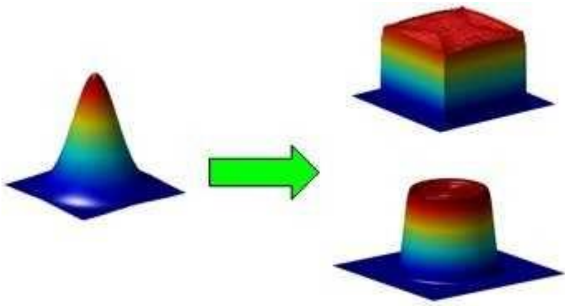
Beam Shaper Application notes

Contents



Introduction

In various industries there is a need to focus a laser beam to a well-defined size and shape with uniform intensity (flat top). A uniform spot enables even laser treatment of the working surface.

In addition, the sharp edges of the spot – or narrow "transition region" - create a clear-cut border between treated and untreated zones.

Typical applications include:

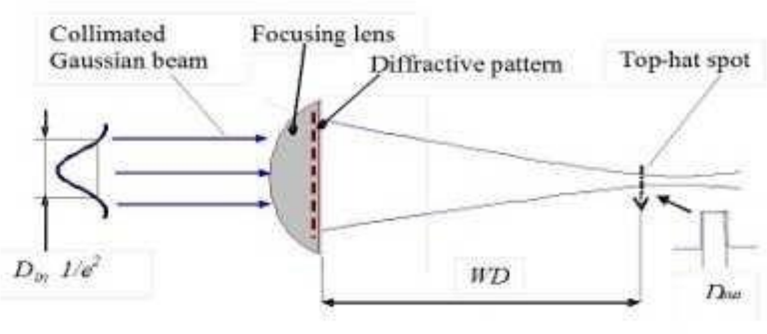
- Laser Ablation
- Laser Welding
- Hole Drilling
- Laser Scribing
- Laser Displays
- Filters for cigarettes
- Medical and aesthetic laser applications

This application note is meant to contribute to the user's understanding of the functionality and share considerations that should be taken into account when using a Beam shaper diffractive or refractive element.

Operation principle:

The most rudimentary set-up in a Beam Shaper application consists of a laser, a refractive / diffractive beam shaper element and the surface to be treated. See fig.1 below.

Figure 1: Basic Operation



The diffractive beam shaper is a phase element that transforms the Gaussian input beam into a uniform spot with sharp edges at a specific working distance WD.
**Note that the Top-Hat spot is <u>NOT</u> at the minimum spot location (minimum waist), but near it.

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

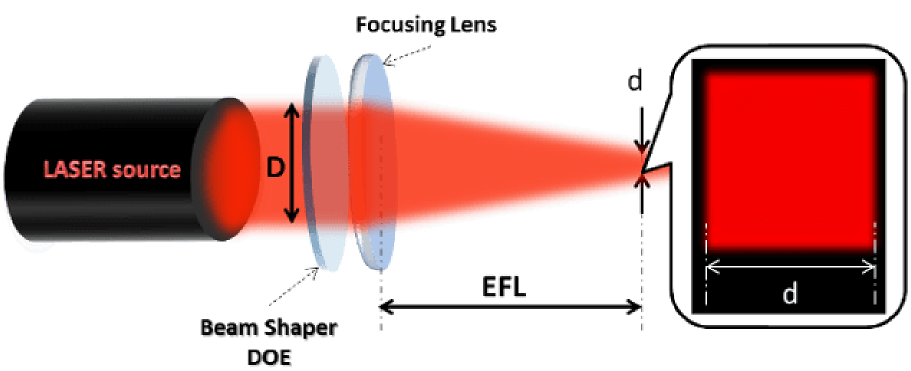
1. Wavelength
2. Input Beam Size (Din)
3. Working distance (WD)
4. Output Spot Size (Dout)

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.

<u>Design Considerations</u>

For good quality beam shaper performance, the laser output should be **Single Mode** (TEM00) with an **M2** value under 1.3. If the M2 is larger, it may still be possible to reduce the M2 value by inserting a spatial filter in between the laser and the DOE lens component.

The **spatial filter** consists of a focusing lens, a small aperture in the focal plane, and a collimating lens. The spatial filter aperture acts to reduce parasitic modes, whose presence in the laser output cause a large M2 value and a degraded Top-Hat performance. The user must take care to use a small aperture, BUT not smaller than 2x the beam size at the aperture plane. Too small of an aperture will give rise to a parasitic interference pattern or ripple in the beam shaper output spot. By manipulating the focal lengths of these two lenses, the spatial filter can also be used as a **beam expander**. Figure 2: Typical Set Up.



d	Top-Hat size
D	Beam Diameter
EFL	Effective Focal Length

The advantage of working with a larger input beam is twofold. First, a larger beam reduces somewhat the sensitivity of the beam shaper output to tolerances. Secondly, a larger input beam will enable achieving a smaller output spot, which is a desired outcome for many beam shapers applications.
As was mentioned regarding the spatial filter aperture, ALL apertures in the beam path must be **at least 2x** larger than the beam size (1/e^2) on the aperture plane (best over 2.5x). These often include mirrors (for beam folding), beam expander, beam splitter and filter/diaphragm.

All optics in the beam path should be of high quality, i.e. have a **low irregularity** figure, in order not to introduce wave-front errors which would degrade the beam shaper performance. This includes mirrors which should have **high flatness** specification. Here, too, a larger beam size incident on the mirror will reduce its sensitivity to aberrations.

As was mentioned above, the beam shaper element requires that the input beam will be **collimated**.
For this reason, as well as for purposes of stability, it is recommended to work with the beam shaper element **in the waist of the laser**. Nonetheless, if the beam has a **small divergence angle** (<1º), there should not be any noticeable effect on the Top-Hat output quality, it will though change the working distance.
If, due to mechanical or other constraints, the diffractive optical element (DOE) will be located at a distance from the beam waist, it is important to take this distance into consideration, along with the beam divergence, in the designing of the DOE. Otherwise, the resultant wave-front aberration can generate an interference/ripple pattern over the output beam, whose intensity will grow as a function of the DOE's distance from waist and the divergence angle.

When designing the desired output Top-Hat size, it is important to be familiar with the physical limits of the minimum spot size. The formula for the diffraction-limited spot size:

$$\frac{4 * L * \lambda}{\pi * D} * M^2 = D.L.spot\ size$$

Where:
L: Working Distance
λ: Wavelength
D: Input Beam Size
M2: M2 value of input laser beam

As a rule of thumb, the **minimum beam shaper spot size** will be between 1.5 to 5 times the diffraction-limited spot size given by the above formula. The precise factor depends on whether the element is a Top-Hat or Stable Top-Hat. See final section for comparison.

<u>Characteristics</u>

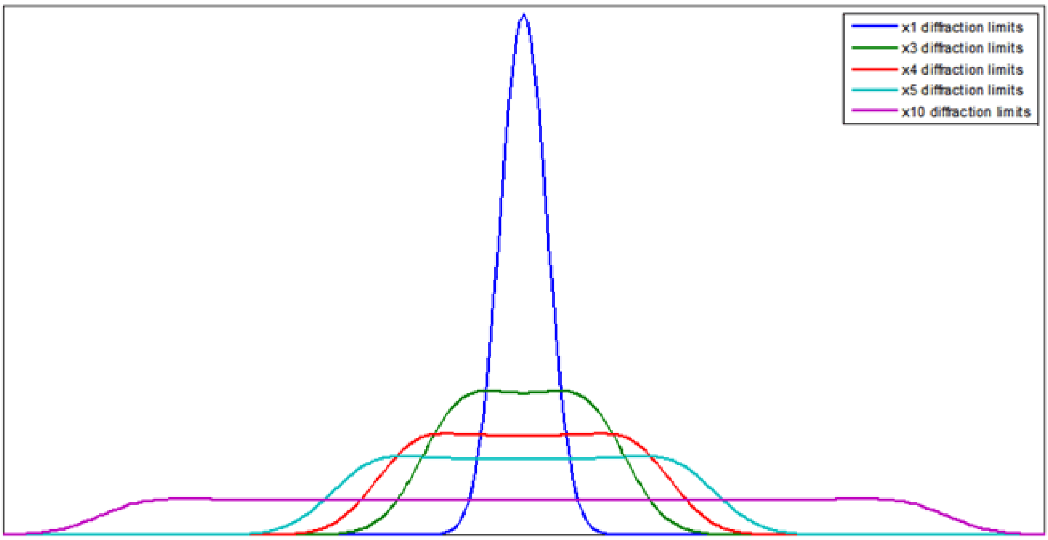
- **Uniform intensity profile:** Typically +/-5%.
- **Steep transition region:** Typically similar to diffraction-limited spot with the same input diameter and working distance.
- **High Power Threshold**
- **High Efficiency**: Typically >95%
- **Sensitivity to X-Y displacement:** Typically 5% of the input beam, in order to keep acceptable performance.
- **Sensitivity to Input Beam diameter**: Typically 5% of the input beam in order to keep acceptable performance.
- **Rotation insensitive:** For round shape.
- **Sensitivity to working distance: Typically** smaller than 50% of the spot size in order to keep acceptable performance.

Consideration of Top Hat (TH) size as a number of diffraction limits

Some basic rules:

- It is impossible to get a Top Hat size smaller than the diffraction limited spot size
- The Factor between the beam shaper size and the diffraction limited spot size defines the quality and efficiency of the beam shaper. A larger factor enables sharper edges
- The transfer region of the beam shaper can't be < 0.5 DL size and is generally ~1 DL

Example of same size TH with different DL number:



A typical application prefers the transfer region (13.5-90 %) to be as small as possible and the Top Hat profile to have a maximum relative size of uniform area.
The TH's quality (Qth) parameter can be defined as relation:

$$Q_{th} = \frac{TH\ size}{DL}$$

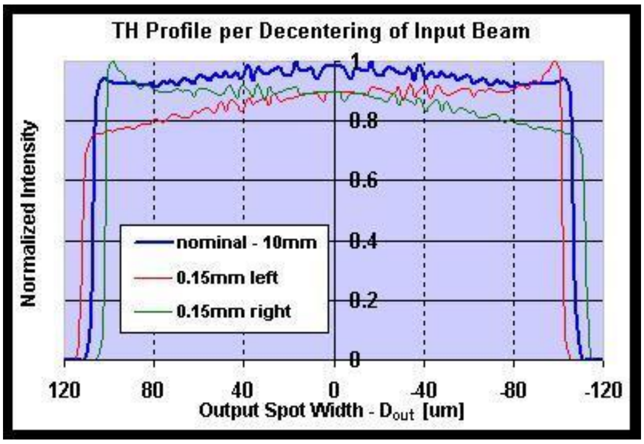
Sensitivity to Alignment and Beam Tolerances:

Beam shaper elements are sensitive to various parameter tolerances [mentioned under the section characteristics]. When one goes about designing a set-up that includes a diffractive optical element (DOE), one should take care to ensure control and stability of these system parameters.
Many of the Top-Hat output 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. For example, for an input beam of 10mm diameter, a mismatch of 5% gives 0.5mm tolerance, while for a beam diameter of 2mm, a 5% tolerance corresponds only to 0.1mm.

Simulated Effects of Tolerances on beam shaper Profile

The best performance will be obtained for a well-positioned perfectly aligned part, located precisely in the plane of the nominal working distance. To illustrate the sensitivity of beam shaper performance to different tolerance parameters, several graphs are included here for a typical beam shaper element (WD: 120mm, λ: 532nm, Din: 10mm).

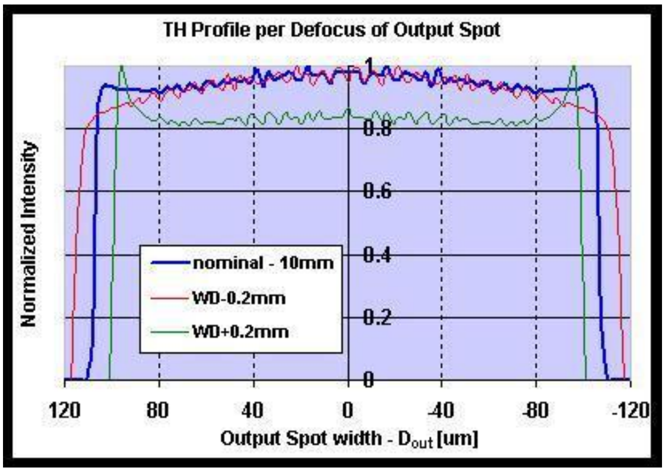
Fig. 4: Effect of x-axis or y-axis de-centering of input beam on Top-Hat Profile



**Noteworthy in figure 4 above is the "tilted" Top-Hat profile due to de-centering; i.e. a slope in the intensity going from one side of the spot to the other.

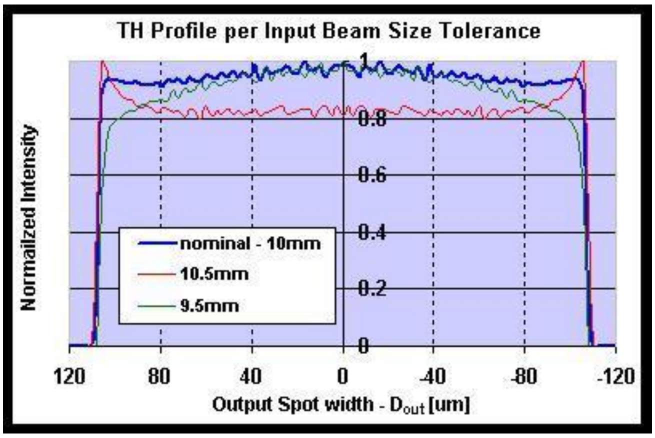
Sensitivity of Top-Hat to **large** decentering of the input beam in relation to the element center.

Fig. 5: Effect of Working Plane Defocus on Top-Hat Profile



Note the different behavior of the Top-Hat profile when located too close (red** curve) as opposed to being too distant (**green** curve). The uniformity suffers a drop in both cases, while the extended distance gives rise to narrow peaks at the Top-Hat spot periphery (like "dog ears"), the shorten distance gives a more rounded output.

Fig. 6: Effect of Input Beam Size Tolerance on Top-Hat Profile

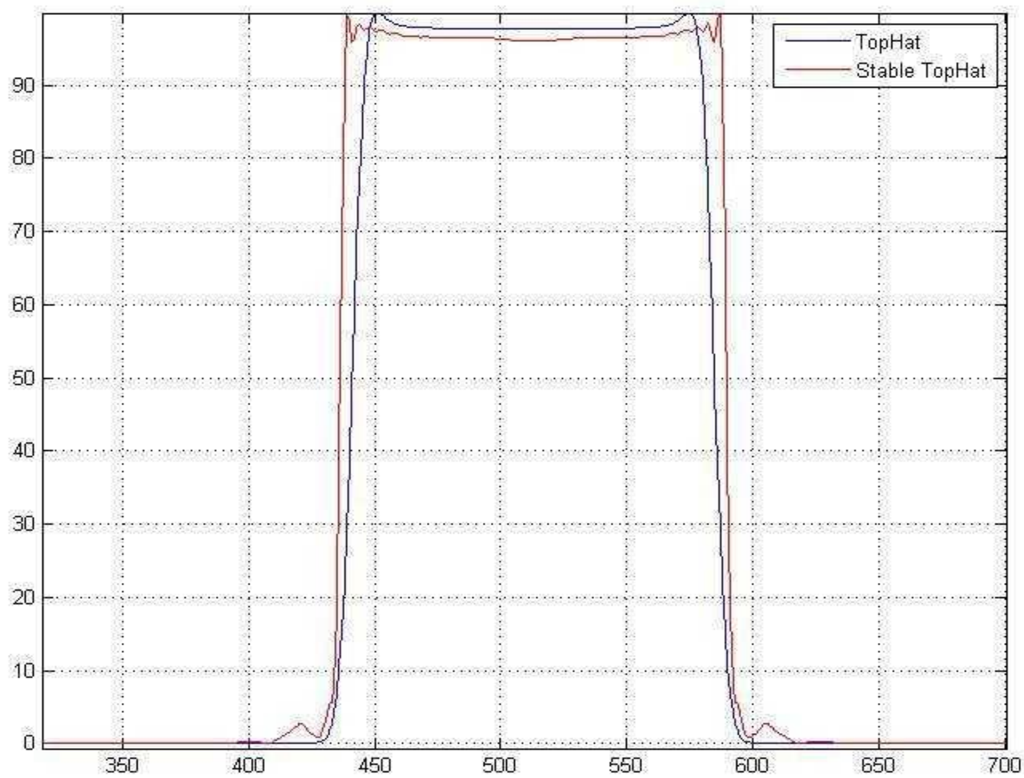


**Interesting to note in fig.6, that this gives a very similar effect as in fig.5. There is a clear parallel between too large beam size and extended defocus. The "dog ears" effect is the same.

Comparison of Top-Hat and Stable Top-Hat

Holo/Or uses two slightly different algorithms for the Top-Hat diffractive pattern, each algorithm with its advantages. The original Top-Hat algorithm produces a higher level of uniformity than its "ST" counterpart, and is also less sensitive to errors in manufacturing. On the other hand, the "ST" algorithm can achieve a smaller spot size (1.5x diff. limit) than the "Top-Hat" (5x diff. limit), and a smaller transition region.

Included below is a typical graph with a superposition of equivalent designs – i.e. with the same spot size.



Comparison of Beam Shaper and Polychromatic Beam Shaper

The standard beam shaper is optimized for a specific wavelength. Other wavelengths will affect the Top-Hat performances. If the customer's application requires a polychromatic source, the polychromatic beam shaper will then normally be a better solution. The polychromatic beam shaper presents the advantage to work well for a broad wavelength range and can also be, in some case, a less expensive solution. However, this product can be less accurate in the Top-Hat size and shape.
You can find below a summary table of comparison between standard beam shaper and Polychromatic beam shaper:

Type	Standard	Polychromatic
Wavelength dependence	YES	NO
Material	Fused silica, ZnSe, plastic	Fused Silica, optical glass
Top Hat shape	Any	Round, Square, Rectangular, Line
Efficiency	> 95%	> 95%
Uniformity	Typically < 5%	Typically < 10%
Top Hat size	very precise	precise
Top Hat shape	very accurate	accurate
Top Hat quality factor (in units of diffraction limits number)	not depends on wavelength	inverse proportional to wavelength
Top Hat diffusion angle	proportional to wavelength	proportional to refractive index

The polychromatic beam shaper appears in angular beam shaper product page with format **PT**-123-A-B-C

Beam Shaper design tool for MATLAB

Holo/Or published a beam shaper design tool for MATLAB. This free of charge service provides intensity distribution for any beam shaper. The designer is free to choose the wavelength, input diameter, spot size and working distance of his preference. A link will be provided to get a fast quotation for the design simulated.

Download P-code for beam shaper design tool

Instructions:

- Unzip the downloaded file
- Change your MATLAB current folder to the unzipped folder
- Write "help TH" in the "Command Window" and click "Enter"
- Follow the instructions in order to simulate your custom Top-Hat design

Beam Shaper design software

HOLO/OR published a completely free of charge beam shaper design tool. The software provides intensity distribution for any Square shape Top-Hats. The designer is free to choose the wavelength, input diameter, spot size and working distance of his preference. The user can receive a fast quotation for the design simulated.

Instructions:

- Installation of environment:
    - Windows 32 bit
    - Windows 64 bit
- Unzip and run the exe file:
    - Windows 32 bit
    - Windows 64 bit

>> Click here to download the beam shaper installation manual

>> Click here for beam shaper standard products