# Square top-hat from a femtosecond laser with a phase-only LCOS SLM

80 W femtosecond laser at 1030 nm, 300 µm square top-hat, average power from 0 to 300 W

### Application

A phase-only spatial light modulator (SLM) can turn the round Gaussian beam of a femtosecond laser into a square spot of even irradiance, called a top-hat. The phase pattern written on the SLM is computed for perfect optics. This note asks what the SLM really delivers on the machine, and what it costs.

### Modelling approach

We modelled the set-up from the laser output to the work plane, through a beam expander, the SLM and a Fourier lens. The beam was propagated as a wave through the real lenses, from cold optics up to 300 W. We judge the top-hat by its uniformity, the standard deviation of the irradiance divided by its mean over the central 90 % of the square. We accept it below 0.2.

## 1 The set-up

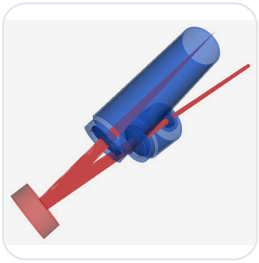


**Figure 1.** The set-up as modelled in etendue. A Galilean expander doubles the beam size. The SLM, tilted by 10° on a water-cooled support, writes the phase pattern. The Fourier lens focuses the beam on the work plane. **Table 1.** Main parameters.

| PARAMETER | VALUE | PARAMETER | VALUE |
|---|---|---|---|
| Average power | 80 W | Beam radius on the SLM (1/e²) | 5.1 mm |
| Pulse energy, duration | 400 µJ, 290 fs | SLM pixels | 1272 × 1024, 12.5 µm |
| Wavelength | 1030 nm | Fourier lens focal length | 250 mm |
| Beam quality M² | 1.2 | Top-hat | 300 × 300 µm |

## 2 The top-hat through the real optics

uniformity 0.179, limit 0.2

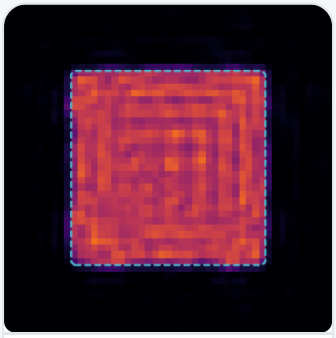


**Figure 2a. Perfect optics.** Uniformity 0.108. Look at the plateau.

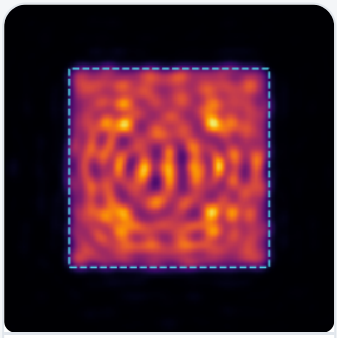


**Figure 2b. Real optics.** Uniformity 0.179. Look at the ripples.

Does the top-hat survive the real lenses and the real beam? Yes, with a small margin. The design promised a uniformity of 0.108. Through the real optics it is 0.179, still under the limit of 0.2.

**0.169**
Uniformity when the SLM also corrects the wavefront error of the lenses.

**92 %**
Share of the light that lands in the square.

**0.19 to 0.28**
Uniformity 0.5 mm either side of the work plane. The top-hat is only flat close to focus.

## 3 Average power

Does heat limit the average power? No. The lenses absorb very little, and the top-hat hardly changes up to the top of the range. The limit is the SLM itself, whose data sheet sets the highest power.

**5 mW**
Heat absorbed by the three lenses at 80 W.

**0.165 to 0.184**
Uniformity from cold optics up to 300 W.

**52 µm**
Focus shift at 300 W.

**200 W**
Highest power in the SLM data sheet.

# Where the top-hat loses its flatness, and what the SLM costs

The SLM receives more beam than the design assumed. That light is not shaped, and no phase pattern can correct it.

### Table 2. Uniformity near the work plane

| Distance from the work plane (mm) | Perfect optics | Real optics | Real optics, SLM correction |
|---|---|---|---|
| -1 | 0.355 | 0.253 | 0.314 |
| -0.5 | 0.224 | 0.194 | 0.222 |
| 0 | 0.108 | 0.179 | 0.169 |
| +0.5 | 0.207 | 0.277 | 0.191 |
| +1 | 0.353 | 0.386 | 0.313 |

The limit of 0.2 applies at the work plane. Negative distances are towards the lens.

### Table 3. Effect of the average power

| Average power (W) | Uniformity | Uniformity, SLM correction | Heat in the lenses (mW) | Focus shift (µm) |
|---|---|---|---|---|
| cold | 0.179 | 0.169 | — | — |
| 80 | 0.180 | 0.168 | 5 | 14 |
| 200 | 0.182 | 0.166 | 13 | 35 |
| 300 | 0.184 | 0.165 | 19 | 52 |

The SLM correction is computed once, with cold optics. Recomputing it at each power changes the uniformity by 0.002 at most.

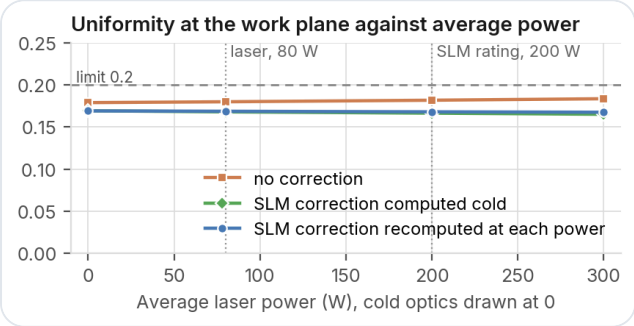



**Figure 3.** Uniformity at the work plane against average power. The dotted lines mark the laser power and the SLM rating.

### Why the top-hat differs from the design

The design assumes perfect lenses and a beam cut to a 12.8 mm disc. On the machine, the SLM receives the whole beam, and part of it falls outside the phase pattern. That light is not shaped, and the uniformity rises from 0.108 to 0.276.

The real expander and Fourier lens change it very little, to 0.262. The real laser beam ($M^2$ 1.2) carries several modes whose ripples partly average out, and the uniformity drops to 0.179.

### What the SLM correction adds

The wavefront error of the lenses is small, 0.034 waves RMS. The SLM can write its opposite on top of the pattern, and the uniformity improves from 0.179 to 0.169. The rest of the difference is in amplitude, and no phase pattern can correct it.

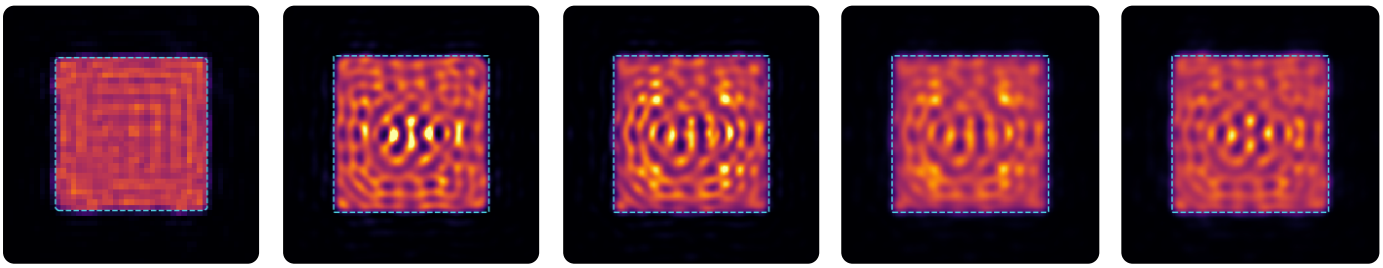
### What it costs

The top-hat is short. At 0.5 mm from the work plane the uniformity exceeds the limit, even with perfect optics (0.21 to 0.22). The work piece has to be held at focus.

The SLM sets the power ceiling. Its data sheet recommends at most 200 W. The liquid-crystal chip may absorb up to 3 % of the power it receives. Its water circuit must remove that heat, which the model does not compute.

The heat in the lenses is negligible. They lose it to the air, and the SLM support, held above the room temperature, even receives 0.5 W of heat from its regulator.

### Figure 4. Irradiance at the work plane, one effect added at a time



**Perfect optics**
uniformity 0.108

**Whole beam on the SLM (clipping)**
uniformity 0.276

**Real expander and Fourier lens**
uniformity 0.262

**Real source, $M^2$ 1.2**
uniformity 0.179

**SLM corrects the optics**
uniformity 0.169

Each map covers ±0.25 mm with the same colour scale. The dashed line is the target square. A uniformity in green is under the limit of 0.2, in red above it.