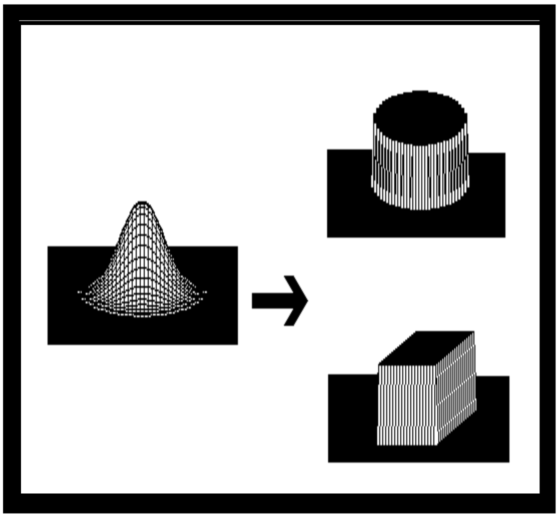
Application Note Top-Hat

Contents



Introduction

In various industries there is a need to create a spot with uniform intensity and sharp transition regions. Typical applications include:

- Laser Ablation
- Laser Welding
- Via Hole Drilling
- Laser Displays
- Filters for cigarettes
- Medical and Esthetical Laser applications

The very basic set-up in a top-hat application includes a laser and a diffractive Top-Hat Element.

A uniform spot enables equal treatment to a surface, excluding over/under-exposure of specific areas. In addition to that the spot is characterized by a sharp transition region that creates a clear border to the treated and untreated area,

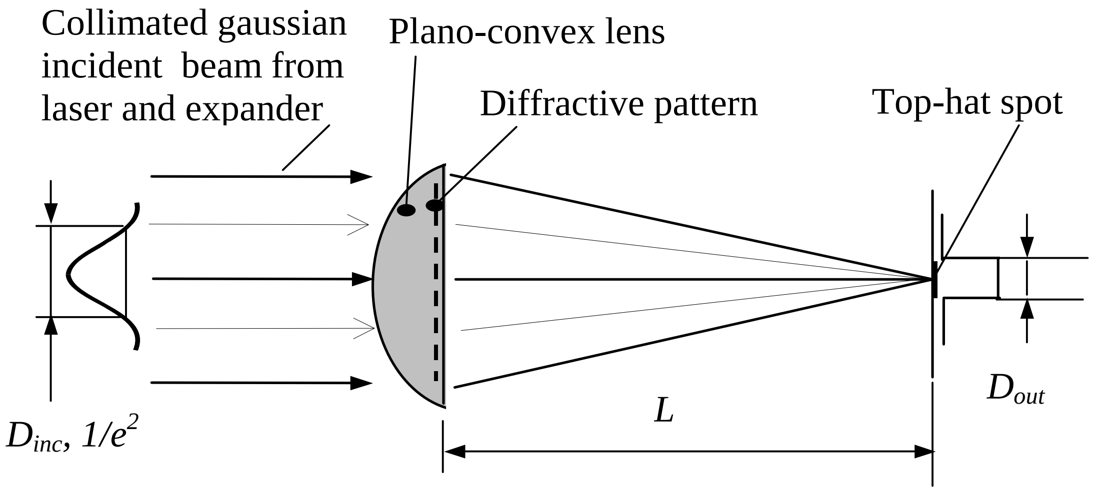
This application note comes to help the project manager better understand the benefit of these elements and their design considerations.

Holo-Or offers a large choice of standard top-hat elements and is also very flexible to tailor elements to very narrow defined requests of a customer. These are available for Lasers from 266nm till 10600nm.

Operation principal:

The diffractive Top-Hat shapers are phase elements that transform a Gaussian input beam with Input diameter Dinc into a uniform intensity spot having a well defined dimension Dout at a specific working distance L.

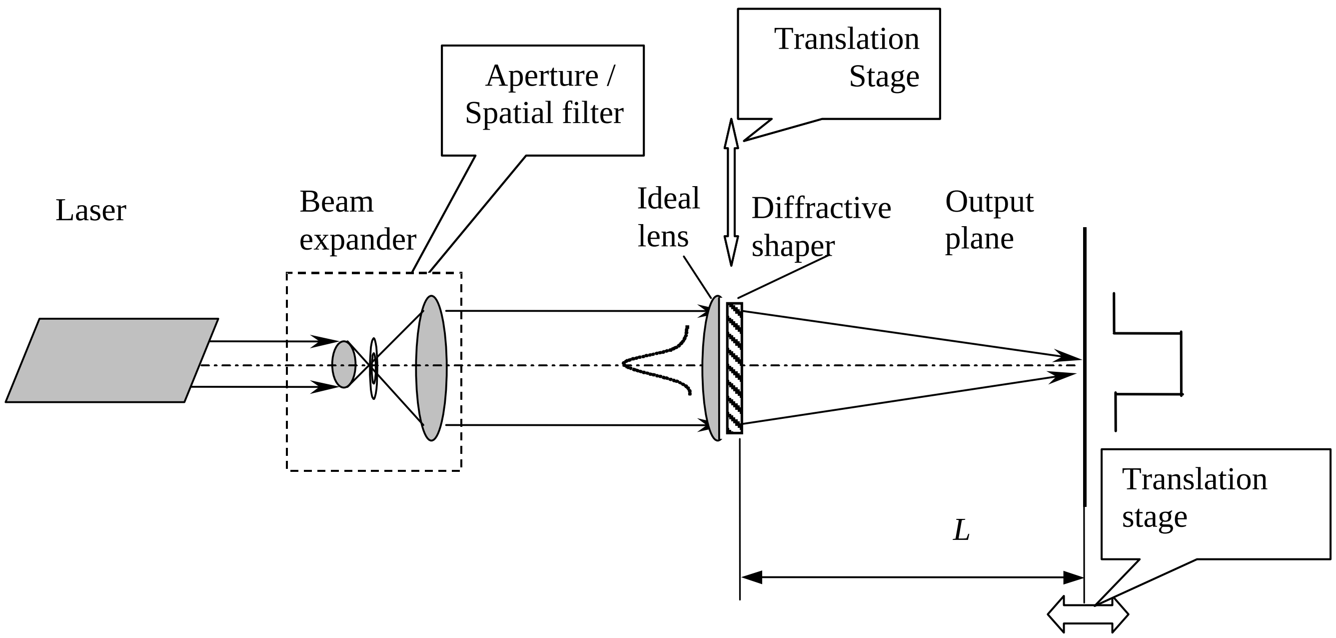
Figure 1: Basic Operation.



The beam profile can be further characterized by a very steep transition region at its borders.

Typical Set-Up

Figure 2: Typical Set Up.



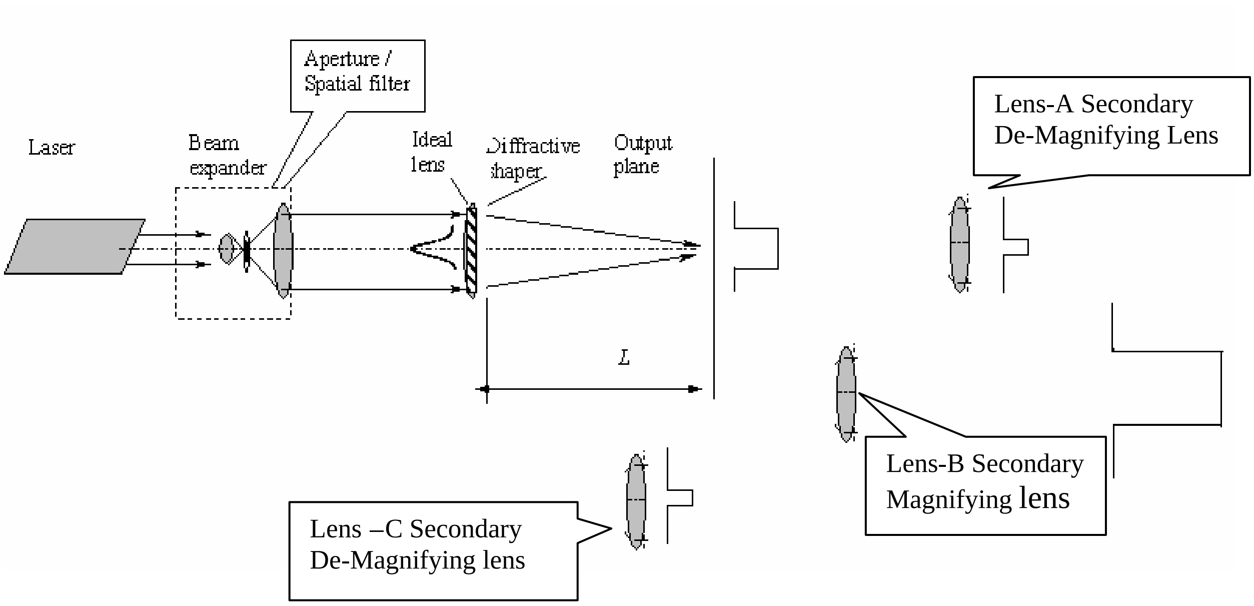
In order to create stable operation, the basic set-up mentioned before can be enriched with the following parts.

- A beam expander.
- An aperture.
- An ideal lens
- A translation stage.
- A 2nd translation stage

The Beam expander creates a larger input dia that ensures more stable operation of the set-up. If one uses a variable beam expander one can fine-tune the beam diameter, to better match the nominal beam diameter. An aperture cleans up the laser-beam, operating as a spatial filter, enlarging the relative TEM00 component of the beam. An ideal lens is required for some designs while other designs don't need this. A translation stage helps to align the top-hat element with the input beam. A 2nd translation stage can fine-tune the position of the object to be exposed, so that it will coincide the nominal working distance.

(De) Magnification Set-Up

Figure 3: Typical Set Up for (De) Magnification.



With secondary lenses or lens system one can add flexibility to the Set-Up. In Figure 3 one can see how an additional lens can (de) magnify the Spot Size of the Top-Hat shape. The fundamental laws of optics indeed allow treating the top-hat image as an object in a secondary lens system. This is true even before the image is formed such as in the set-up of Lens-C.

Characteristics

The diffractive Top-Hat elements from Holo-Or have the following features:

- **Uniform intensity profile;** This can vary from ripples down to 0.1% till ripples of +/-20%, typically we can say +/-5%.
- **Steep transition region;** This is typically similar to that of a diffraction limited spot with the same input diameter and working distance.
- **High Power Threshold:** The typical element consists of pure Fused Silica or ZnSe with high power thresholds.
- **Optional Ar/Ar Coated**; This reduces the back reflection and increasing the efficiency
- **High Efficiency;**

- **Sensitive for X-Y displacement:** The element will loose its function with displacement. One should in general keep displacement smaller than 5% of the input beam, in order to keep acceptable performance.
- **Insensitive for Z displacement:** If the element is designed for a collimated input beam
- **Sensitive for Input Beam diameter;** The element will loose its function with an input diameter different from the nominal input diameter. One should in general keep the mismatch smaller than 5% of the input beam in order to keep acceptable performance.
- **Rotation insensitive:** This is true as long as the spot is radial symmetric.
- **Rotation sensitive;** Parts that have non-radial symmetric output spots will rotate with the rotation of the element.
- **Sensitive for input mode;** In general the elements are designed for a pure TEM00 Gaussian input beams. The element will loose its function with an input beam different from this.
- **Sensitive for Beam Quality;** In general the elements are designed for a M^2 of 1.0. The element will loose its function with an input beam different from this. One should in general keep the M^2 smaller than 1.3 in order to keep acceptable performance.
- **Sensitive for working distance;** The element will loose its function if one uses the spot in a plane different from the nominal work plane. One should in general keep this mismatch smaller than 50% of the spot size in order to keep acceptable performance.
- **Collimated input.** Most designs require the input beam to enter the Top-Hat collimated. At present the only exception for that is the part TH-002. This part requires a converging input beam that would produce a spot at a distance of 250mm from the DOE, before placing thee DOE. For a more detailed explanation we wish to refer to the manual of the TH-002 part that is available upon request..

Design considerations:

Mismatch with parameters

Top-Hat elements are sensitive for the parameters mentioned under the section characteristics. When one starts designing a set-up that includes a DOE one should take care to ensure stable parameters in the system.

As in figure 2, typical set-up, accurate translation stages, high quality laser beams, spatial filters and (variable) beam expanders all form a part of this set-up.

Many of the specifications depend on the relative displacement and/or mismatch of the input beam diameter. Therefore the system can be made less sensitive by expanding the input beam prior to the design. E.g. with an input beam of 10mm dia a mismatch of 5% gives 0.5mm tolerance, while for a beam dia of 0.8mm this will give a tolerance of only 40um.

Typical Performance

The performance will depend on the design. In the table below one can see a range of typical performance for various parameters. Below that a table with selected design is displayed.

Typical Performance

Performance[1]	Energy in desired Spot (1/e2)	Ripple / Uniformity	Working distance	Transition region	Input Dia	Wavelength	Spot size
From	75%	+/- 0.5%	25mm	5um	0.8mm	266nm	15um
Till	75-98%	+/-20%	Infinity	100um	35mm	10600nm	100X100meter

[1] Depends on design

Selection of Standard Top-Hats:

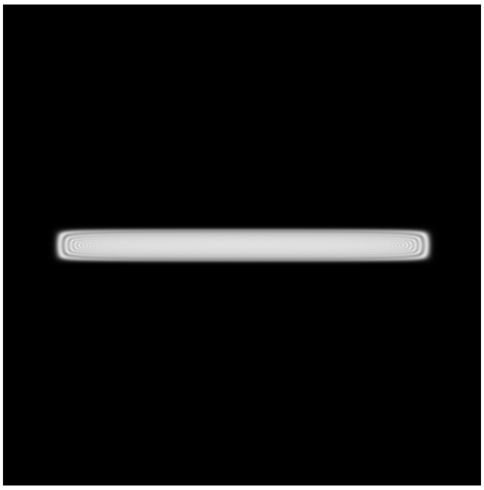
	Part No.	Function	Diameter Component	Wavelength in µm	Diameter Input beam (1/e2)	Working distance	Spot size(1/e2)	Note	Spot Shape
Selected designs	TH-001	Top-Hat	1.5”	10.6	25 mm	250 mm	3 mm		Round
	TH-002	Top-Hat	1.1”	10.6	12 mm	250 mm	6 mm	Converging	Square
	TH-003	Top-Hat-1D	0.5”	10.6	3.7 mm	42.5 mm	0.3X0.1mm		Line
	TH-004	Top-Hat	1.1"	10.6	12 mm	63.5 mm	0.39 mm		Round
	TH-005	Top-Hat	1.1"	9.25	12 mm	63.5 mm	0.35 mm		Round
	TH-006	Top-Hat	1.5”	10.6	25mm	125.4mm	15X1mm		Rectangular
	TH-008	Top-Hat	1.1”	9.25	12mm	62.9mm	0.26mm		Square
	TH-012	Top-Hat	20mm	1.319	7.0mm	43.2mm	0.17mm		Round
	TH-013	Top-Hat	1”	1.064	7.0mm	infinity	1x1 degree		Square
	TH-014	Top-Hat-Sharp edge	20 mm	1.064	7.0 mm	42.52 mm	0.190 mm		Round
	TH-015	Top-Hat-1D	1"	1.064	5.1 mm	infinity	0.83 deg x input		Line
	TH-016	Top-Hat	1"	0.980	7.0 mm	infinity	0.94x0.94 deg		Square
	TH-017	Top-Hat	50 mm	1.064	39.0 mm	20 meter	635 mm x 5.3 mm		Rectangular
	TH-018	Top-Hat	1.5"	1.064	13.0 mm	20 meter	635 mm x 635 mm		Square
	TH-019	Top-Hat	1"	1.064	3mm	100mm	210umx210um		Square
	TH0101	Top-Hat	1"	1.064	3mm	100mm	150um dia.		Round
	TH-031	Top-Hat	1”	0.532	5 mm	52.4 mm	0.1 mm		Round
	TH-032	Top-Hat	1”	0.532	10.9 mm	200 mm	2 mm (FWHM)		Round
	TH-033	Top-Hat	1”	0.80	6.0 mm	200.29 mm	3.0 mm		Round
	TH-034	Top-Hat	1”	0.532	2.5mm	99.5mm	100umx100um		Square
	TH-035	Top-Hat	1”	0.532	2.5mm	99.5mm	90um Dia		Round
	TH-041	Top-Hat	1”	0.355	2 mm	100 mm	0.1 mm		Square
	TH-042	Top-Hat	1”	0.355	2.5 mm	50 mm	0.05mm		Round
	TH-043	Top-Hat	20 mm	0.355	8.0mm	49.8mm	0.015mm		Round
	TH-044	Top-Hat	20 mm	0.337	8.0 mm	49.395 mm	0.020 mm		Round
	TH-045	Top-Hat	0.5”	0.355	8.0mm	94mm	170*170um		Square
	TH-051	Top-Hat	1”	0.266	5 mm	42 mm	0.015mm		Round

Typical Simulation Mismatch Set-Up

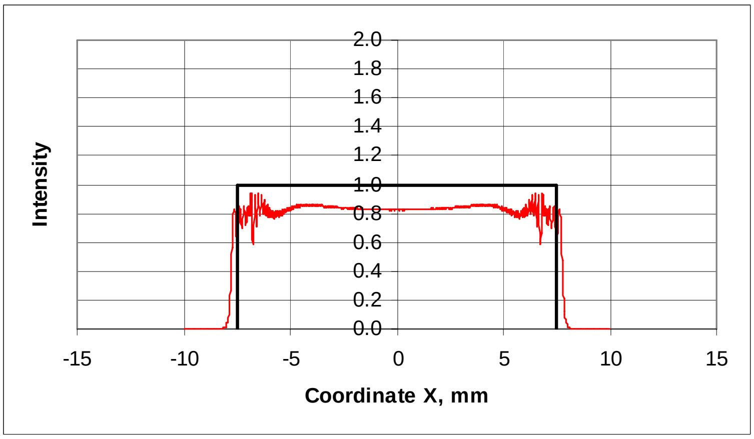
The best performance will be obtained for a well-positioned perfectly aligned part, exactly in the plane of the nominal working distance. To illustrate what typically happens in non-ideal situations we display some simulations done for selected Top-Hat Designs.

1) Mismatch in Working Distance TH-006

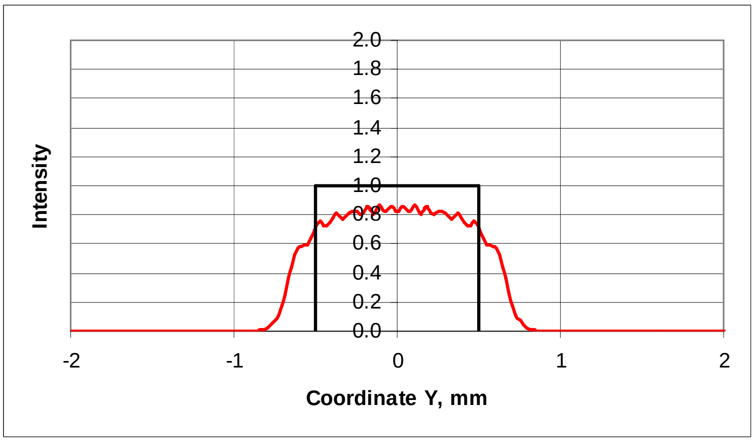
Most of the Top-Hat designs are defined to operate in a specific work-plane. If one deviates from that plane the uniformity will normally decrease. We display below simulations of our standard TH-006 top hat design at its nominal working distance and at other distances. This should help to understand the sensitivity to work distance for other Top-Hat designs as well.



a)



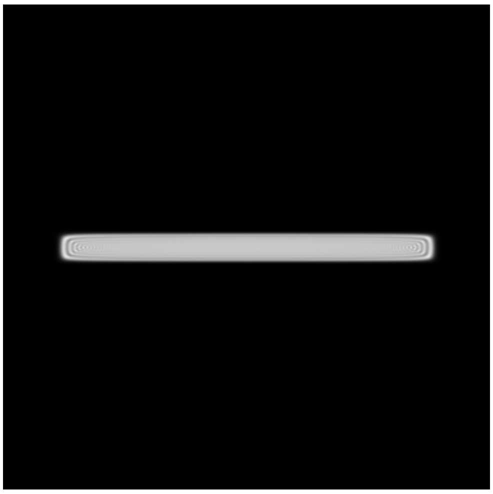
b)



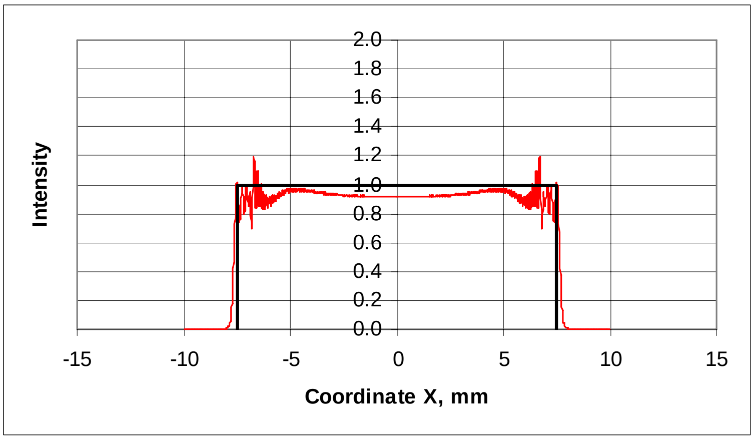
c)

Fig. 4. Intensity distribution at the output plane at the deviation –1.500 mm from design distance *L*=125 mm. Efficiency 75.7%.

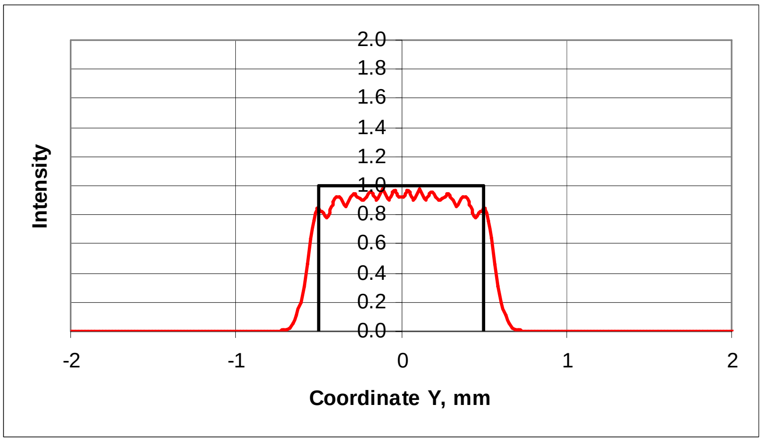
a) 2-D picture (white color corresponds to maximum intensity),
b) in horizontal direction, non-uniformity = 0.027,
c) in vertical direction, non-uniformity = 0.127.



a)



b)

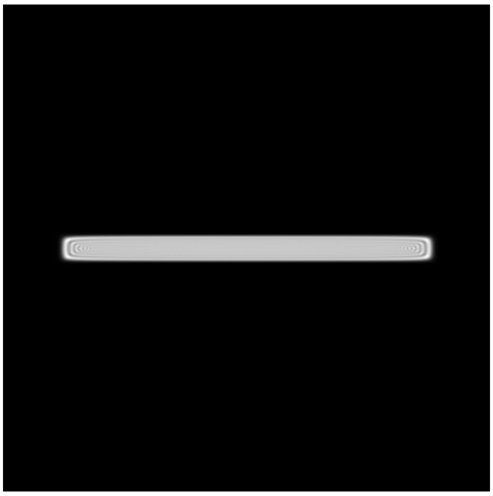


c)

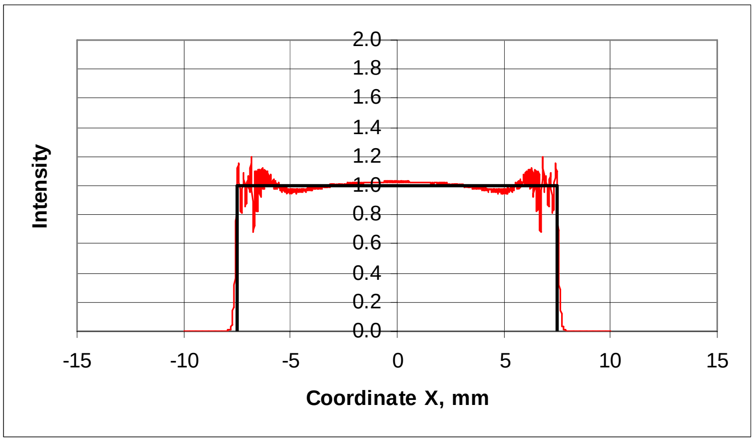
Fig. 5. Intensity distribution at the output plane at the deviation –0.550 mm from design distance *L*=125 mm. Efficiency 86.0%.

a) 2-D picture (white color corresponds to maximum intensity),

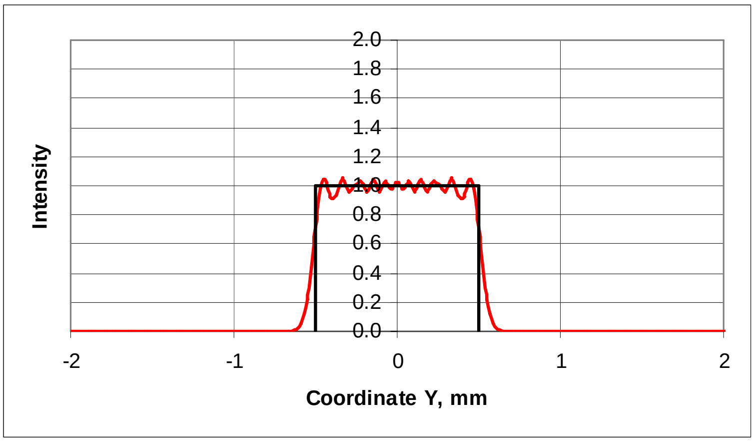
b) in horizontal direction, non-uniformity = 0.0262,
c) in vertical direction, non-uniformity = 0.1206.



a)



b)



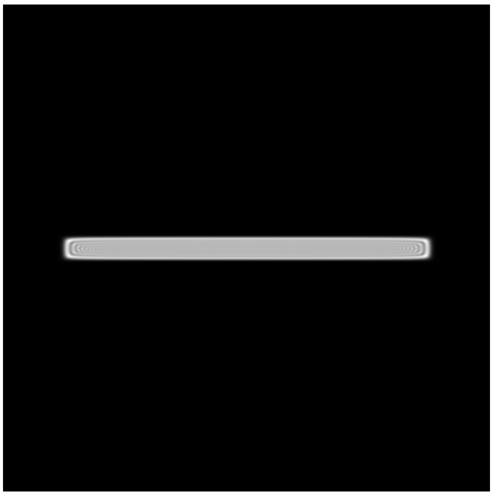
c)

Fig. 6. Intensity distribution at the output plane exactly at the design distance *L*=125 mm. Efficiency 93.8 %.

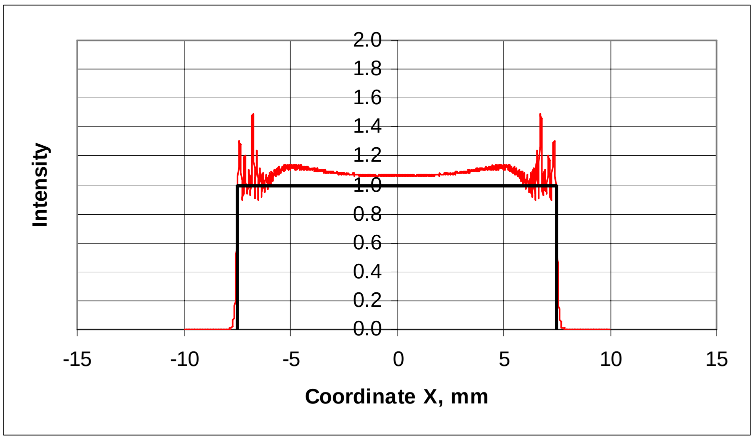
a) 2-D picture (white color corresponds to maximum intensity),

b) in horizontal direction, non-uniformity = 0.026,

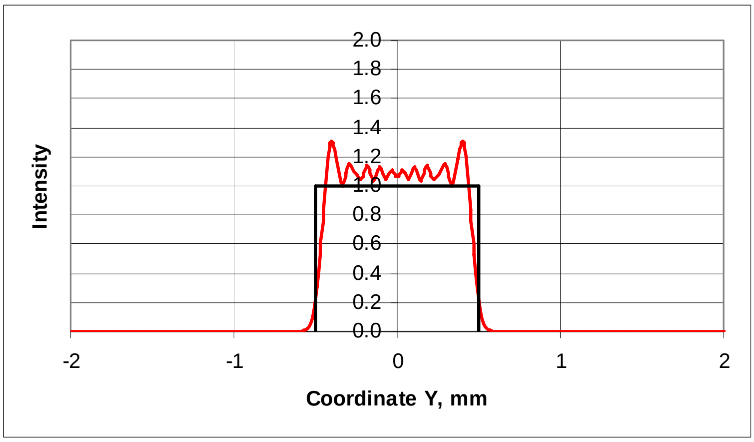
c) in vertical direction, non-uniformity = 0.107.



a)



b)

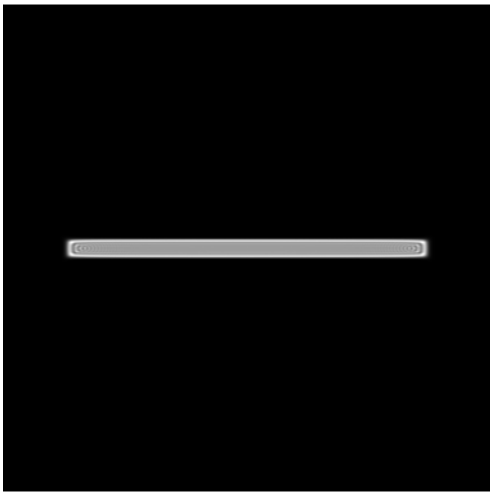


c)

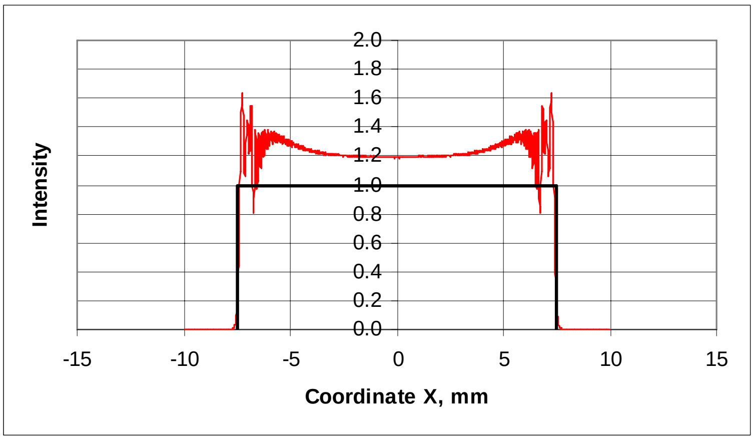
Fig. 7. Intensity distribution at the output plane at the deviation +0.550 mm from design distance L=125 mm. Efficiency 98.5%.

a) 2-D picture (white color corresponds to maximum intensity),

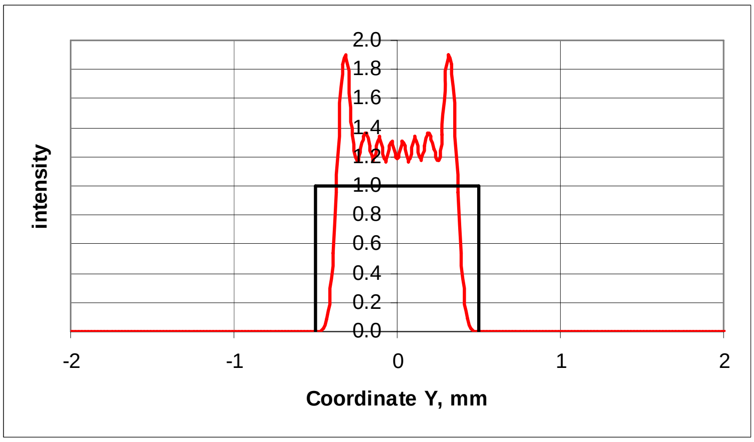
b) in horizontal direction, non-uniformity = 0.026,
c) in vertical direction, non-uniformity = 0.185.



a)



b)



c)

Fig. 8. Intensity distribution at the output plane at the deviation +1.500 mm from design distance *L*=125 mm. Efficiency 99.8%.

a) 2-D picture (white color corresponds to maximum intensity),

b) in horizontal direction, non-uniformity = 0.030,
c) in vertical direction, non-uniformity = 0.345.

2) **Mismatch caused by de-centering**

This simulation concerns a part that is exclusive to a specific customer. However we can show part of the simulations on the de-centering as they should hold for similar parts as well. The sensitivity to de-centering strongly depends on the beam diameter. For this part the beam diameter was about 8mm.

Main conclusions on de-centering for a ~8mm input dia

1. De-centering introduces re-distribution of intensity from one of the edges to another.

2. De-centering +/-0.050 mm adds about +/-5% to the non-uniformity in top-hat region and does reduce substantially total diffraction efficiency.

3. De-centering +/-0.100 mm adds about +/-10% to the non-uniformity in top-hat region and does reduce substantially total diffraction efficiency.

3. De-centering about +/-0.500 mm almost destroys the designed intensity distribution.

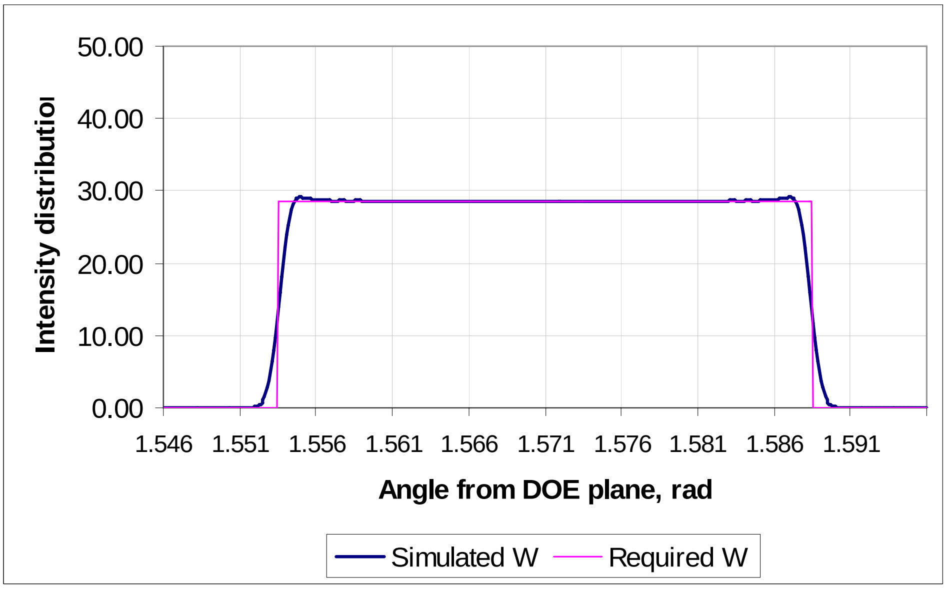


Fig. 9. Cross-sections of intensity distribution at the output plane for **de-centering +0.000 mm** (AS DESIGNED).

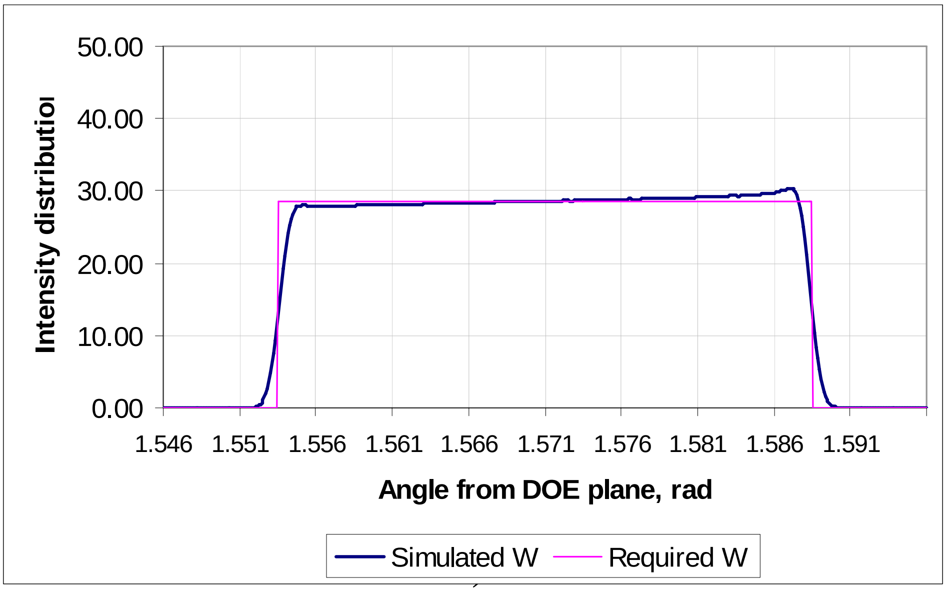


Fig. 10. Cross-sections of intensity distribution at the output plane for **de-centering +0.050 mm in horizontal direction**.

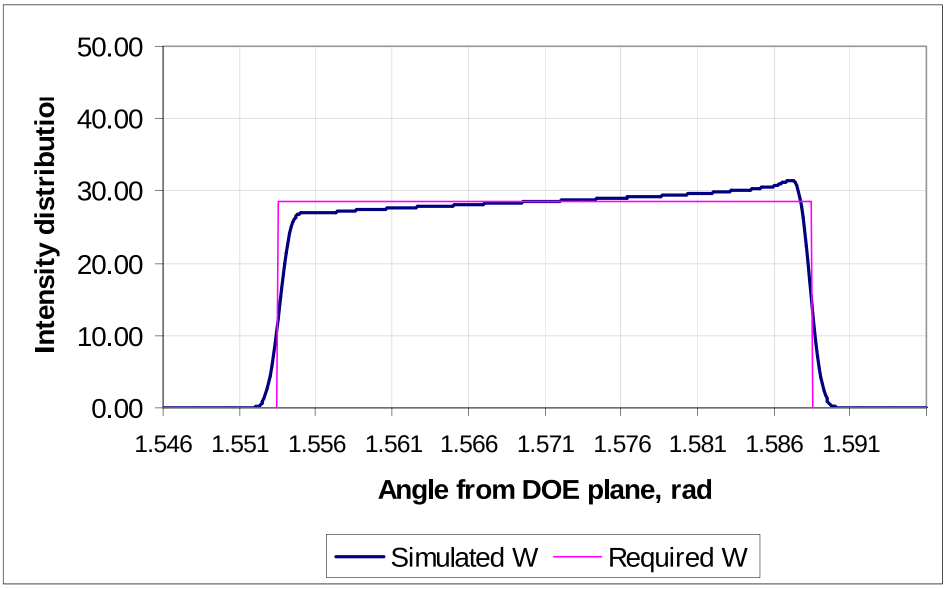


Fig. 11. Cross-sections of intensity distribution at the output plane for **de-centering +0.100 mm in horizontal direction**.

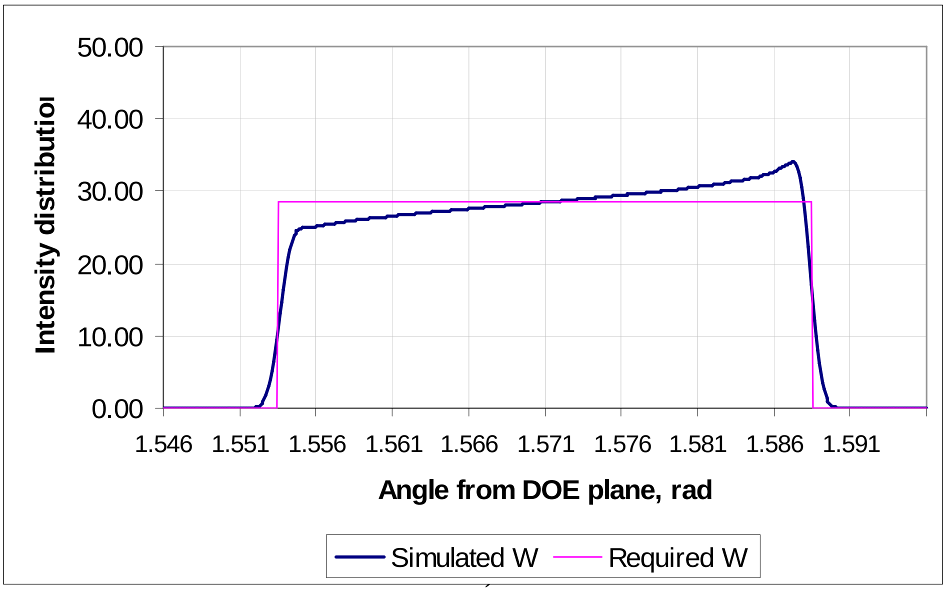


Fig. 12. Cross-sections of intensity distribution at the output plane for **de-centering +0.200 mm in horizontal direction**.

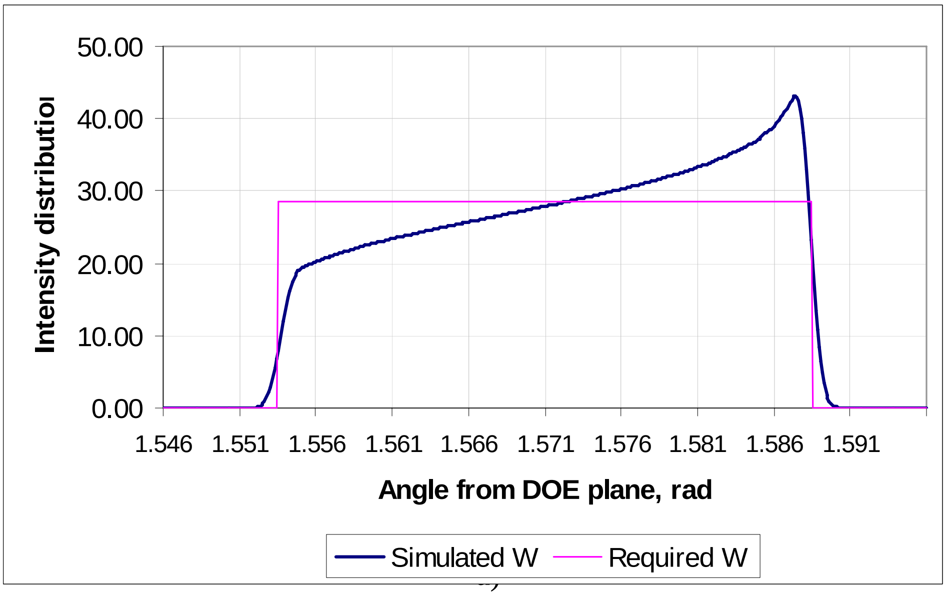


Fig. 13. Cross-sections of intensity distribution at the output plane for **de-centering +0.500 mm in horizontal direction**.