Top-Hat beam shaper
Installation manual

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Version: 3

Contents

1. Safety

General recommendations when working with a laser

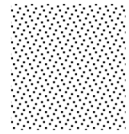
http://web.princeton.edu/sites/ehs/laserguide/appendixB.htm

- Locate beam at waist level or below. Do not place beam at eye level.
- Close and cover your eyes when stooping down around the beam (where you will pass the beam at eye level).
- When leaning over a table, beware of beam directed upward.
- Enclose as much of the beam as possible.
- Do not direct beam toward doors or windows.
- Terminate beams or reflections with fire-resistant beam stops. Anodized aluminum or aluminum painted black (which is not necessarily fire-resistant) can work well for this purpose.
- Use surfaces that minimize specular reflections (mirror-like reflection).
- Locate controls so that the operator is not exposed to beam hazards.
- Make sure warning/indicator lights can be seen through protective filters.
- If you can see the beam through your laser eyewear, you are not fully protected.
- View applications remotely.
- Do not wear watches or reflective jewelry around Class 3B or 4 lasers.
- Do not wear neckties around Class 4 open beam lasers.
- In reality, all interlocks can fail.
- The best defense is good understanding of the hazards.

Recommendations for alignment:

- Isolate process.
- Use lowest practical power.
- View diffuse reflections only.
- Use IR/UV viewing cards/eyewear.
- Where possible, use HeNe alignment lasers.

2. Handling:

Use gloves	Mechanical damage	Chemical	Dust
			

3. Introduction

The **Top-Hat (TH) beam shaper** is a phase element, mainly based on diffractive technology (Diffractive Optical Element - DOE), used to transform a near-Gaussian (TEM_{00}) incident laser beam into a uniform-intensity spot of either round, rectangular, square, line or other custom shapes with sharp edges in a specific work plane. It is important to note that the Top-Hat spot is NOT at the minimum spot location (minimum waist), but near it.

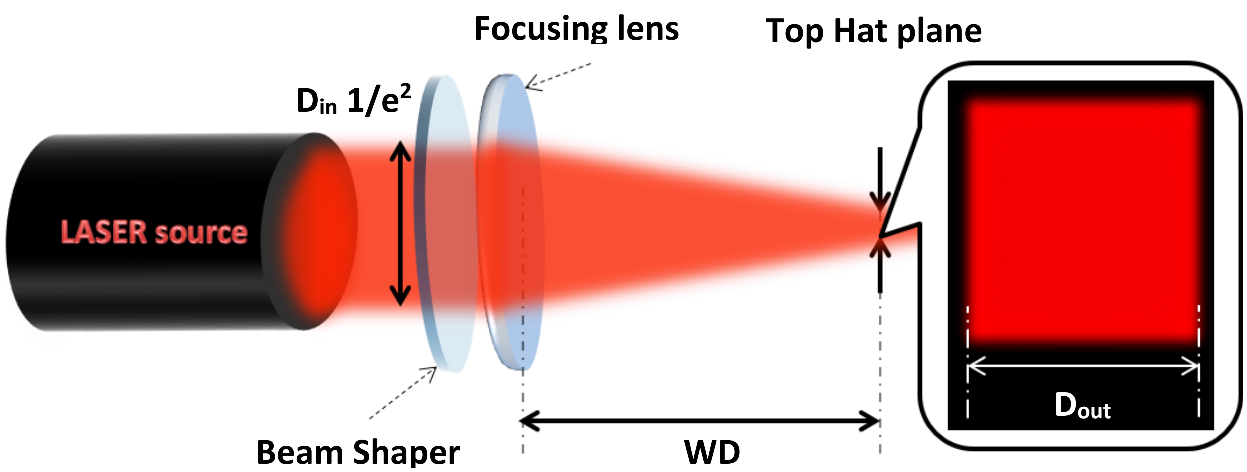


Figure 1 - Basic Operation

Each TH shaper is designed for a specific use with a unique set of optical system parameters:

- Wavelength
- Input Beam Size (D_{in})
- Working distance (WD)
- Output Spot Size (D_{out})

Altering any one of the vales in this parameter set will degrade the performance of the Top-Hat beam shaper element, and possibly render it useless.

The beam shaper can be a:

a. Focal Beam Shaper: Hybrid element (singlet lens) or a module, which gives a Top-Hat intensity distribution at a specific working distance (EFL of the lens or distance from exit location of the module to Top-Hat plane).

Laser beam → Focal Beam Shaper → Focal plane

b. Angular Beam Shaper: Optical element (window) which gives a Top-Hat intensity distribution at infinity or in the focal plane of an aberration free customer's lens.

Laser beam → TH DOE → Focusing system → Focal plane

Picture of basic optical setup:
From left to the right – single mode laser, Beam expander to adjust beam size, Top-Hat beam shaper mounted in XY translator, focusing lens mounted in XY translator, detector.

4. Initial optical setup

The TH beam shaper is mainly being used in situations where highly uniform image and superb accuracy on output shape and size are important. This comes with a cost:

a) Sensitive to X-Y displacement
b) Sensitive to input beam diameter
c) Sensitive to working distance
d) Requires $M^2 < 1.3$ (higher value will result in poorer results)
e) Some designs are rotation sensitive (mainly, non-radial designs)

To solve the issues above, some solutions on the system level can be applied:

f) X-Y stages
g) Beam expander (preferred variable)
h) Z-stage for Focusing module or stage for focal plane (@WD)
i) Spatial filter
j) Optional notches for correct placement

Before adding the TH element to the system, we recommend on a few simple steps that will later save time and effort when installing the TH element.
The initial optical setup should include:

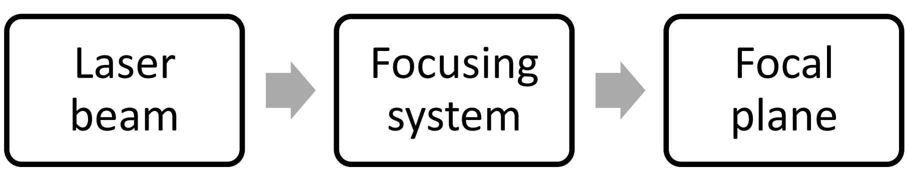


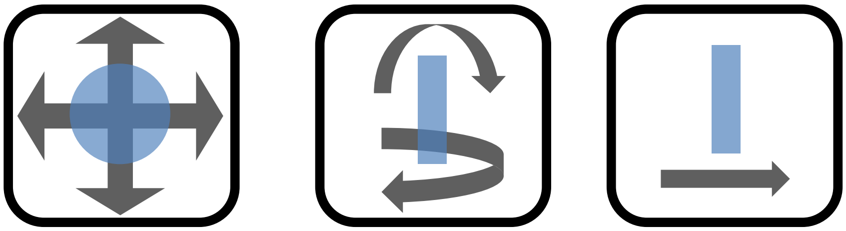
Figure 1 - Schematic optical setup before installing Top-Hat beam shaper

4.1 First, check that the laser beam has the required parameters as defined for each TH element.

$M^2<1.3$	Beam size at DOE plane is correct	Beam is collimated

4.2 Align the laser beam, focusing system and focal plane (via a detector) to be centered and parallel relative to the optical axis, by means of:

X / Y shift   Tip / Tilt   Z shift



4.3 Find the focal plane that has the smallest spot size by moving your detector along the optical axis (Z-axis) – this will later be the Top-Hat plane.

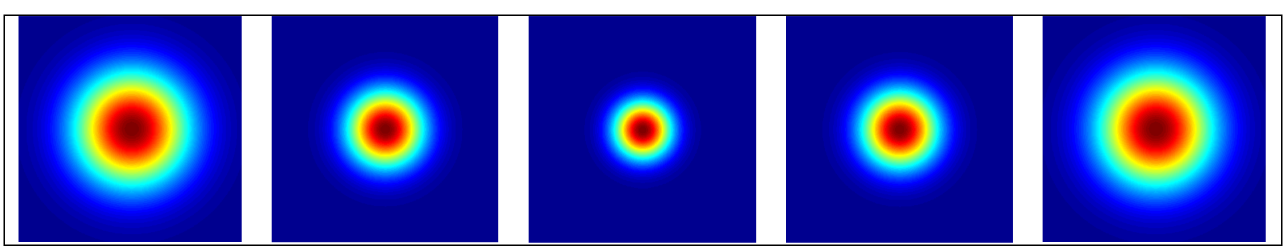


Figure 3 - Spot size along the optical axis, near the focal plane of the system

5. Installing the TH beam shaper

5.1 Position of TH inside an optical system.

For TH elements with small divergence angle, the distance between the TH beam shaper and a Focusing system is not important, as long as the clear aperture of the Focusing system will be large enough (~x2.5 input beam size) to prevent diffraction losses at the clear aperture at the entrance and also at other clear apertures inside the Focusing system.

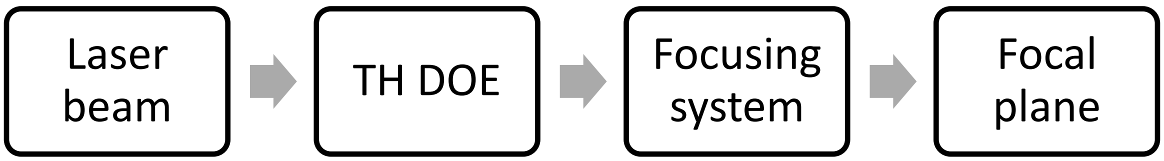
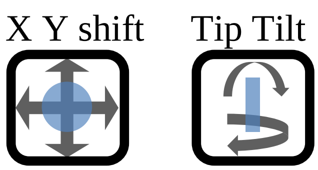


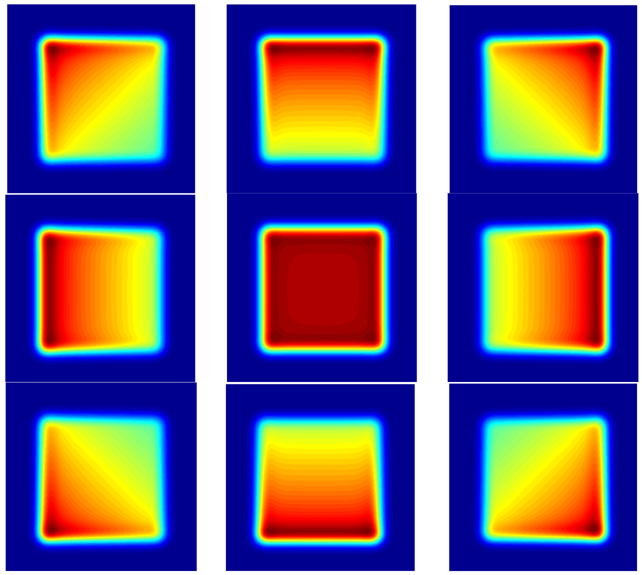
Figure 4 - Schematic optics setup with Top-Hat beam shaper

5.2 Alignment of the TH beam shaper on the optical axis.

The image in the focal plane should have a symmetrical shape around the optical axis. This can be adjusted by X-Y translation and angular rotation of the TH beam shaper.

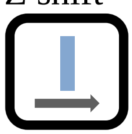


Misalignment effect for square Top-Hat shape.
(see also https://youtu.be/bjXRG7fGC48)

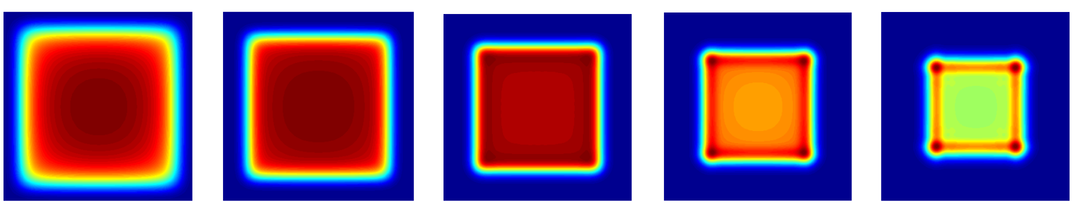


5.3 **Adjustment (Fine tuning) of the image plane in a very small range (distance) around the focal plane in small steps**, in order to achieve the best shape, uniformity, and size of the Top-Hat beam. The reference point for the defocusing range can be the Rayleigh distance.

Z shift



Defocus effect for square Top-Hat shape. (https://youtu.be/79GlQdgFxbI)



6. Problems and solutions:

6.1 X-Y Misalignment

If the intensity profile looks tilted, i.e. a slope in the intensity going from one side of the spot to the other, this is probably due to misalignment in X-Y plane (perpendicular to propagation axis). To solve it, simply shift the DOE position relative to the optical axis:

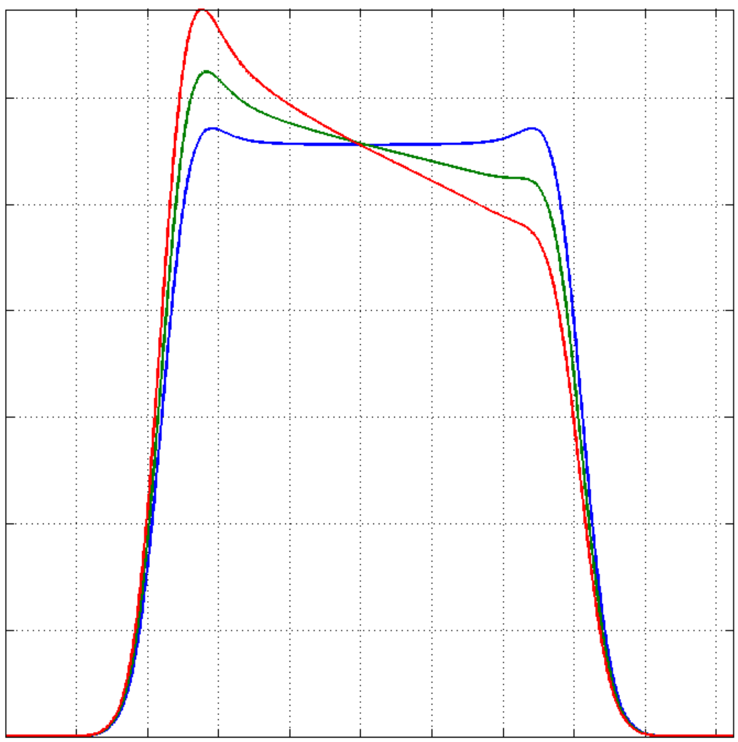


Figure 5 - Decenter effect

Misalignment video - https://youtu.be/bjXRG7fGC48

6.2 Defocus

If output image has "dog ears" or "convex" like intensity profile, this can be either a defocus issue or non-nominal input beam size -> Scan with a detector on the optical axis to find the optimal position, if this does not solve the problem, it might be that input beam size is not nominal.

	Before ideal position	After ideal position
Top-Hat size	larger	smaller
Edges	wider	thinner
Top-Hat intensity	"convex"	"dog ears"

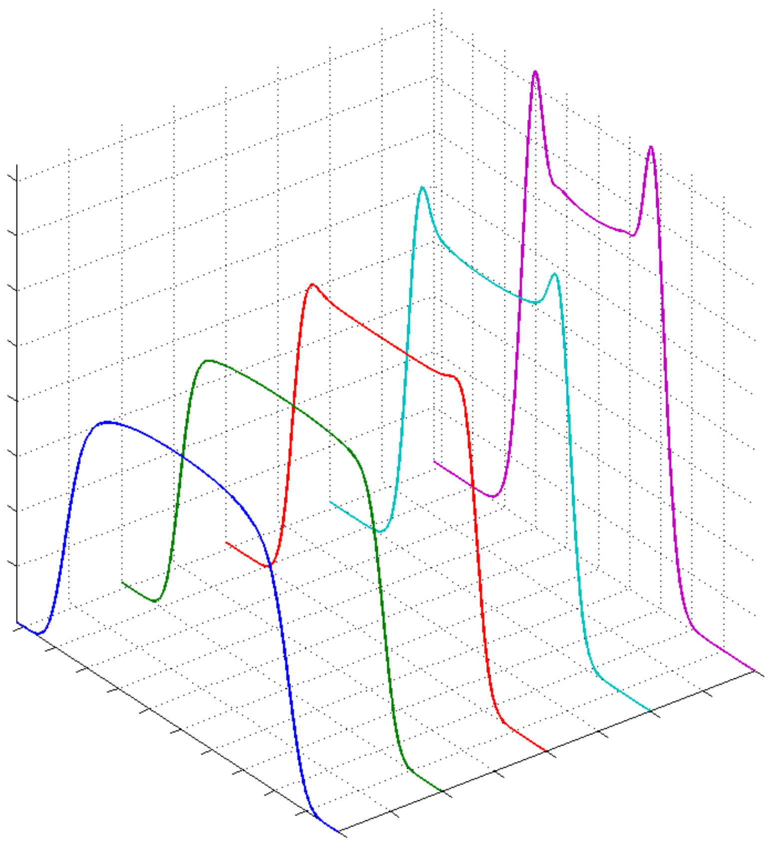


Figure 6 - Defocus effect:blue line before nominal position and violet after

Defocus video - https://youtu.be/79GlQdgFxbI

6.3 Input beam size

Increase / reduce input beam size with a beam expander/reducer to find the optimal size by viewing the top part of the TH intensity profile.

	Smaller beam	Larger beam
Intensity of top part	"convex"	"dog ears"

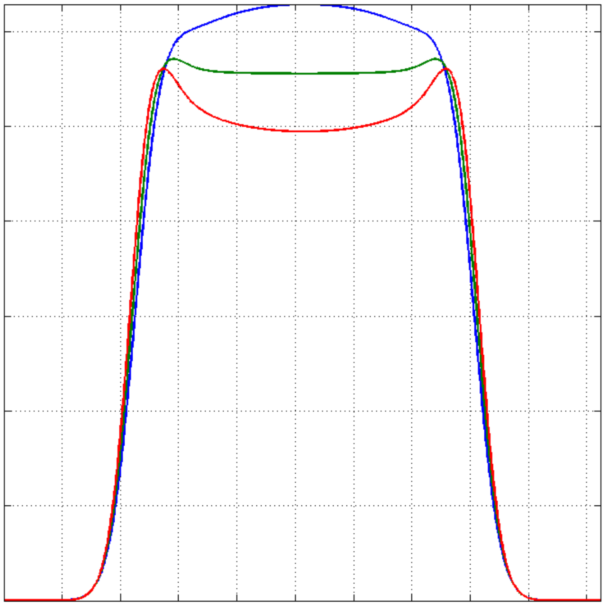
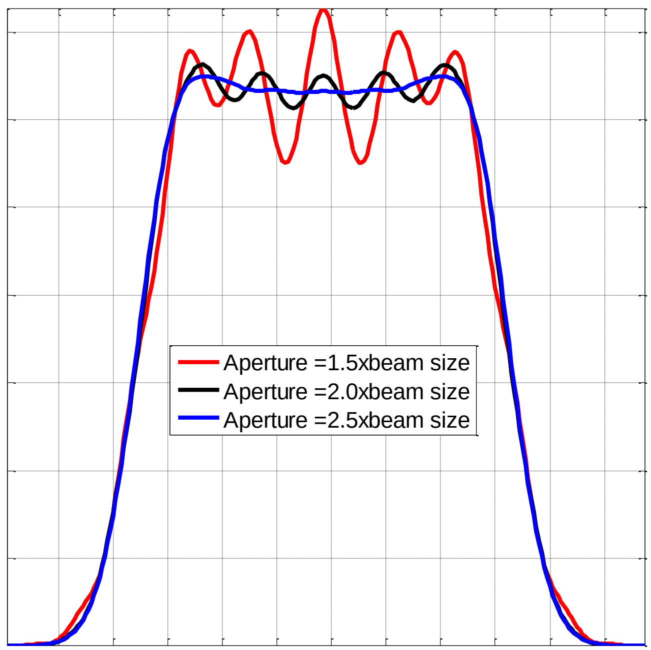


Figure 7 - Beam size effect: blue line smaller than nominal, red larger than nominal

Generally, correcting the beam size is a more complex mission (especially with no variable beam expander), so in some cases it can be compensated by applying a defocus.

6.4 Input beam size ratio to clear aperture size.

It is important to keep all clear apertures of the optical system at least X2 the Top Hat input beam size (preferable x2.5). . Below, we show how smaller apertures affect Top-Hat uniformity. Note, shape and size remain unchanged, the effect is on the uniformity of the flat top.



6.5 Non-collimated incident beam

For perfectly collimated incident beam, Top-Hat (*TH*) image will be resolved at the *EFL* of the system, and its image size calculated by: $2 \times EFL \times \tan\left(\frac{\theta_{\text{full}}}{2}\right)$.

Note, incident beam size on beam shaper should be nominal.

For non-collimated incident beams (diverging or converging), *EFL* is replaced by *working distance* (*WD*), which is the distance to "new" image plane (where smallest spot size is measured without the DOE). Top-Hat image size is changed according to shift in *WD*. "new image size"= $2 \times WD \times \tan\left(\frac{\theta_{\text{full}}}{2}\right)$

To clarify, for converging incident beam the distance to Top-Hat image plane will be smaller (compared to EFL), and so the Top-Hat size will be smaller (same proportion). Moreover, it is the other way around for a diverging incident beam, meaning, longer distance to image plane and larger Top-Hat size. See illustration below:

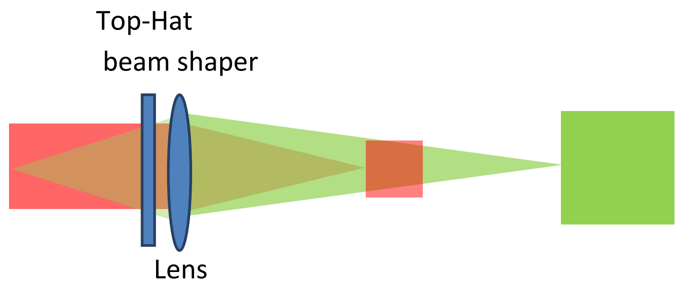
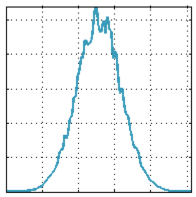
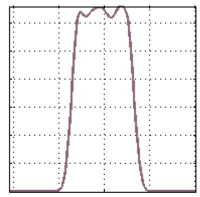
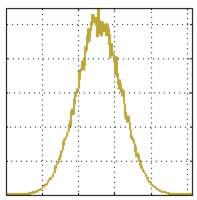
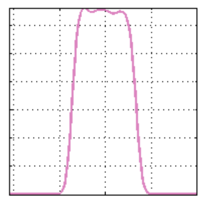
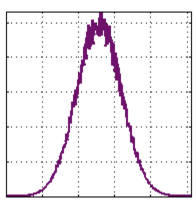
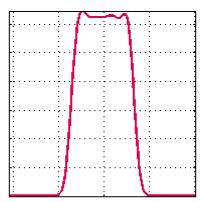


Figure 8 - Schematic sketch of collimated beam (red color), and non-collimated beam (green color)

6.6 **Perturbations inside input beam (Gaussian)**

On the following examples (right), we show how input intensity profile with white noise influence on the output. This can lead to interference effects, which appear generally as rings in the output intensity profile.

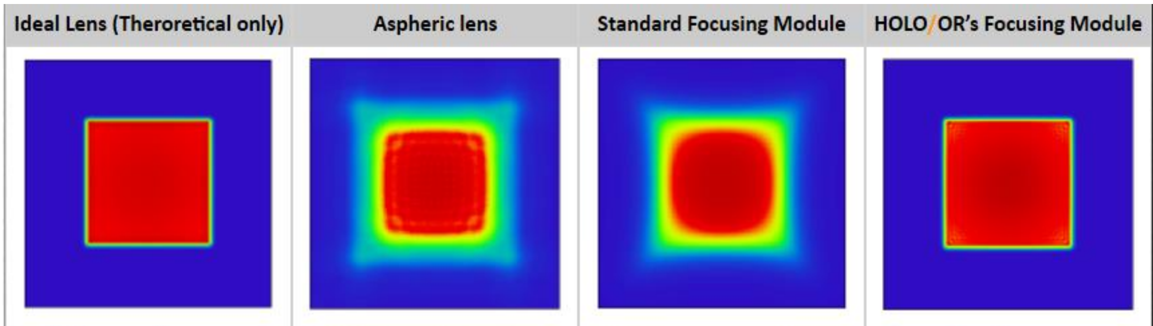
Low frequency noise brings more undesired fluctuation than high frequency noise.

Input	Output
	
	
	
Gaussian intensity profile of input beam with low frequency noise (top figure) to high frequency (bottom figure)	Top-Hat intensity profile in one axis.

6.7 **Aberrations of refractive elements / lens**

Aberrations within an optical system degrade functionality of Top-Hat beam shaper. Edges become wider, uniformity becomes worst, and efficiency reduces.

For short wavelengths (UV region) or EFLs <50[mm], refractive focusing system requires special attention when integrating Top-Hat beam shaper. Typical effects can be seen below:



Simulation results for a Square Top-Hat 100x100[µm2] in size, with (from left to right): perfect lens (not real lens) for ideal spot, aspheric lens, standard focusing module not optimized for use with a Beam Shaper and Holo/Or's focusing module optimized for use with Beam Shapers.

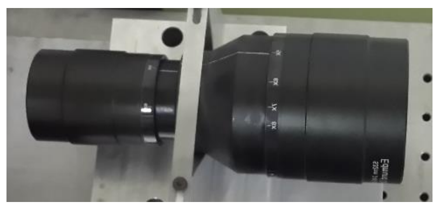
7. General tips:

7.1 Manipulation of the output shape size

It is possible to reduce or enlarge the Top-Hat size by adding a Beam expander / reducer into the optical setup between the DOE and Focusing system. Using an expander reduces the spot size and a beam reducer expands the spot size.

Laser beam → TH DOE → Beam Expander/reducer → Focusing system → Focal plane

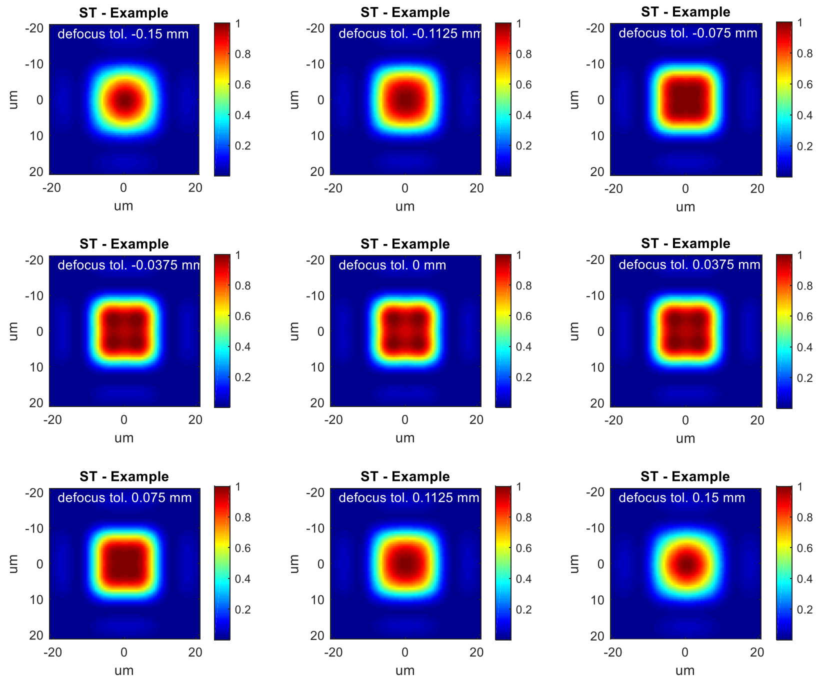




7.2 Small Top Hat X1.5 DL tolerances

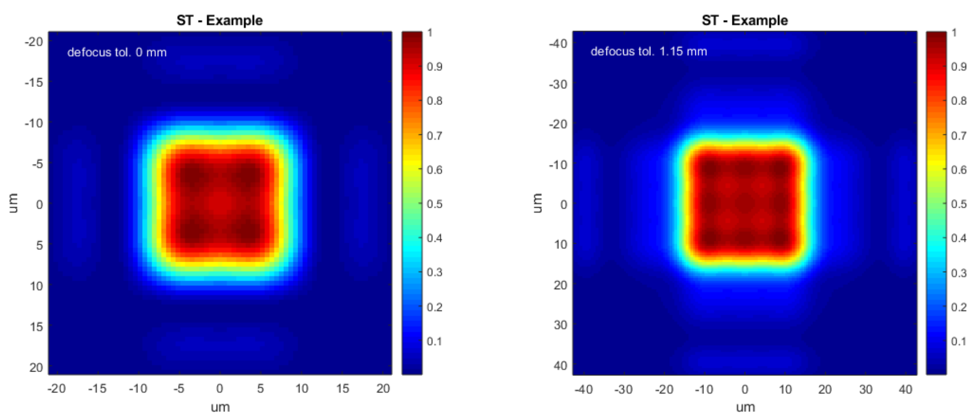
Sensitivity of Binary ST to defocus: In general, Small Binary ST have a high sensitivity to defocus. Please follow the procedure in section 4 carefully to find the focal plane.

Unlike regular TH, defocus of Binary-ST has a symmetrical behavior around the focal plane for both negative and positive defocus, see simulations below.



Small ST- Negative and positive defocus and its effect on the final shape.

At certain large defocus values, a Binary ST will give a wrong top hat with twice the size of the deigned top hat, at what we call the first Talbot plane. See below. If you see a top hat much larger than designed, please re-do the procedure in section 4 in this manual to find the right focal plane.



ST-Example, image on the left at the focus plane. The image on the right at the first Talbot-plane.