97712860	0.20934382	10.23095881	10.17613427	0.53875603 %
11.64000000	3.18468330	0.23029466	10.34462178	10.28509397	0.57877749 %
11.76000000	3.40515078	0.25264008	10.45866913	10.39414773	0.62074731 %
11.88000000	3.63936681	0.27644266	10.57311616	10.50329663	0.66473918 %
12.00000000	3.88823432	0.30176778	10.68797883	10.61254176	0.71082944 %

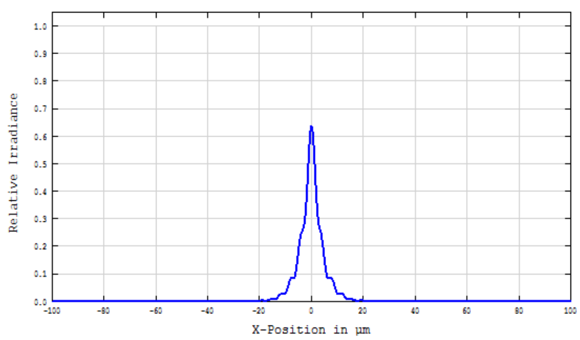
b) The Airy radius on axis is 3.34 μm, the diameter therefore on axis 6.7 μm.

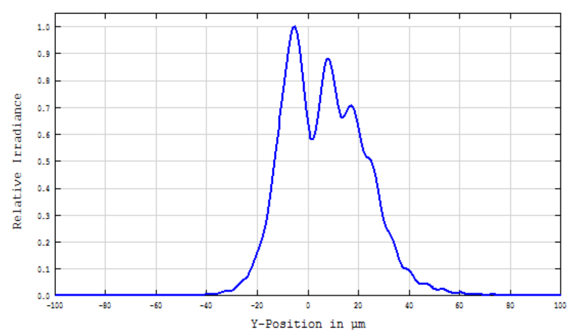




If the MTF is calculated, a strong separation between tangential and sagittal is seen for the field position due to coma and vignetting.

If the cross section of the point spread function is calculated for the field position, we get a large difference in x- and y-direction respectively. A rough estimate of the diameters at intensity 10 % are:
Dx = 12 μm , Dy = 60 μm.





A corresponding width of the grating bars is obtained for the spatial frequencies
$\nu x = 0.5 / 0.012 = 42$ Lp/mm and $\nu y = 0.5 / 0.060 = 8.3$ Lp/mm. According to the zoomed MTF curve we get a corresponding behavior with a contrast of 60 % - 70 %.