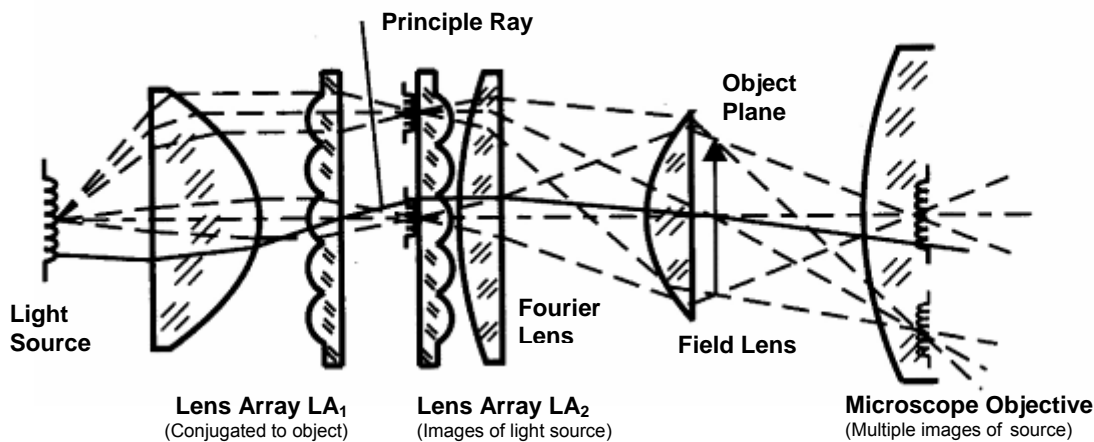


SMO TECHINFO SHEET 10 - BEAM HOMOGENIZING



Source: Naumann, Schröder, Bauelemente der Optik, Hanser Verlag

Strategies for beam homogenizing

Since more than 100 years **Fly's Eye Condensers** are used to **homogenize** light emitting from a light bulb and to efficiently illuminate extended object fields in the object plane of the microscope.

Similar homogenizers with **Microlens Arrays** are used today for homogenizing of a wide variety of modern light emitters from line-narrowed Excimer Lasers to high power LEDs.

This data sheet summarizes optical and physical properties of Beam Homogenizers using refractive, plano-convex **Microlenses** as supplied by SUSS MicroOptics. All data given is based on simulations using [Zemax-EE](#) and [FRED](#) optical design software or experimental results. For a more detailed discussion of this subject, we recommend to read p.129 – 155 in Fred M. Dickey's book on Laser Beam Shaping Applications.<sup>1</sup>

There are two main types of **Microlens Beam Homogenizers**: (A) the **Non-Imaging** and (B) the **Imaging** Microlens Homogenizer. Both types use either cross-cylindrical or square microlens arrays to divide the incident beam into beamlets. These beamlets are then passed through a spherical lens FL to be overlapped at the homogenization plane FP located in the back focal plane of the spherical lens FL. The spherical lens FL causes parallel bundles of rays to converge in the homogenization plane FP and is therefore called a **Fourier lens**. It carries out a two-dimensional Fourier transformation. The intensity pattern in the homogenization plane is related to the spatial frequency spectra generated by the microlens array(s) entering the Fourier lens.

The decision whether to use a **Non-Imaging** or **Imaging** Homogenizer depends very much on the light source and the desired application. Following Dickey's<sup>1</sup> suggestion the Fresnel number FN should be used as a general guideline. [For a detailed discussion about the importance of the Fresnel number FN for Microlens Arrays, please read our [Technical Information Sheet 11.](#)]

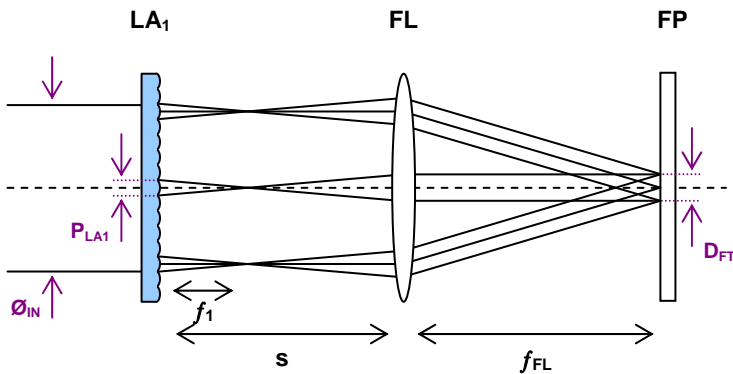
The Fresnel number FN of a microlens beam homogenizer is defined as  
 whereas  $P_{LA}$  is the pitch of the microlens array,  $D_{FT}$  is the dimension of the flat-top intensity profile in the homogenization plane FP,  $f_{FL}$  is the focal length of the Fourier lens FL and  $\lambda$  is the wavelength.

$$FN \approx \frac{P_{LA} \cdot D_{FT}}{4 \cdot \lambda \cdot f_{FL}}$$

**Non-Imaging Homogenizers** often show dominant diffraction effects due to Fresnel diffraction at the microlens array. The Fresnel diffraction is related to the **Fresnel number FN**. Higher Fresnel numbers give sharper edges and smaller variations of the flat-top profile. In practice, Non-Imaging Homogenizers should have Fresnel numbers  $FN > 10$ , better  $FN > 100$ , to obtain a good uniformity. **Non-Imaging Homogenizers** are well suited for **large area illumination**, as the flat-top dimension  $D_{FT}$  is proportional to the Fresnel number FN. For small Fresnel numbers  $FN < 10$  or high uniformity flat-top requirements, the **Imaging Homogenizer** is the preferred solution.

### A) NON-IMAGING HOMOGENIZER: One Microlens Array LA1, spherical lens FL

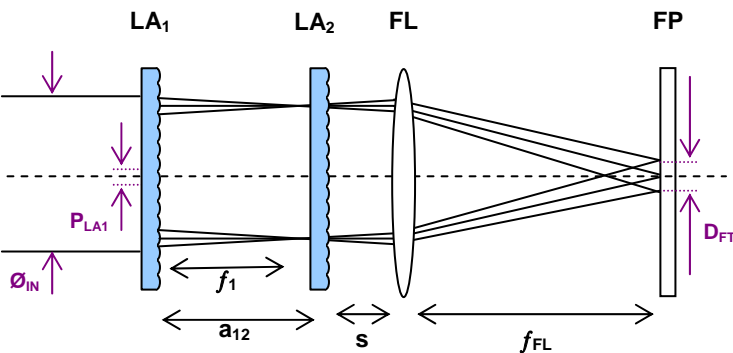
The homogenization plane FP is located at one focal length distance  $f_{FP}$  behind the spherical lens FL. The dimensions of the beam in the homogenized plane are given by  $D_{FT}$ .



$$D_{FT} = \left| \frac{P_{LA1} \cdot f_{FL}}{f_{LA1}} \right|$$

### B) IMAGING HOMOGENIZER: Two Microlens Arrays LA1 and LA2, spherical lens FL

The homogenization plane FP is located at one focal length distance  $f_{FP}$  behind the spherical lens FL. The dimensions of the beam in the homogenized plane are given by  $D_{FT}$ .



$$D_{FT} = P_{LA1} \frac{f_{FL}}{f_{LA1} \cdot f_{LA2}} [(f_{LA1} + f_{LA2}) - a_{12}]$$

where  $f_{LA1} < a_{12} < f_{LA1} + f_{LA2}$   
 $a_{12}$  : separation of LA<sub>1</sub> and LA<sub>2</sub>

The **Imaging Homogenizer** uses the first microlens array LA<sub>1</sub> to divide the incident beam into multiple **beamlets**. The second microlens array LA<sub>2</sub>, in combination with the spherical lens FL, acts as an array of objective lenses that superimposes the images of each of the beamlets in the first array onto the homogenization plane FP.

The size of the flat-top now depends on the separation  $a_{12}$  of the two microlens array. This allows a variation of the flat-top dimensions by shifting the position of the second microlens array. However, care must be taken not to damage the second microlens array by focusing high-power laser beams into the lens material or to generate crosstalk by overfilling the lens apertures of the second microlens array.

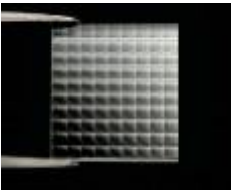
For **Imaging Homogenizers** the divergence  $\theta$  (half angle) after the homogenized plane is given by

$$\tan \theta < \frac{1}{2} \frac{(\varnothing_{IN} + D_{FT} - 2P_{LA})}{f_{FL}}, (D > P_{LA})$$

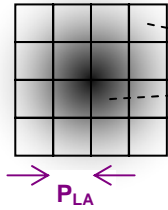
$$\tan \theta \approx \frac{1}{2} \frac{(\varnothing_{IN} + D_{FT})}{f_{FL}}, (D < P_{LA})$$

Usually, Imaging Homogenizers consist of two similar microlens arrays with identical lens pitch. **Square-type** lens apertures generate a square flat top or top hat intensity distribution in the Fourier plane. **Circular** or **hexagonal** microlenses will generate a circular respectively hexagonal flat-top.

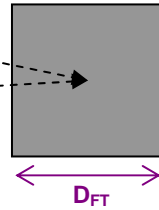
Square Microlens Array



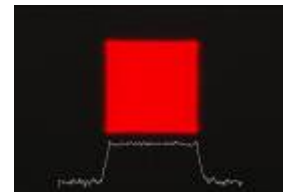
Microlens Array LA<sub>1</sub>



FP: Overlay of magnified lens apertures



Measured profile in FP



Although these two basic principles of **Microlens Beam Homogenizers** seem to be quite simple, the proper system layout for a specific illumination task is not always easy to find. There are no common cookbook recipes that work out for all the light sources and lasers.

### C) HOMOGENIZER DESIGN CONSIDERATIONS

We will now explain and discuss some additional design considerations that might be helpful for the layout of a **Microlens Beam Homogenizer** system.

**Microlens pitch:** For standard laser beams, the **overlay** of some 9-10 microlenses is usually sufficient to achieve a good flat top uniformity. Consequently, the beam diameter  $\varnothing_{IN}$  constrains the maximum microlens pitch  $P_{LA1} \leq \varnothing_{IN}/3$ . Typical homogenizers use 5x5 to 7x7 microlenses, but a larger number of microlenses do not have negative effects. For large Excimer laser beams, homogenizers with many thousands of microlenses provide excellent flat-top profiles.

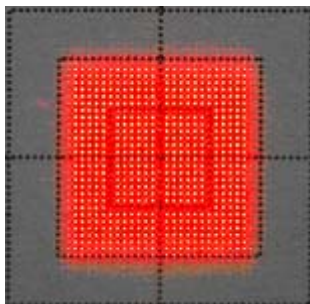
**Diffraction effects:** For small microlens apertures and a long focal length, i.e. for microlens beam homogenizers with a Fresnel Number  $FN < 10$ , the flat top profile might be distorted by **Fresnel diffraction** at the lens apertures. Thus for small laser beams a beam expander is usually the better solution than using microlens arrays with a very small lens pitch.

**Crosstalk:** For Imaging Homogenizers the diameter of the individual beamlets at the second microlens array LA<sub>2</sub> must be smaller than the lens pitch to avoid an **overfilling** of the lens aperture and the **loss of light**. For a collimated laser beam, the separation of the two microlens arrays is given by  $f_{LA1} < a < f_{LA1} + f_{LA2}$ . For laser beams with a significant beam divergence the diameter of the beamlets at the second microlens array scales with the beam divergence. The maximum allowed beam divergence for a given microlens homogenizer is  $\tan \theta \leq P_{LA1}/(2f_{LA1})$  for  $a = f_{LA1}$ .

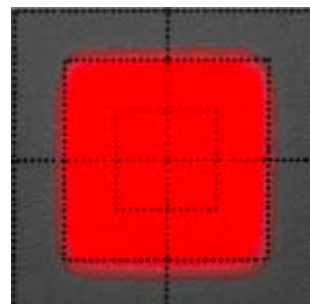
**Damage:** For **high-power laser beams**, a focusing into the material of the second microlens array or the spherical lens must be avoided. An additional diffuser might be used to properly fill the aperture of the second microlens array.

**Divergence:** The beam divergence is increased by the beam homogenizer.

**Coherence:** Fulfilling the image condition for **Imaging Beam Homogenizers** holds a severe disadvantage for coherent laser beams. Microlens arrays are periodic structures, where the pitch  $P_{LA1}$  is the grating period. Each microlens array will behave like a diffraction grating and will generate **diffraction orders** with a period  $\Lambda_{FP} = f_{FL} \cdot \lambda / P_{L1}$  in the homogenization plane FP.



*Distorted flat top profile for a coherent laser beam due to grating diffraction.*



*A rotating diffuser reduces the coherence and provides a perfect flat top for coherent lasers.*

The flat top intensity pattern of a coherent laser beam is distorted by an array of spots with the diameter  $\delta x = 2f_{FL} \cdot \lambda / \varnothing_{FL}$ , whereas  $\varnothing_{FL}$  is the diameter of the Fourier Lens FL.

These distortions by **grating diffraction** and **interference** could be reduced by different measures:

- A larger microlens pitch  $P_{LA1}$  leads to a finer period  $\Lambda_{FP}$  in the Fourier plane.
- A detuning of beam homogenizer components, e.g. a shift of the microlens arrays or the working plane out of its correct positions allows reducing the modulation of the flat top profile.
- A rotating ground glass diffuser plate to reduce the coherence of a cw-laser.

**ROTATING DIFFUSER:** For **coherent cw-lasers**, a rotating diffuser plate is the appropriated mean to avoid the grating diffraction. Placing the diffuser at the focus of the beam, e.g. by using a beam expander in front of the homogenizer, reduces the coherence by creating a new extended light sources, whereas the size of the source is equal to the spot diameter on the rotating diffuser.

Unfortunately rotating diffusers do not work for pulsed lasers like Nd:YAG with picosecond laser pulses. Different measures, such as stair case beam splitters are applied.

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Reference: <sup>1</sup> F.M. Dickey, S.C. Hoswade, D.L. Shealy, Laser Beam Shaping Applications, Taylor & Francis, ISBN 0-8247-5941