Beam forming for a Laser Based Auto-stereoscopic Multi-Viewer Display

Hadi Baghsiahi, David R. Selviah, Eero Willman, F. Anibal Fernández, and Sally E. Day

h.baghsiahi@ee.ucl.ac.uk, d.selviah@ee.ucl.ac.uk

Dept. of Electronic and Electrical Engineering, University College London (UCL), London, UK

Kishore V. C., Erdem Erden and Hakan Urey

Dept. of Electrical Engineering, Koç University. Istanbul, Turkey

Phil. A. Surman

Imaging & Displays Research Group, De Montfort University, Leicester, United Kingdom

Outline

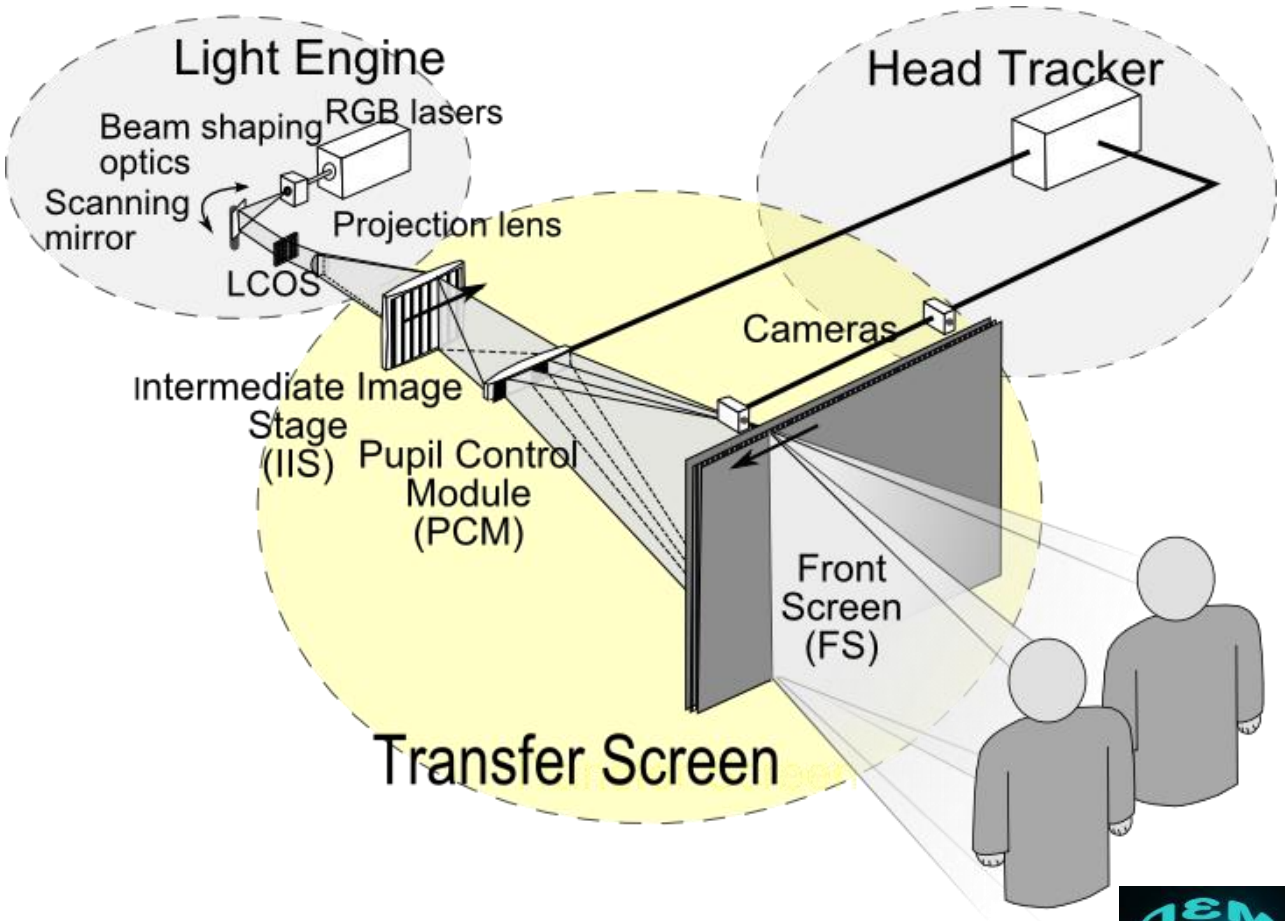
- Introduction: Laser-based Multi-user Multi-modal 3D Display
  - Light engine (illumination)
  - Transfer screen
  - Head tracker
- Requirements of the HELIUM3D display system
  - Laser-based display, advantages and disadvantages
  - Rear projected display with horizontal scanning.
- Experiments and results
  - Lasers characterization
  - Speckle suppression due to:
    - Number of diffusers
    - Number of independent emitters
  - Material stability in exposing high optical power
  - Laser beam homogenizing and beam shaping
- Conclusions

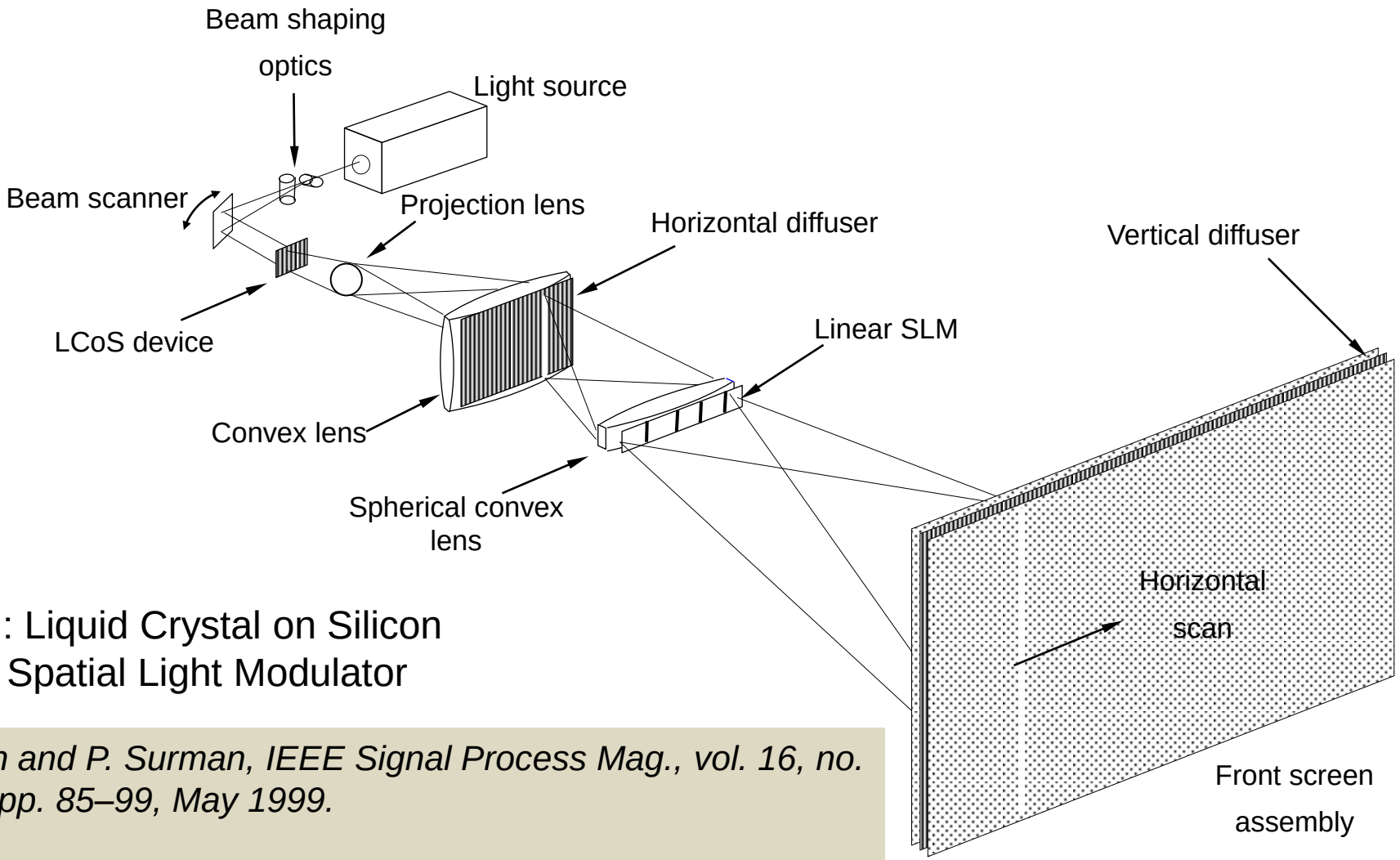
HELIUM3D System

High Efficiency Laser-based Multi-user Multi-modal 3D Display

The HELIUM3D display consists of 3 main sub-systems:

1. **Light Engine**
   Produces horizontally scanned columns of image frames.
2. **Head Tracker**
   Determines viewer eye positions.
3. **Transfer Screen**
   Relays the scanned image columns to viewer locations





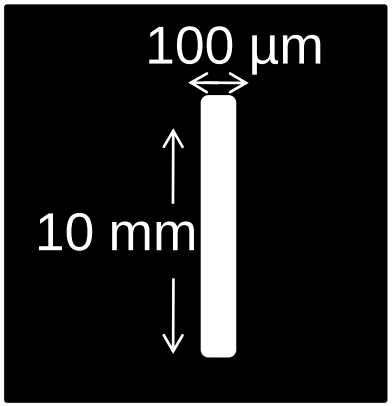
LCoS : Liquid Crystal on Silicon
SLM : Spatial Light Modulator

Sexton and P. Surman, IEEE Signal Process Mag., vol. 16, no. 3, pp. 85–99, May 1999.

E. Willman, et al. "The Optics of an Auto-stereoscopic Multi-view Display" 2010 SID International Symposium Digest of Technical Papers. Society for Information Display, (16.4).

HELIUM3D special requirements:

- A narrow homogenized beam to scan across the LCoS to illuminate the image.
- Scanning beam is required so that the whole exit pupil volume can be accessed .
- Output of the light source must be shaped to give a narrow light line with low étendue.
- High power light sources are required to provide enough optical energy.



RGB Laser based Light Engine

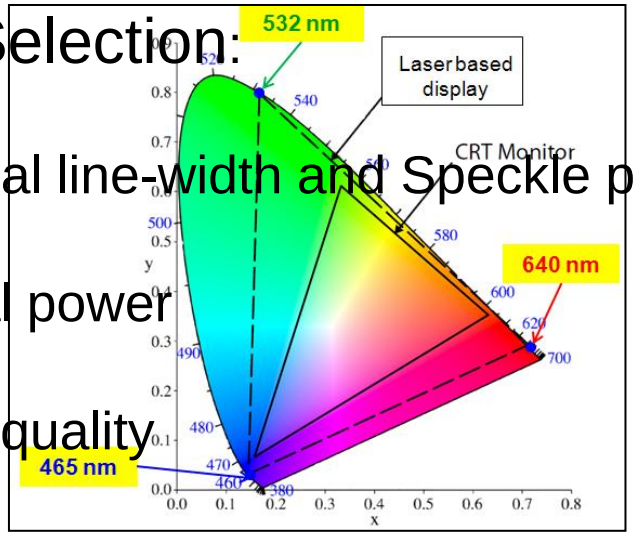
Advantages:

- High optical power
- Large colour gamut
- Low étendue

Disadvantages:

- Speckle problem
- Power density
- Safety issues
- Cost

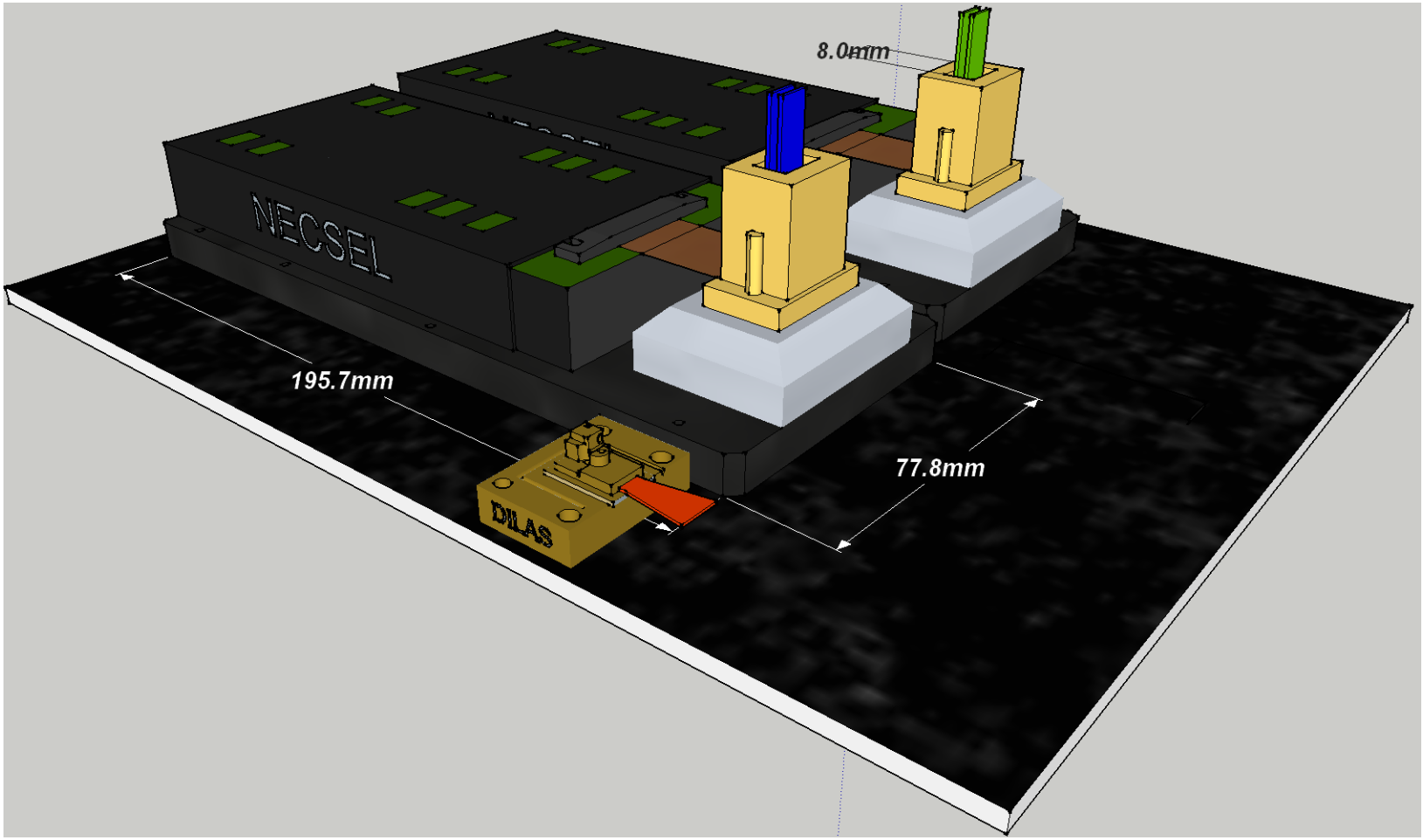
Laser Selection:



- Spectral line-width and Speckle problem
- Optical power
- Beam quality
- Polarization ratio
- Size of the laser
- Cost

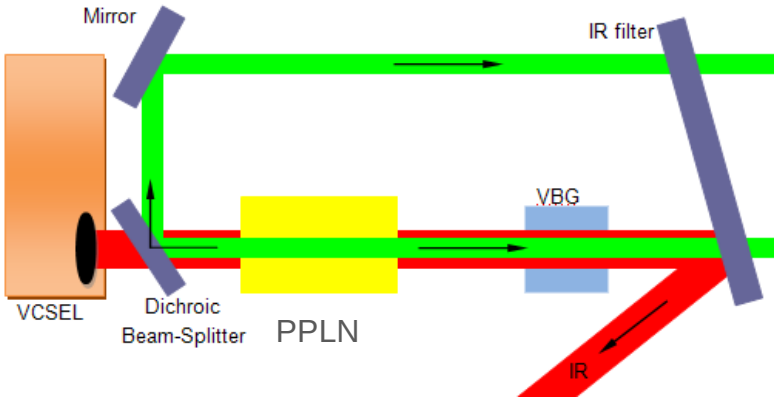
Light sources for the light engine

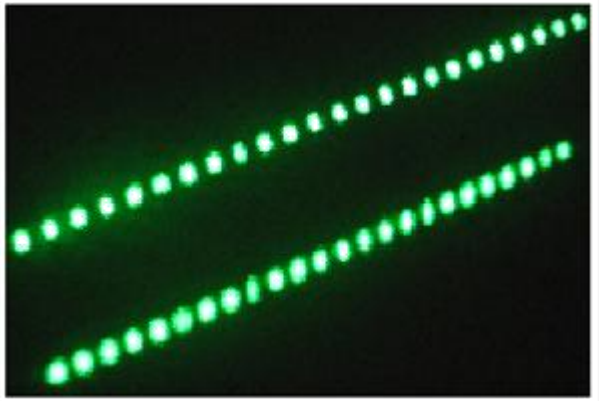
2 laser arrays, green and blue (NECSEL), and one red laser bar



Parameters of the RGB Laser used as the light source

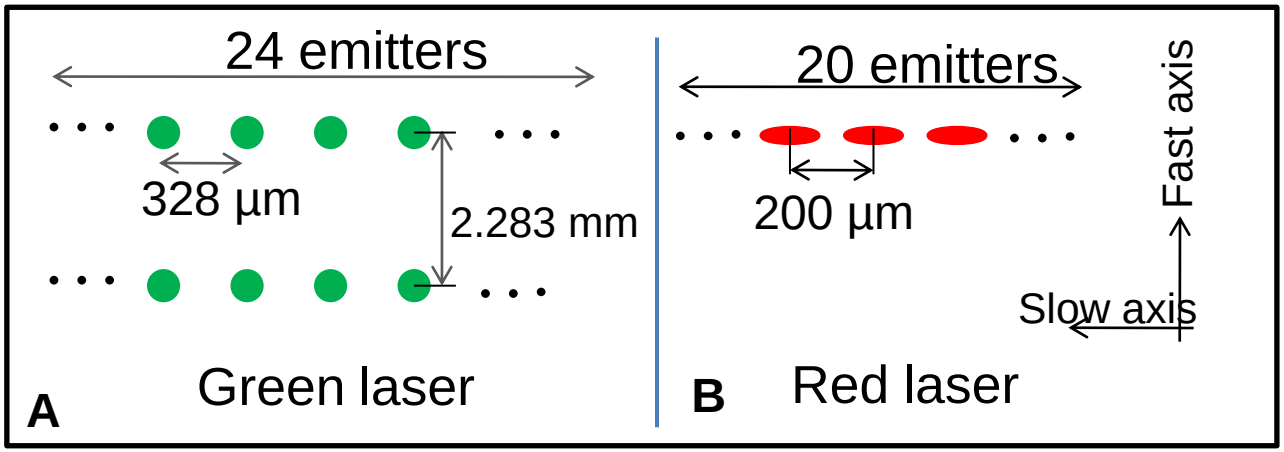
NECSEL structure (one single emitter)





Laser type	Surface emitting diode laser	Surface emitting diode laser	Edge emitting Diode laser
Wavelength (nm)	**457 ± 5**	**532 ± 5**	**639 ± 5**
Output power (mW)	**4000**	**4000**	**5000**
Number of emitters	**2 × 24**	**2 × 24**	**1 × 20**
Output array size (mm)	**3 × 8**	**3 × 8**	**1 × 4**

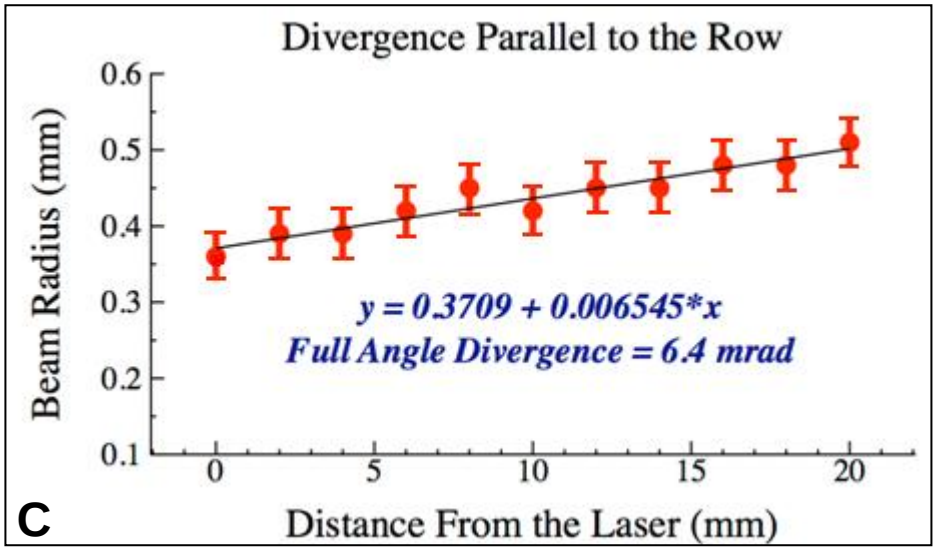
Laser characterization



A: Emitter spacing of NECSEL
(48 emitters in two rows)

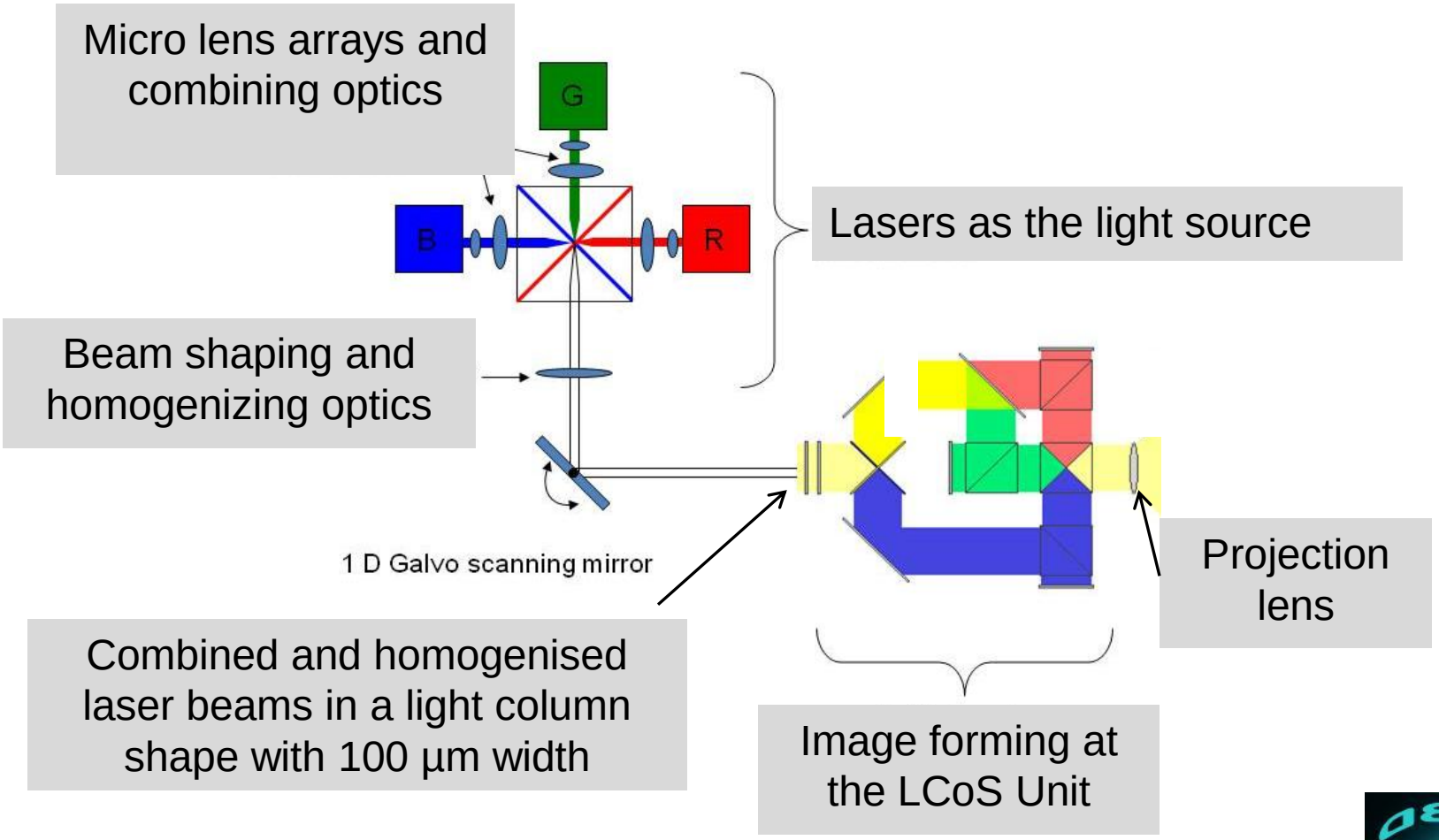
B:Emitter spacing of red diode laser
(20 emitters in one row)

C: Divergence of one emitter (top row)



Light Engine

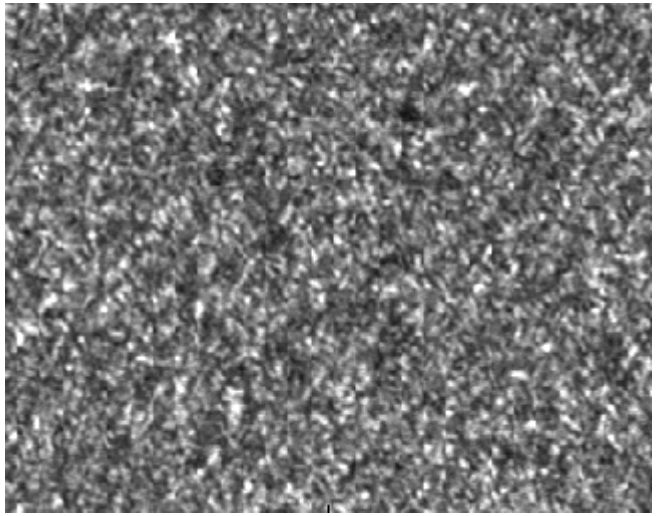
The light engine produces time-multiplexed scanned views of the displayed image content.



Speckle contrast measurements

Speckle is a fine scale granular interference pattern, quantified by the speckle contrast which is defined as:

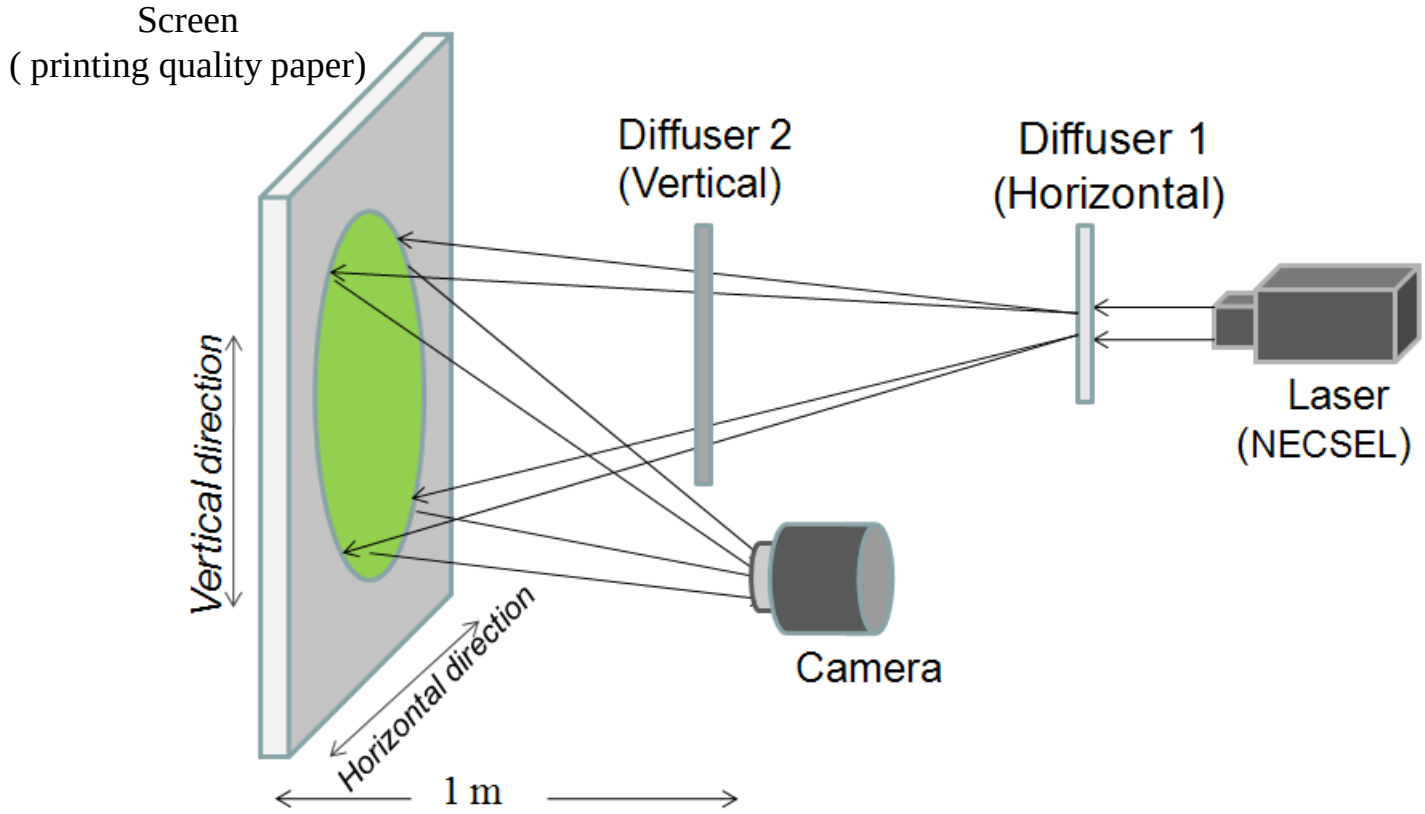
$$\text{Speckle contrast} = \frac{Standard\ deviation}{Mean\ value}$$



1. Speckle suppression due to the diffusers

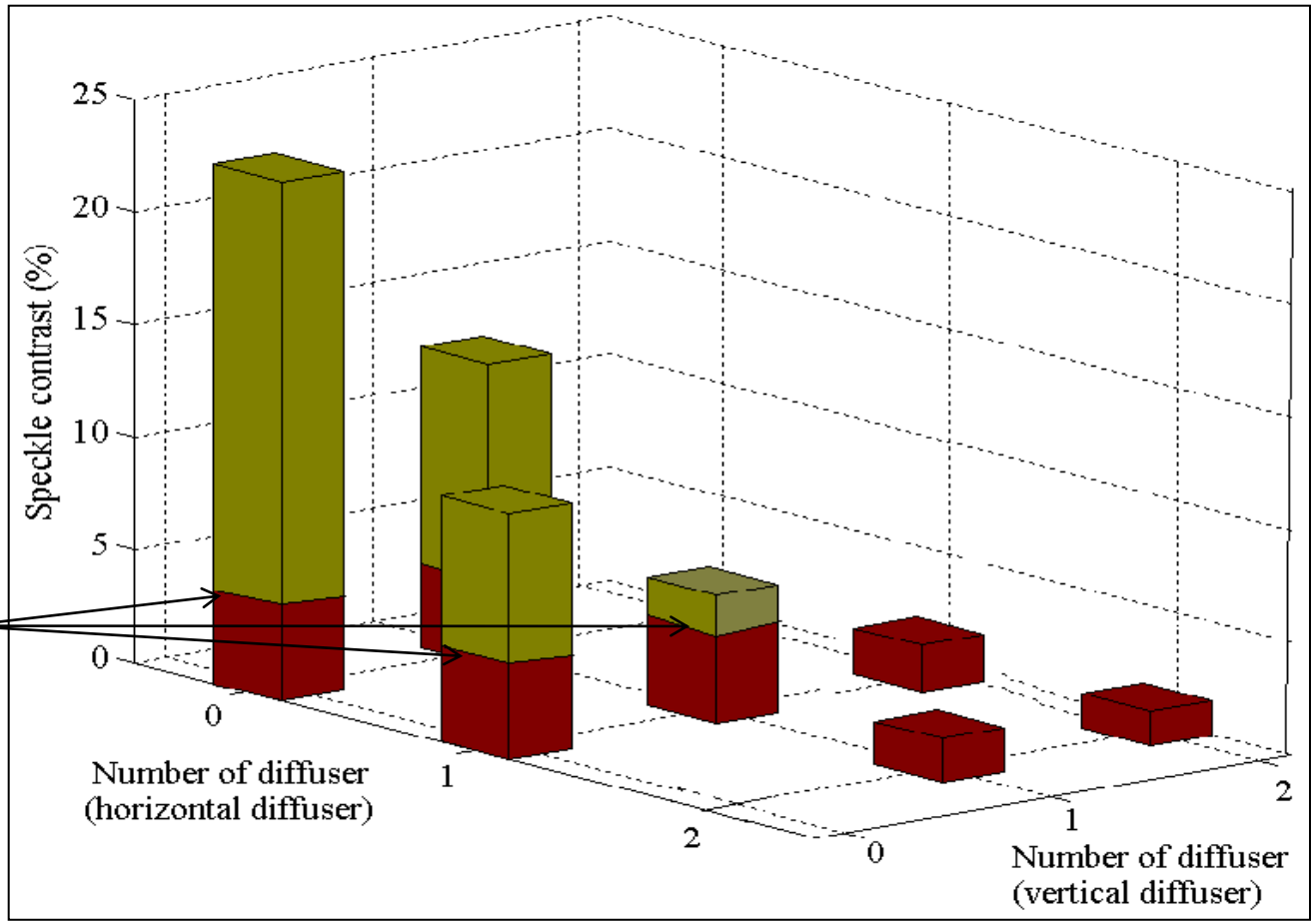
2. Speckle suppression due to the multiple sources.

Speckle contrast measurements with diffusers



Schematic diagram of the experiment of measuring the speckle contrast.
(The diffusers and the space between them is the same as the real system)

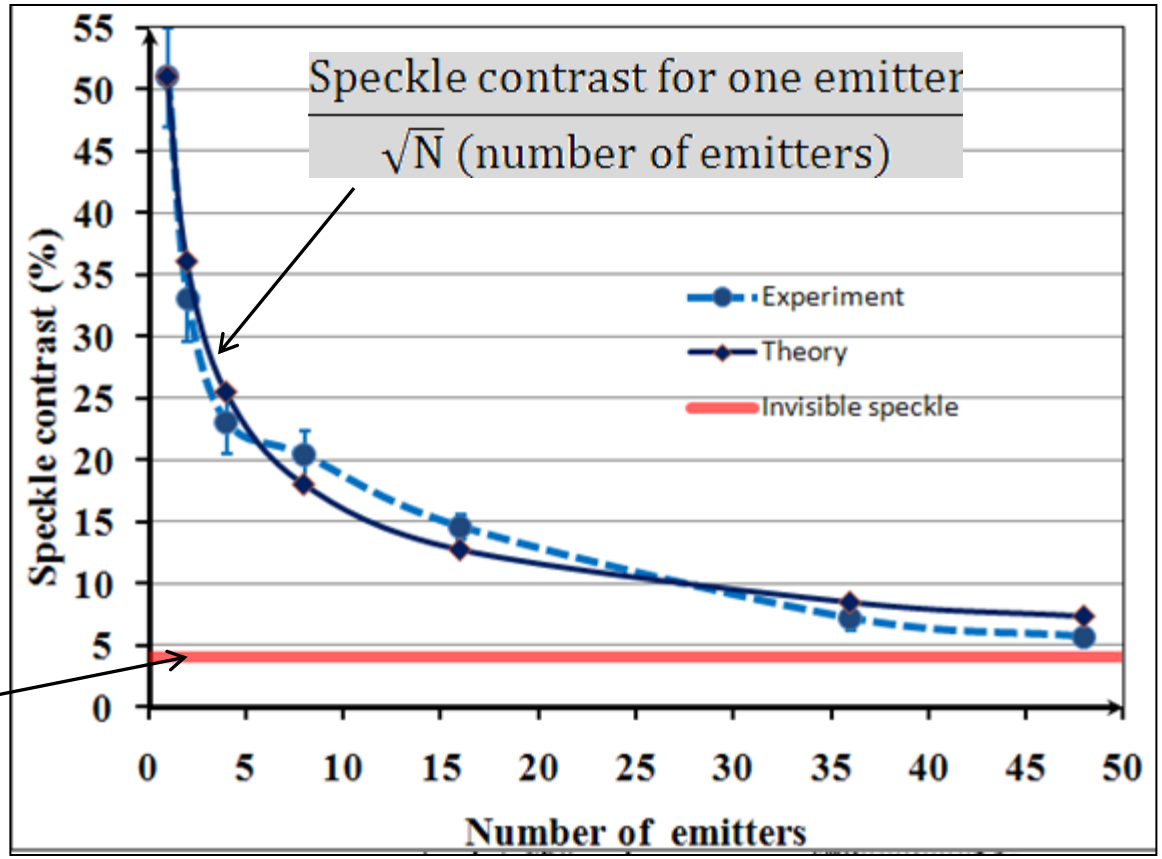
Threshold of speckle visibility *



Speckle contrast for various numbers and orientations of diffusers. Each diffuser diverges the light by 30 5 (523 mrad). Only 10 emitters are operating to reduce the power density at the diffusers position.

* L. Wang, T. Tschudi, et al. Appl. Opt. 37, 1770–1775 (1998)

Speckle contrast variation with number of emitters



Threshold of speckle visibility

Speckle contrast obtained as a function of number of independent emitters. Any speckle pattern with a contrast below the red line (<4%) is imperceptible

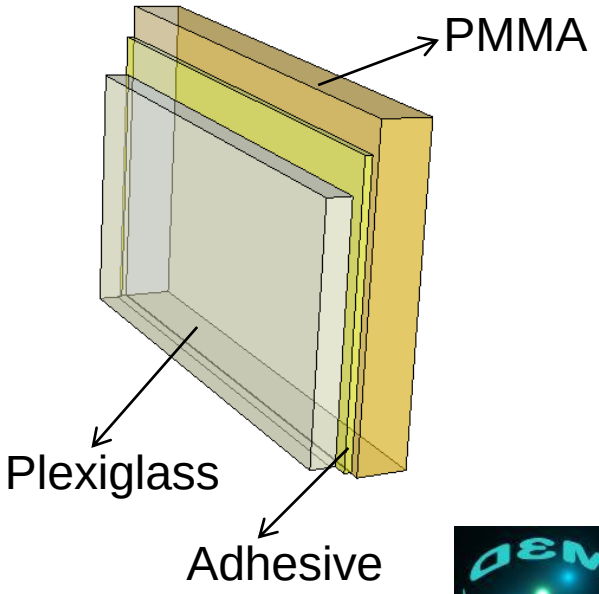
High optical power density - material dependence

The microlenses used for beam forming are made from three layers

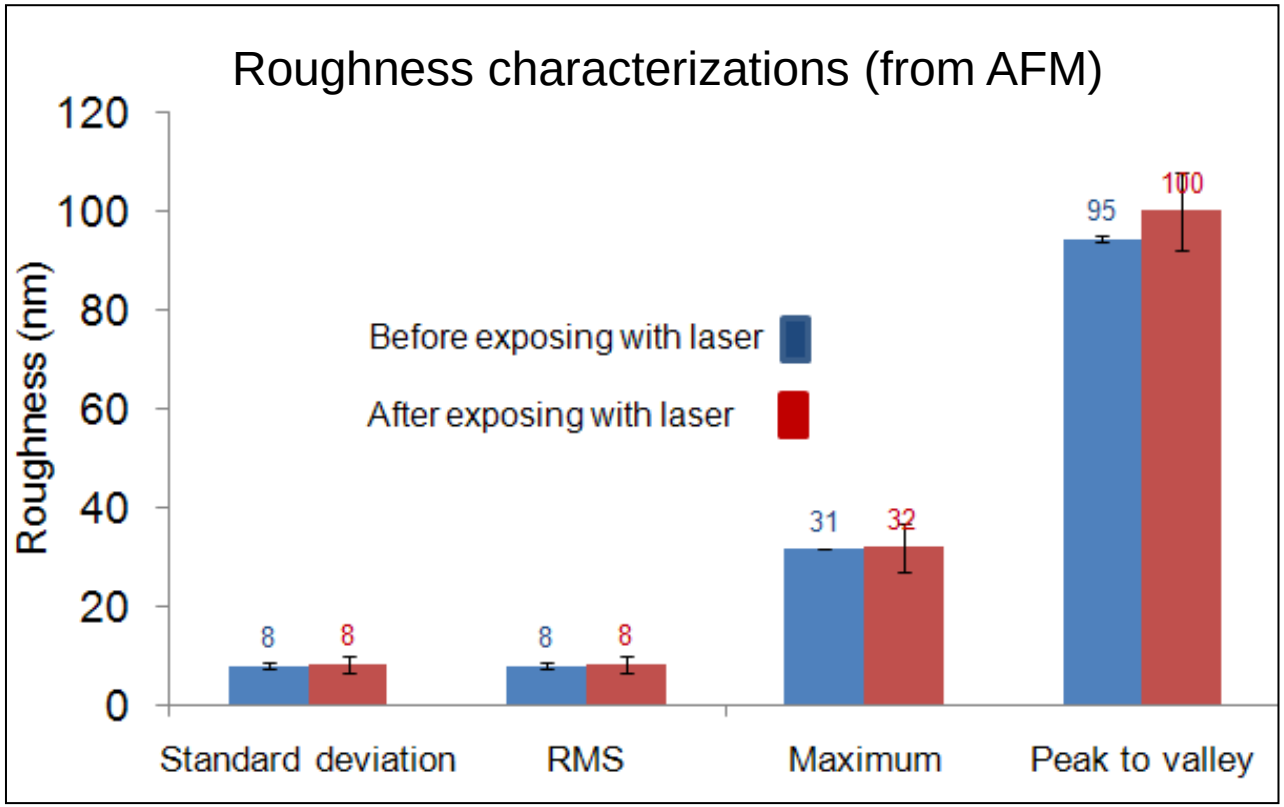
– The sample was exposed directly to a green NECSEL laser for 2.5 hours.

– The power density was 0.7×10^7 W/m^2 (0.7×10^3 W/cm^2) at the surface of the sample

Layer	Thickness (μm)	Material	Refractive index
Layer 1	4000 10	PMMA	1.51 0.01
Layer 2	50 5	Adhesive	1.49 0.02
Layer 3	250 10	Plexiglass	1.49 0.01

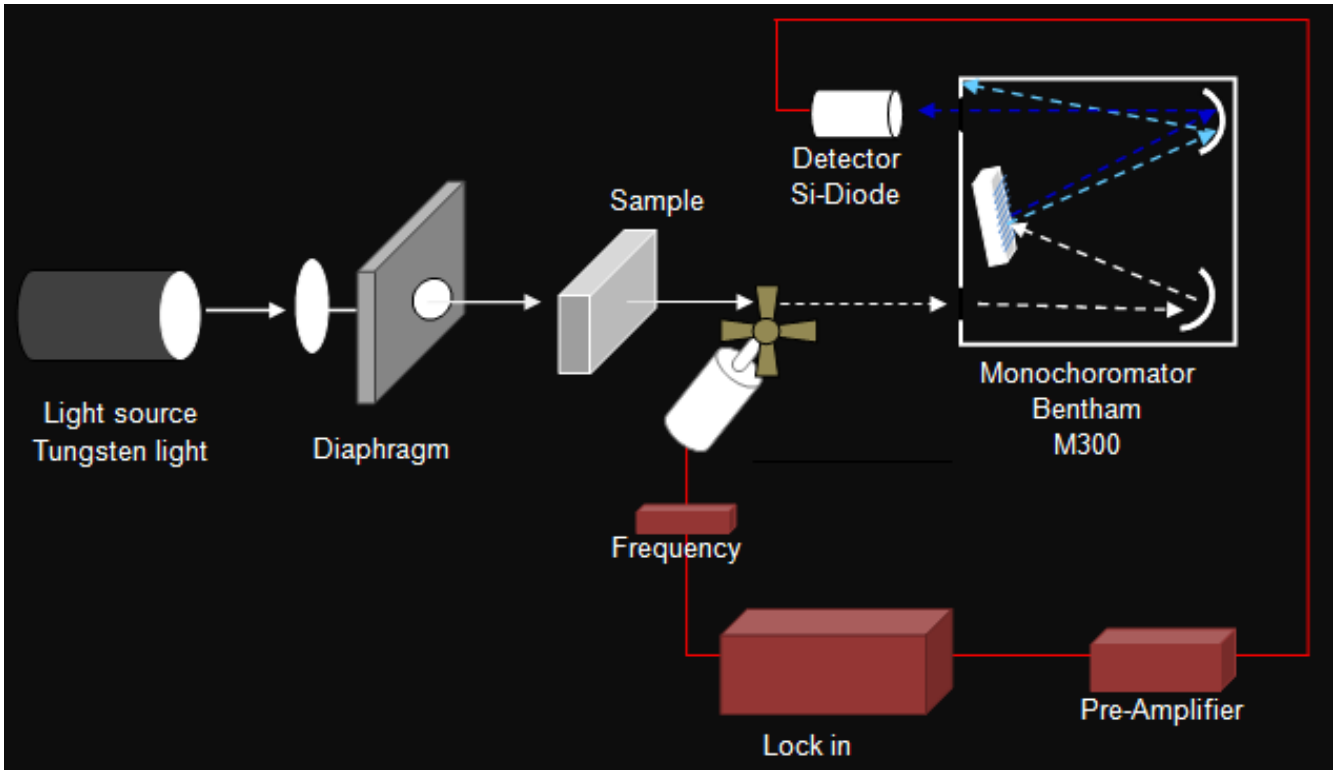


High optical power density - material dependence



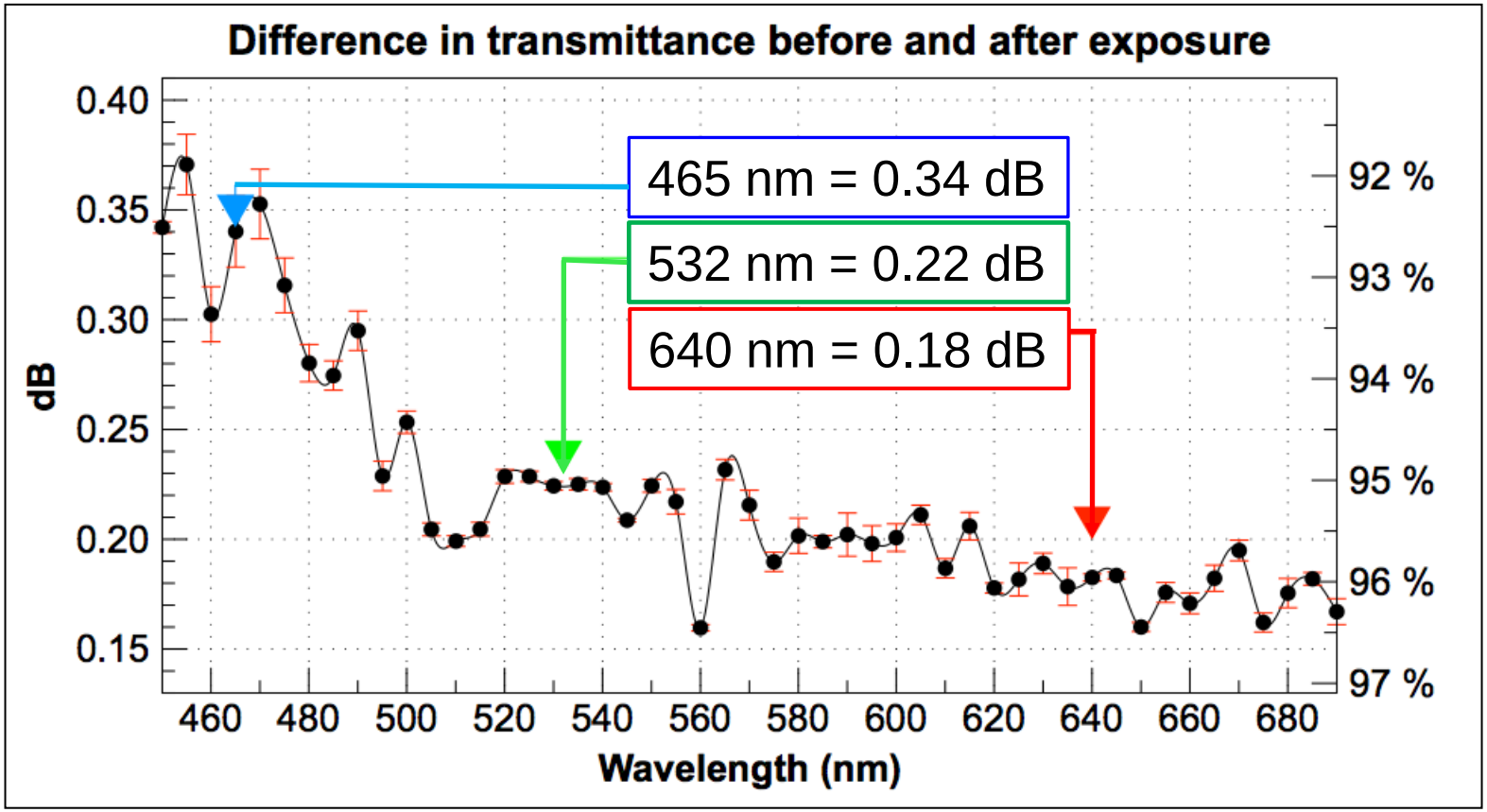
A comparison of the roughness for the polymer (PMMA) before (blue) and after (red) exposing with the high power laser.

High optical power density - material dependence



Experiment configuration of the measurement of transmitted spectrum of the sample

High optical power density - material dependence



Difference in spectral transmission before and after exposure

Beam shaping and homogenizing

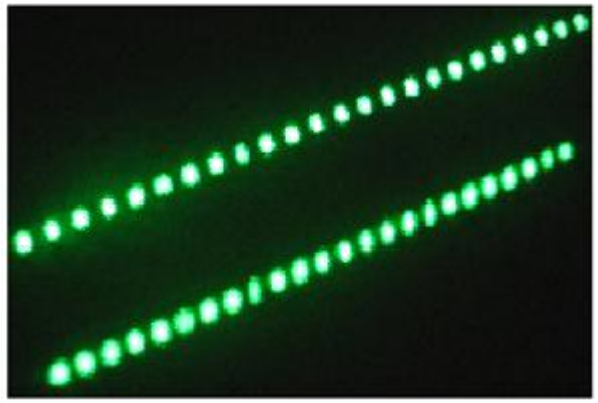
The light engine must produce a homogenised light line to scan on the LCoS device.

There are different methods to homogenize the beam:

- Using microlens array in free space approach
  - Emitters are arranged in two rows
  - Each emitter is a coherent Gaussian beam
  - Interference pattern applies a non-uniformity on the line
  - Using two rows of emitters will require complex design.
- Using wave
  - Optical
  - All the e
  - No inter
  - Safe an
  - Can be

multimode

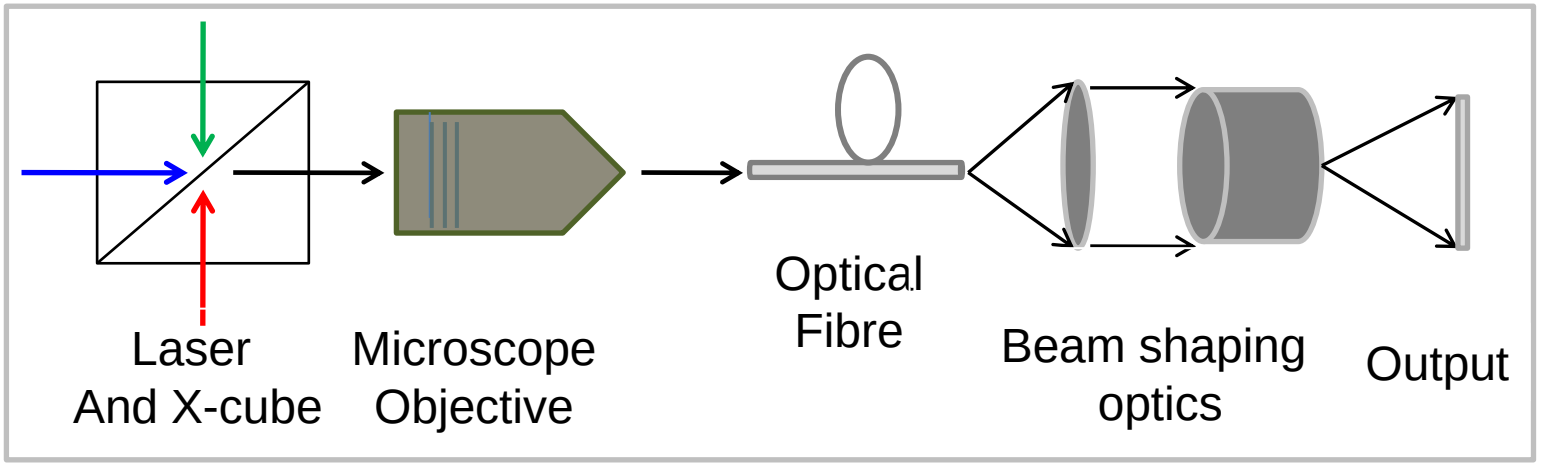
ckle



Reinhard Voelkel, Kenneth J. Weible, '' Laser Beam Homogenizing: Limitations and Constraint'', SPIE Europe, September 2008.

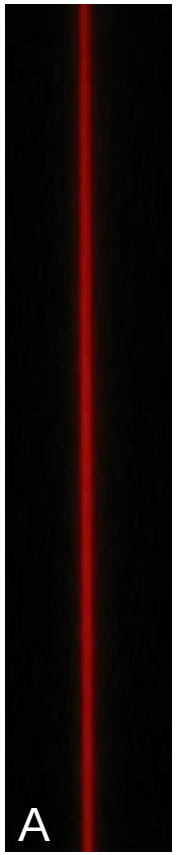
Beam shaping and homogenizing

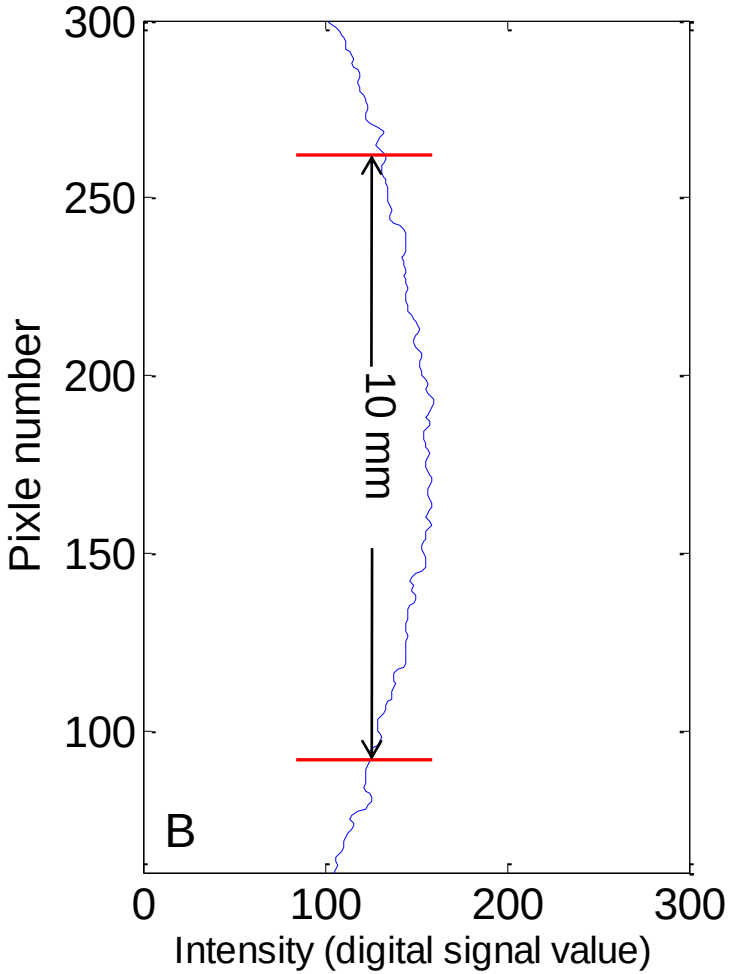
- The output of the laser are combined by means of dichroic mirror
- The combined beams are focused into the multimode fibre
- Multimode optical fibre is used to homogenise the laser light



Experiment set up for laser-fibre coupling

Maximum = 161
Minimum = 137
Standard deviation = 5.7
Uniformity = 85%





The shape of the beam after homogenizing and shaping by using optical fibre.
A: picture of the line
B: The profile of the intensity across the line

Conclusions

- Multi-emitter lasers were characterized and used as the light source.
- Speckle was reduced by using diffusers and multi-emitter lasers.
- Both diffusers and multi-emitter lasers are needed to reduce the speckle contrast to below the threshold of human perception.
- Optical fibre is used to homogenize the laser beam. (85% uniformity)
- Using optical fibre enables efficient use of the laser power and provides high flexibility to the system.
- Multimode optical fibre can be adopted in other display systems for homogenization and to reduce the system size.

Thanks for your attention

www.helium3d.eu

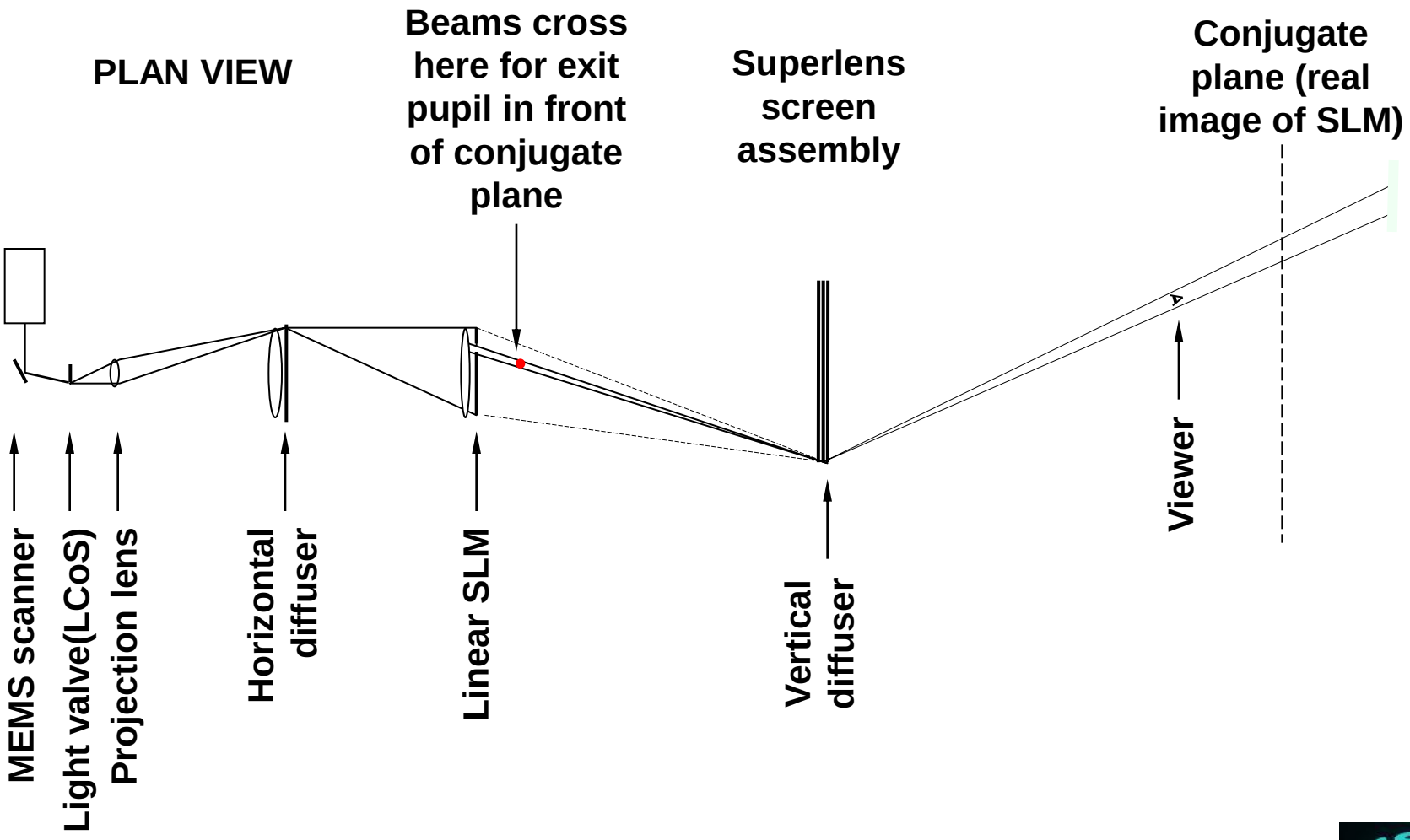
h.baghsiahi@ee.ucl.ac.uk

– The HELIUM3D project is funded from the European Union Framework 7 (Grant 215280).

– We would also like to thank Dorothy Hodgkin Postgraduate Awards (DHPA) and Engineering and Physical Sciences Research Council (EPSRC) UK for funding.

– Thanks also to the other members of the HELIUM3D consortium.

HELUIM3D system



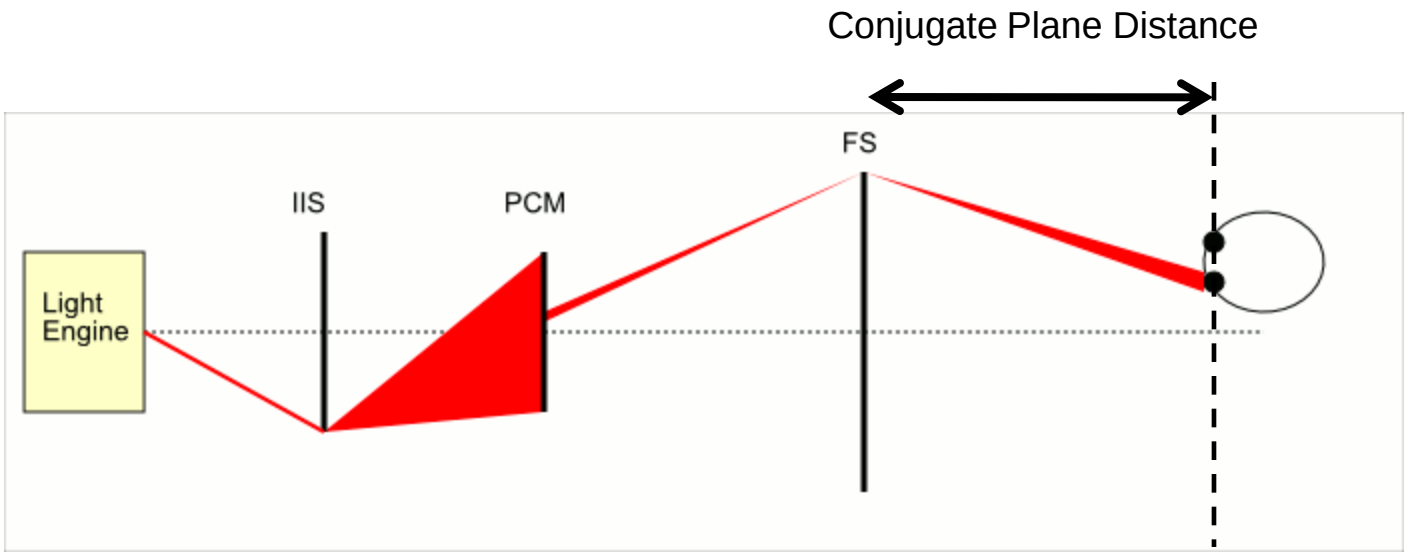
Examples

4 examples showing operation of time multiplexing of scanned views in different cases.

Example 1

Single Aperture – Viewer at Conjugate plane

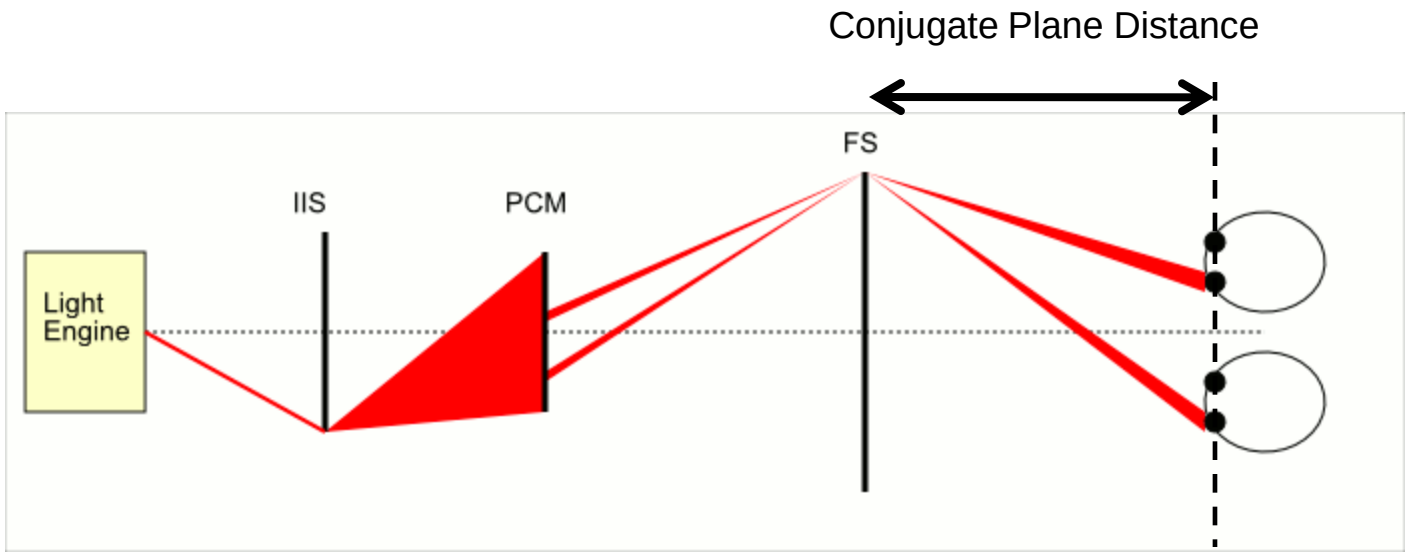
- SLM opening location corresponds to exit pupil location
- SLM opening location is stationary during a scan



Example 2

Multiple Apertures – Viewers at Conjugate Plane

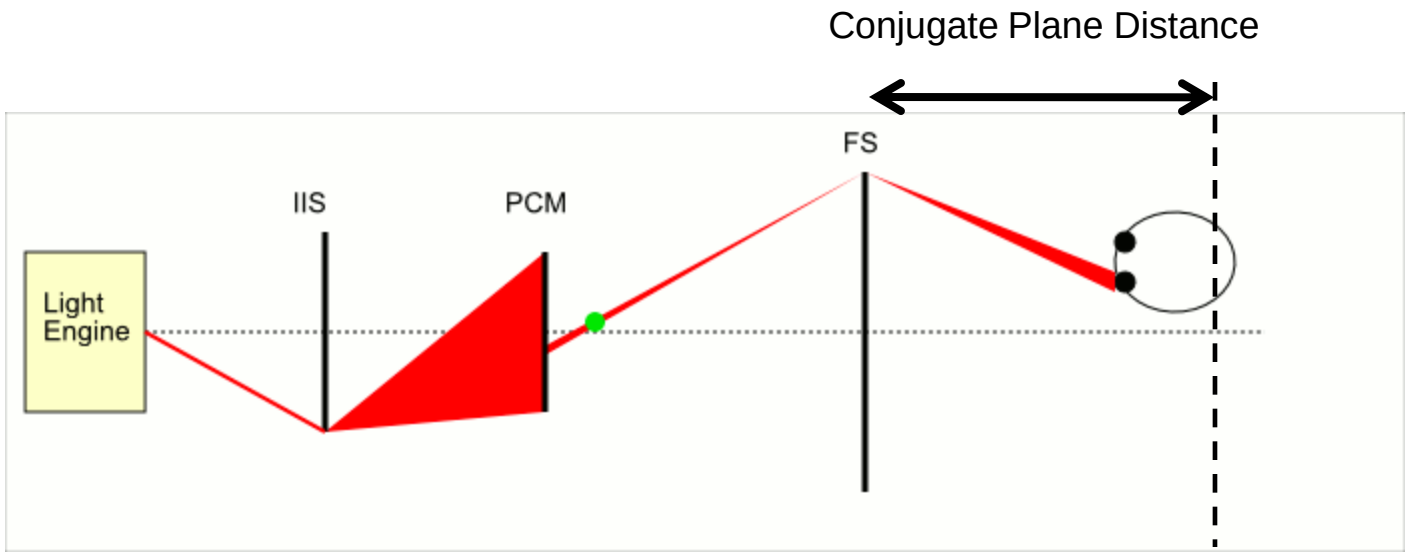
- SLM opening location is stationary during frame
- Multiple simultaneous apertures allow for more than one viewers



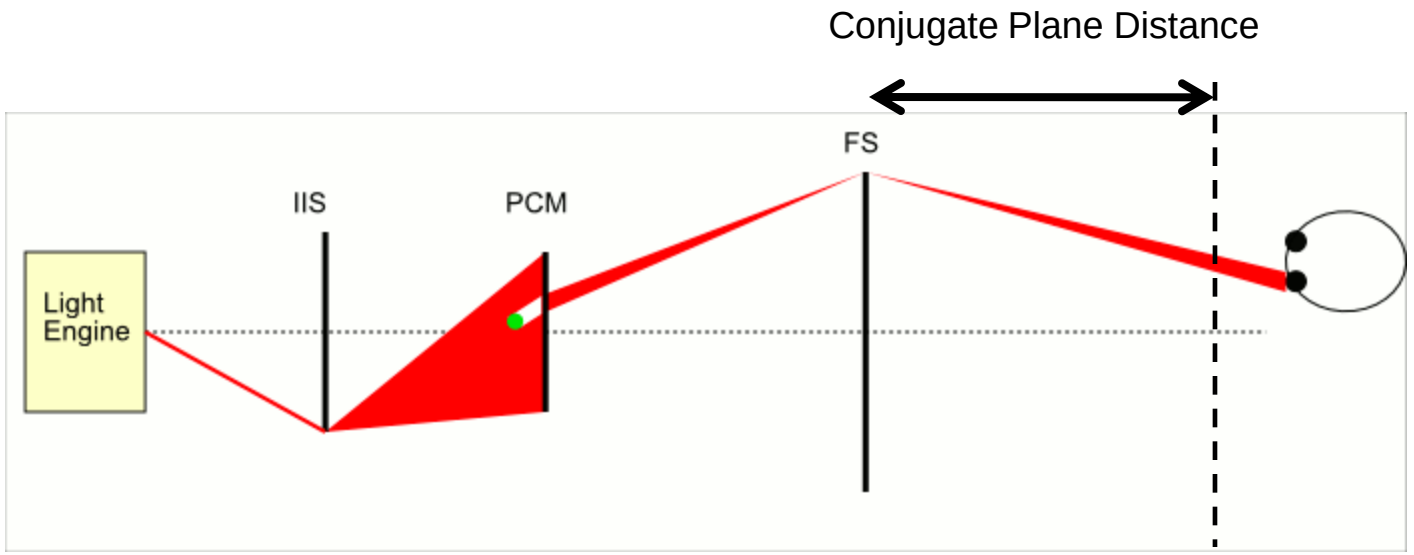
Example 3

Near-Field Operation

- SLM aperture moves during scan when viewer is not at conjugate plane
- Beam passes through a stationary ‘virtual’ point (green)



Example 4

Far-Field Operation

- SLM aperture moves during scan when viewer is not at conjugate plane
- Beam passes through a stationary ‘virtual’ point (green)