



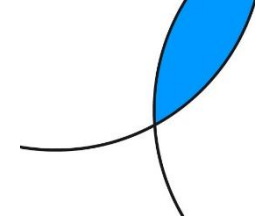
shaping the future of optics



Optotune Laser Speckle Reducers (LSR)

Dietikon, December 2023
David Leuenberger, Head of Product Management

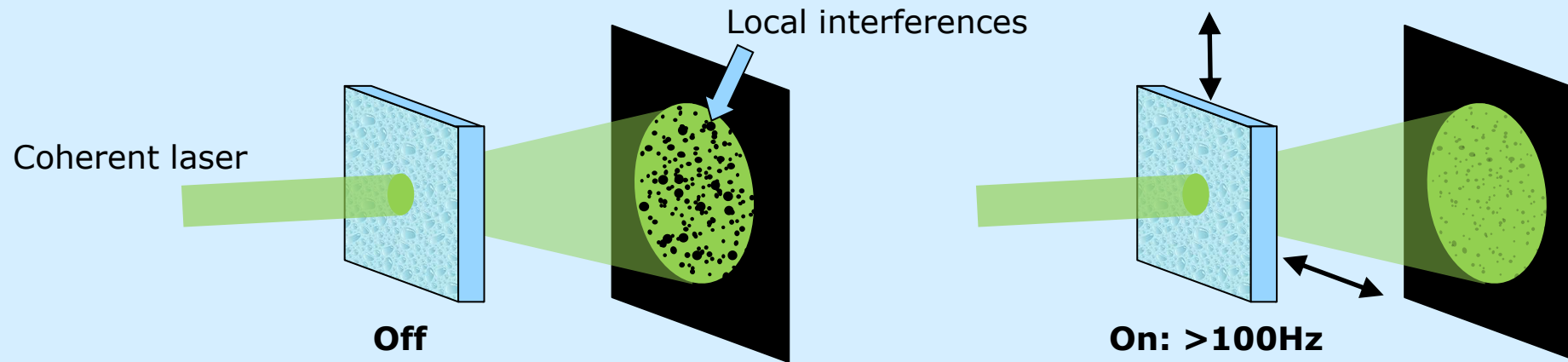
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- Introduction
- Products
- Roadmap
- Applications

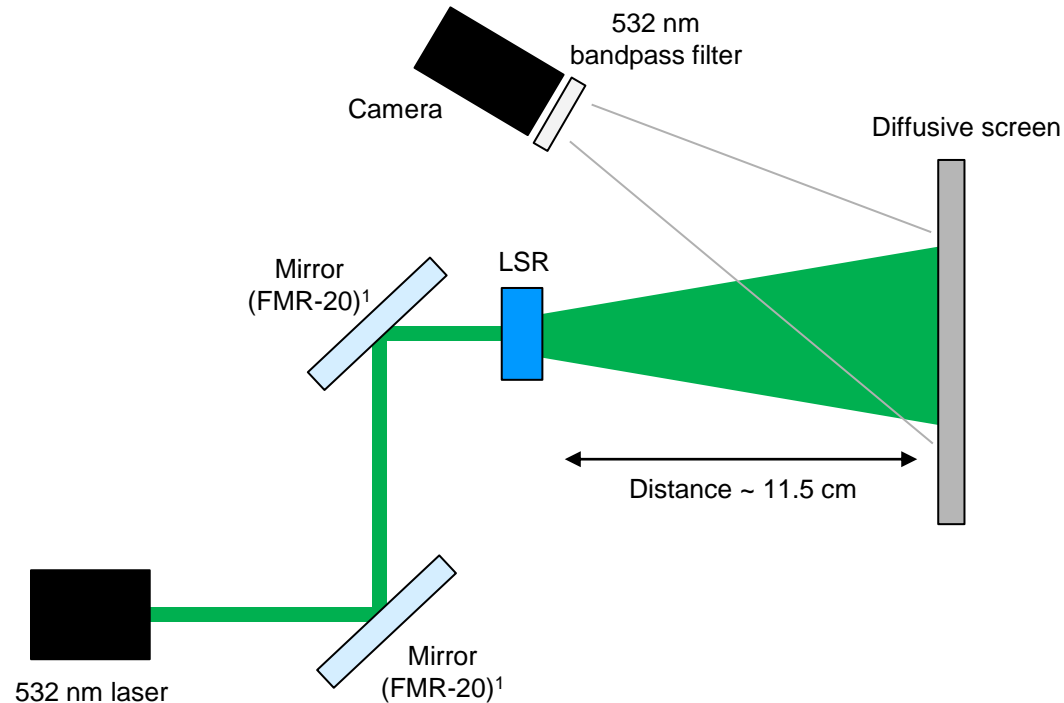
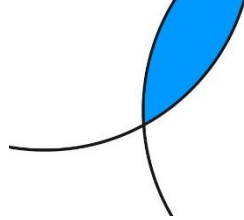
Speckle reduction principle: A moving diffuser is used to increase angular diversity

Principle



By moving a diffuser multiple speckle patterns are overlapped to reduce the perceived speckle noise

Speckle contrast measurement



- 532 nm laser
- f=35 mm, f/5.6 lens
- 2/3", 5MP camera, 10 ms integration time
- diffuser: fused silica, 8.5° diffusion angle, Gaussian profile
- comparing LSR-10 (closed loop) and LSR-4C (open loop)

Speckle contrast S = normalized intensity deviation

$$S = \frac{\sigma}{\mu}$$

$$\mu = I_{\text{mean}} = \frac{1}{N} \sum_{i=1}^N I_i$$

mean intensity

$$S = \frac{\sigma}{\mu}$$

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (I_i - I_{\text{mean}})^2}$$

standard deviation

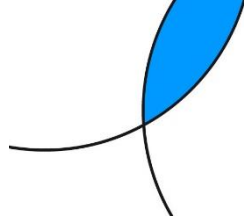
S is evaluated for 7x7 pixel areas («windows») where $\mu > 0.15 A$.
 A is the maximum intensity of a Gaussian fit to the speckle pattern.
 The final speckle contrast is the mean of S for all windows.

¹ The FMR-20 is used as a static mirror in the current setup. Future tests in which the FMR-20 is used to finely steer a beam at high frequency across a static diffuser are planned.

Agenda

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De-speckling solutions



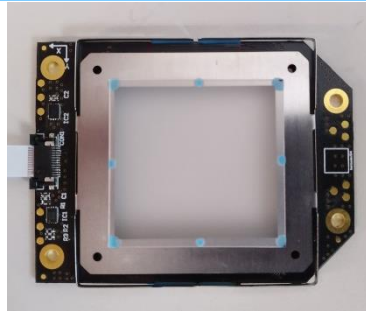
Reluctance force-based LSR

In production



Voice coil based LSR

Prototype



Prototype



Prototype

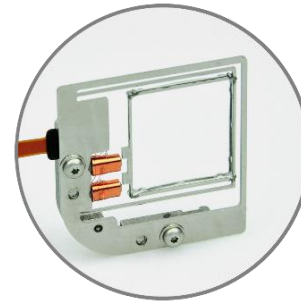


Name	LSR-4C	LSR-30	LSR-60	LSR-10
Aperture	18.5x18.5 mm	30x30 mm	60x60 mm	10x7 mm
Diffuser type	Glass or polycarbonate	Glass or Polycarbonate	Polycarbonate	Glass or polycarbonate
Transmission	>98%	>98%	92%	>98%
Oscillation type	1D (linear)	2D	2D	2D
Oscillation amplitude	0.8 mm p-p	1mm (radius)	1.5mm (radius)	0.2 – 0.5 mm (radius)
Resonant frequency	~120 Hz (depends on diffuser weight)	~50 Hz	~65 Hz	~350 Hz
Operating lifetime	>40'000	Designed for long lifetime	Designed for long lifetime	Designed for long lifetime
Electronics	5 VDC (coils are pulsed with current)	PWM current driver	PWM current driver	PWM current driver

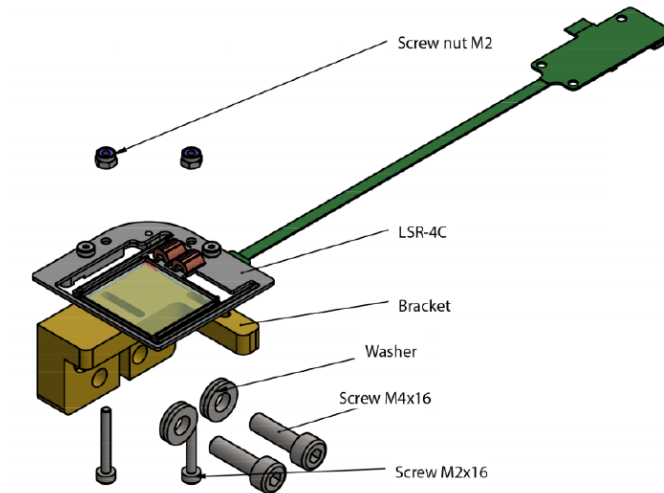
LSR-4C options

- 3 diffuser types available from Optotune
 - VIS-coated fused silica: 8.5°
 - Uncoated fused silica: 8.5°
 - Uncoated polycarbonate diffusers: 1, 5, 10, 20°
- Brass bracket available for prototyping
- USB power supply

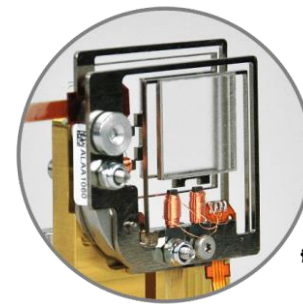
- Single diffuser configuration:



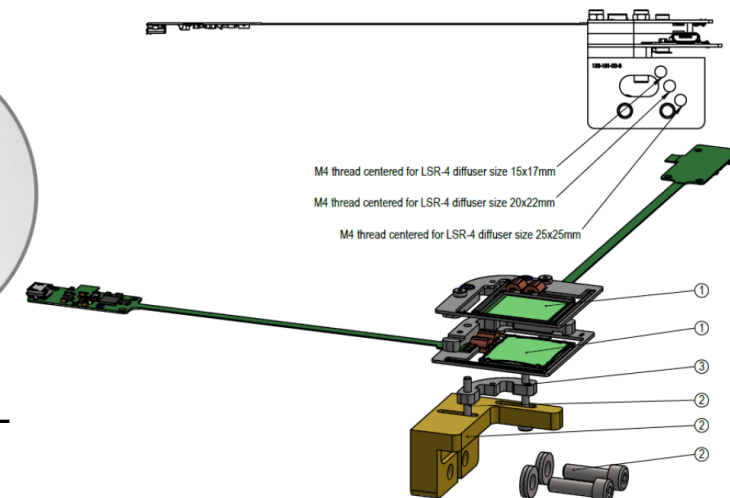
LSR-4C-L



- Double configuration



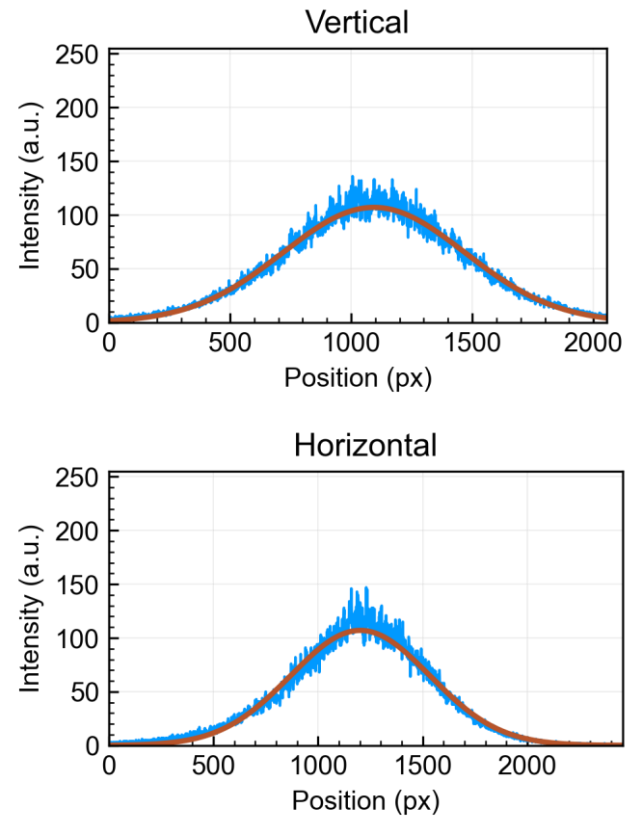
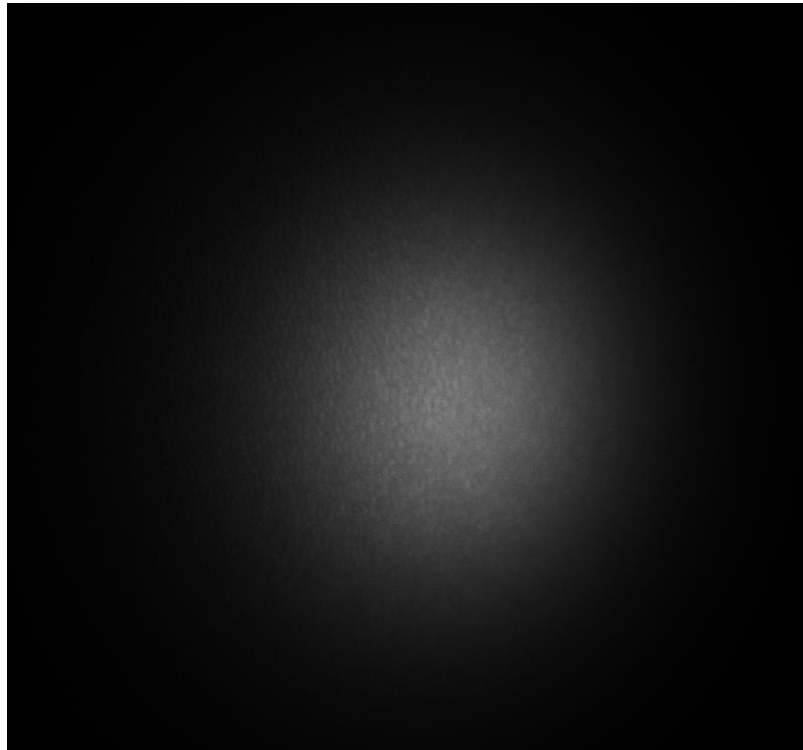
LSR-4C-LL



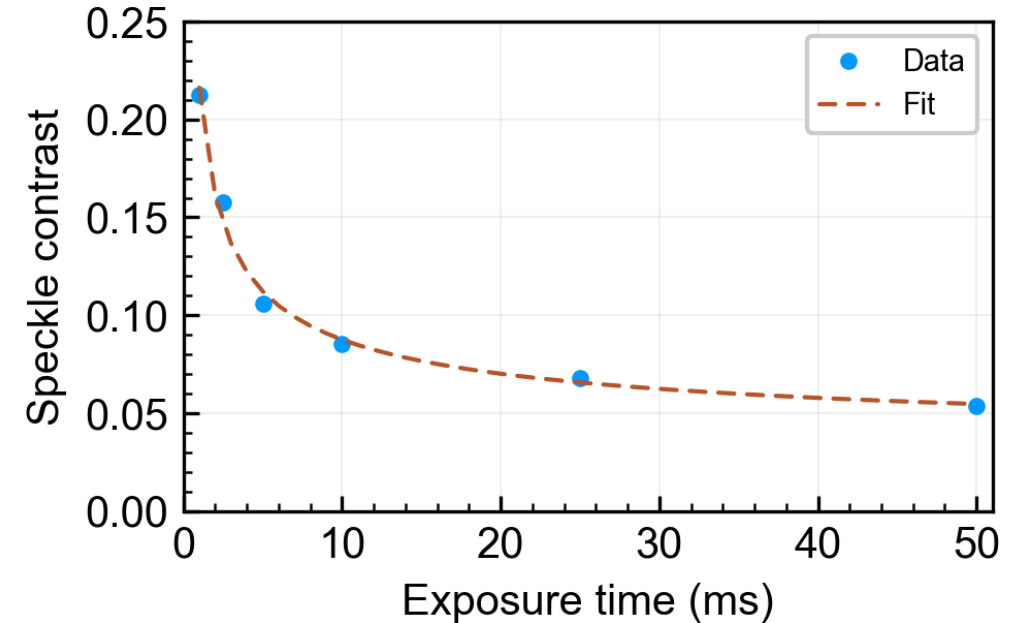
LSR-4C speckle reduction: 1D oscillation (y)

- 120 Hz, 0.4 mm amplitude in y

Speckle contrast at 10 ms exposure time: 0.086



Speckle contrast as a function of exposure time



$$\text{Fit: } S(t) = a + bt^{-0.5}$$

$$a = 0.028$$

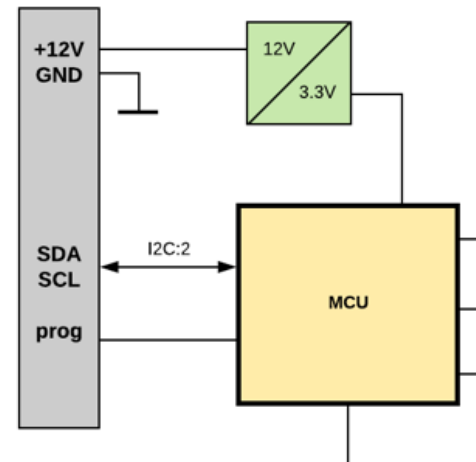
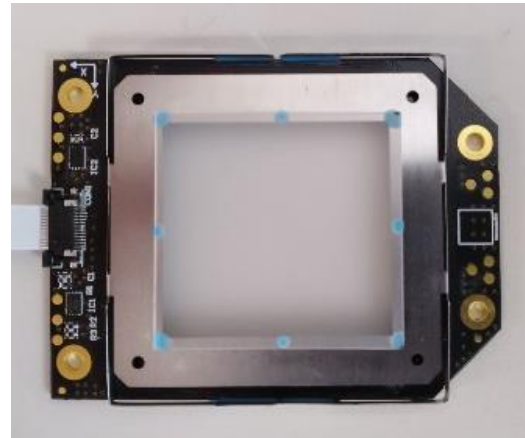
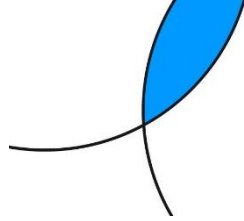
S : speckle contrast

$$b = 0.188$$

t : exposure time

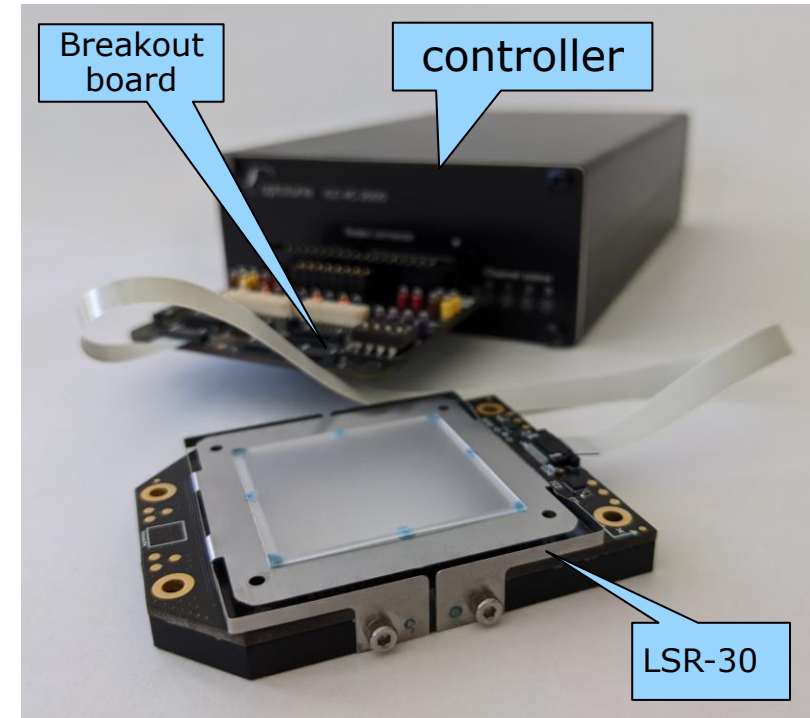
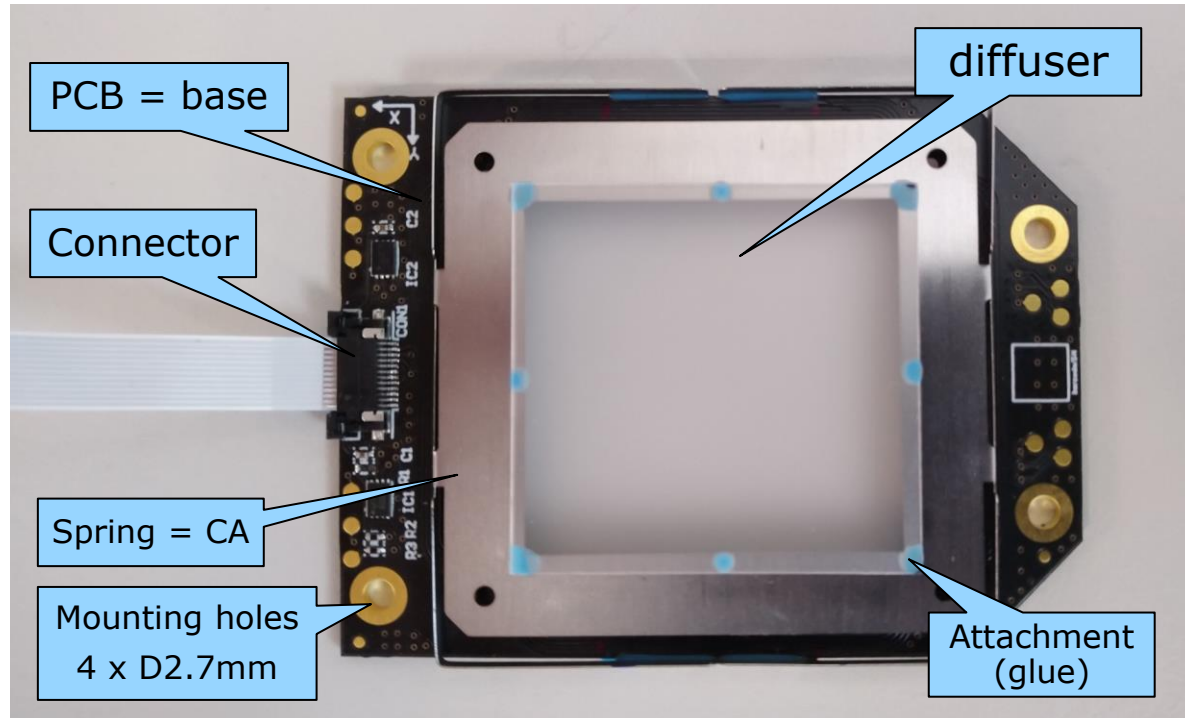
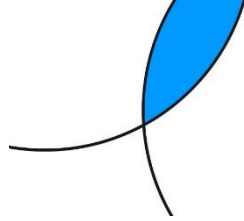
a, b : fit coefficients

New LSR platform concept



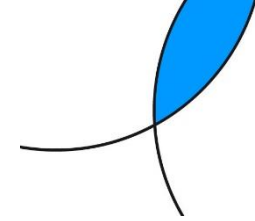
- 2D movement
- Clear aperture from few mm to > 60x60 mm²
- Up to 2mm movement radius
- Integrated design
- Leverage XPR platform (proven design for high-volume manufacturing)
- Can be customized to different apertures (customization project)
- Various operating modes possible
- System integration possibilities
 1. Optotune provides actuator only
 2. Optotune provides actuator with simple calibrated electronics on board (12V power supply, I2C interface)

Optotune offers LSR-30 devkit to validate the technology in the application

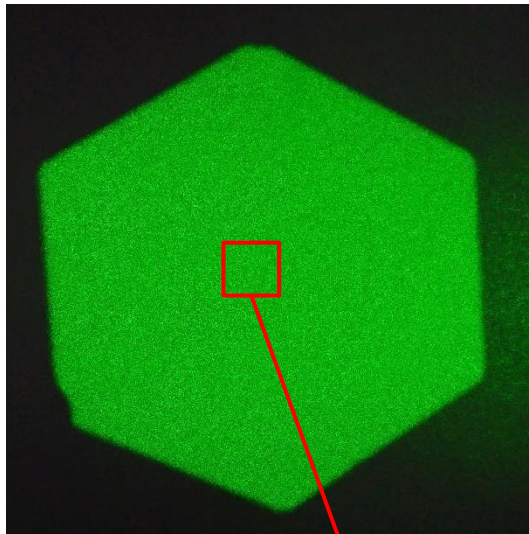


- What is included
 - LSR-30 engineering sample + PWM driver
 - Diffusor options: Polycarbonate, various angles
 - Characterization sheet indicating optimum operation parameters

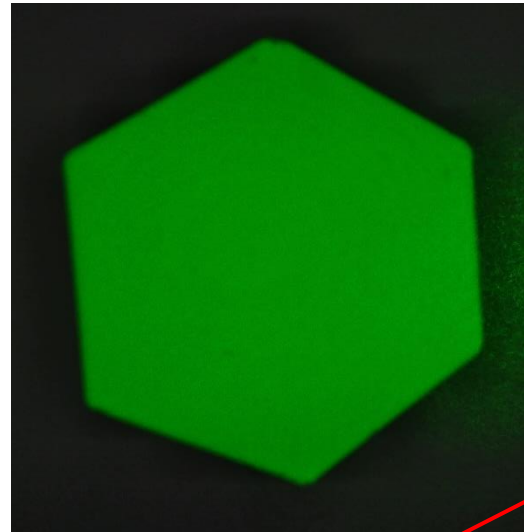
LSR-30: Visual checked, it de-speckles well



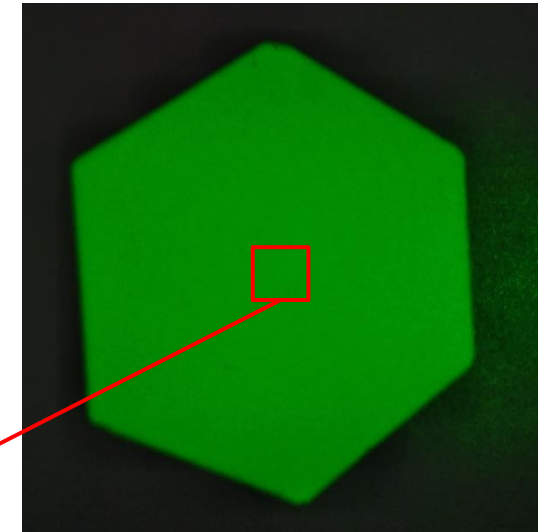
Beam de-speckling at different excitation amplitudes



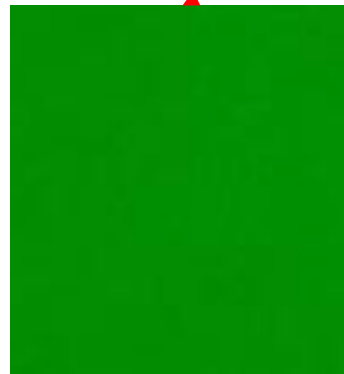
LSR off



LSR at 74mA



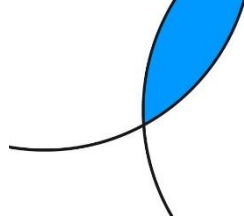
LSR at 213mA →
ca. 1.1mm orbit



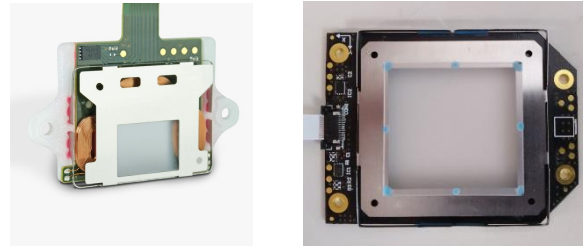
Result:

- (visually checked) the objective speckles are reduced significantly

New 2D LSRs vs spinning disk diffuser



New 2D LSRs



Spinning disk diffuser



Fill factor (CA vs size)	50-60%	<35%
Non-isotropic diffusors (e.g. elliptical)	Possible	Not possible
Constant speed over aperture	Yes	No
Movement	True 2D	1D (rotation)
Integration	Only 4mm thick, actuator integrated	Requires a lot of space for motor
Reliability/lifetime (e.g. shock & vibration)	Solid-state, no bearings	Bearings could degrade under shock & vibration

LSR-10 Development kit

- The development kit consists of the LSR-10 engineering sample and the 4-channel PWM driver ICC-4C.

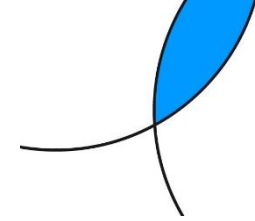


LSR-10
(engineering sample)

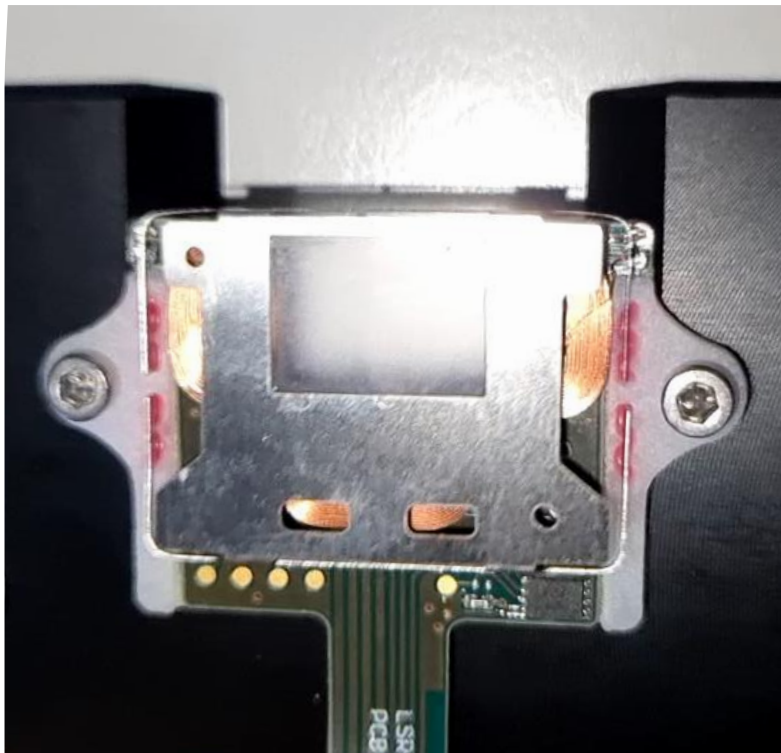


4-channel PWM driver ICC-4C.

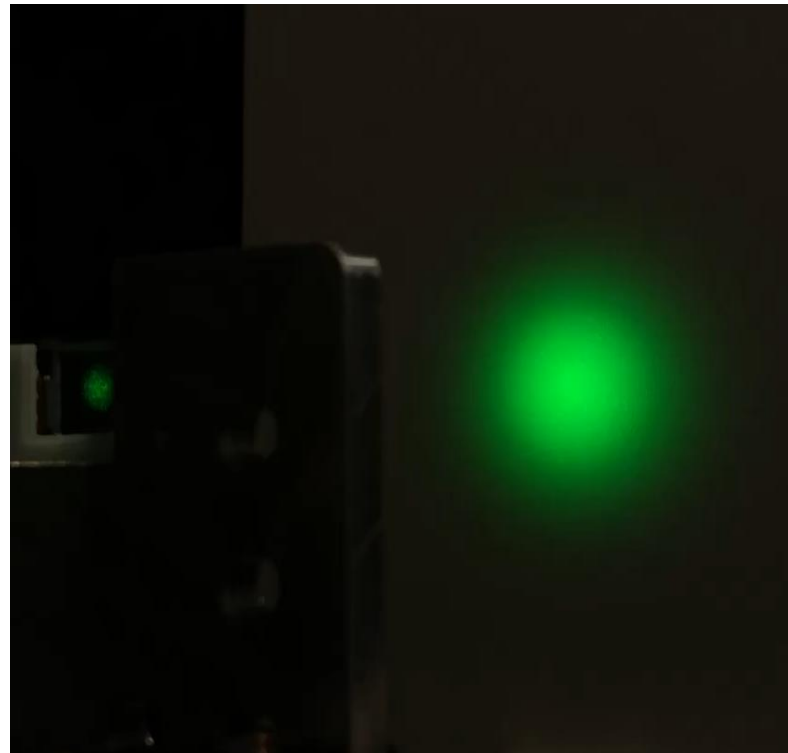
LSR-10 in operation



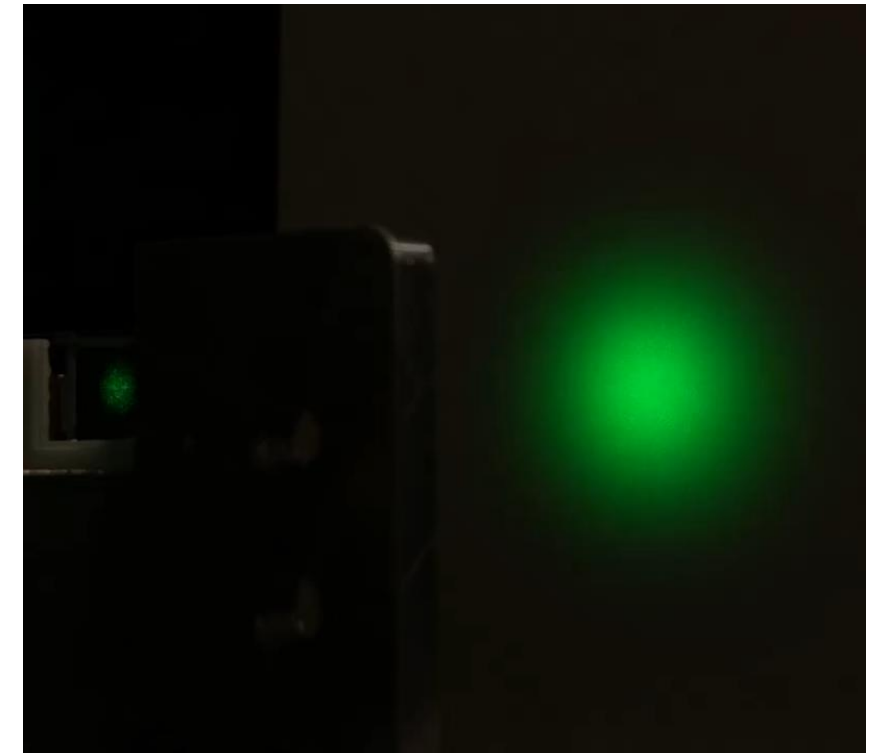
2D oscillation under
stroboscope illumination



Speckle reduction,
2D oscillation



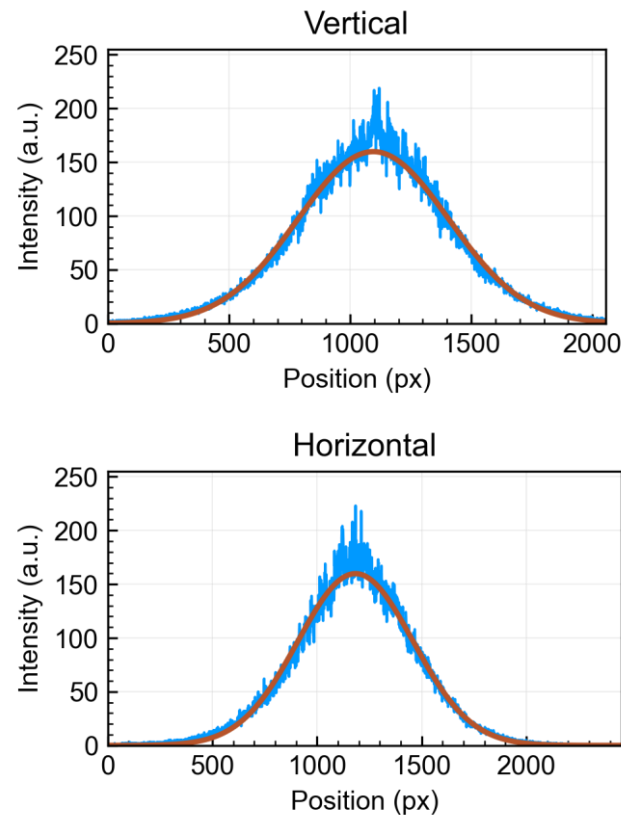
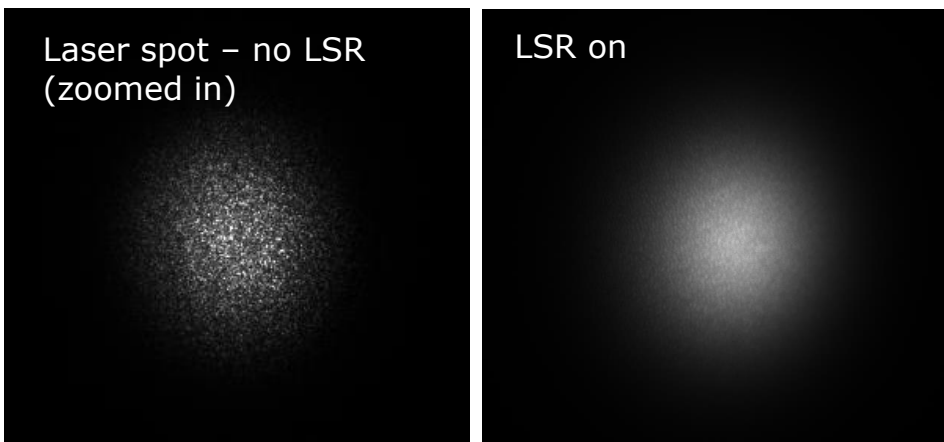
Speckle reduction,
1D oscillation (x)



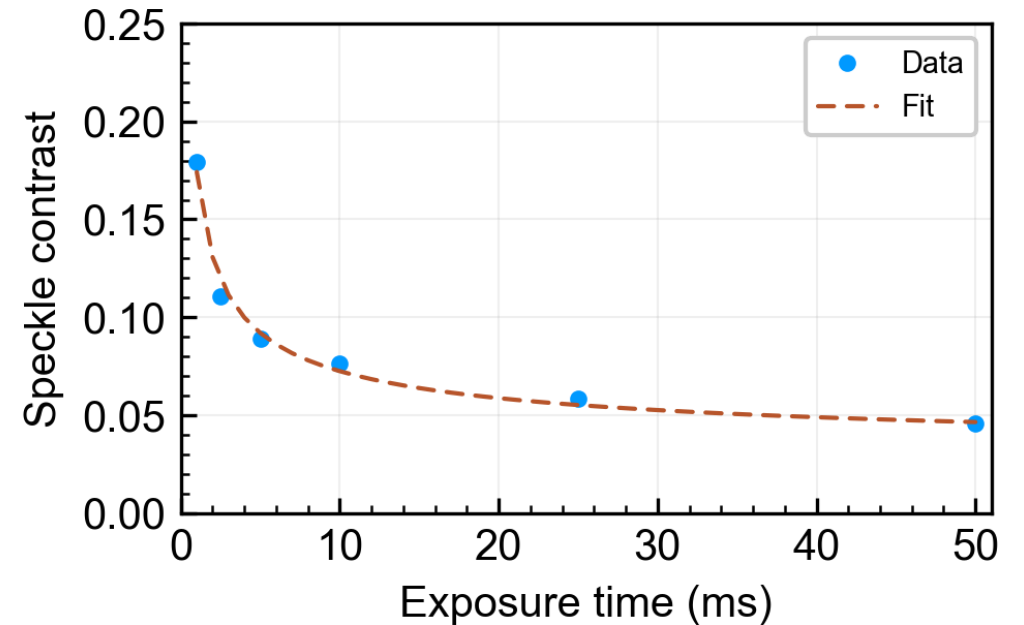
LSR-10 speckle reduction: 2D oscillation

- 330 Hz, 0.3 mm amplitude in x, 0.3 mm amplitude in y

Speckle contrast at 10 ms exposure time: 0.077



Speckle contrast as a function of exposure time



$$\text{Fit: } S(t) = a + bt^{-0.5}$$

$$a = 0.025$$

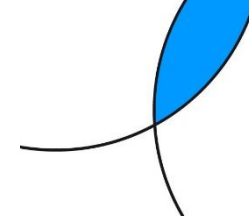
S : speckle contrast

$$b = 0.149$$

t : exposure time

a, b : fit coefficients

LSR-10 – preliminary specs



Mechanical specifications

Clear aperture	10 x 7	mm
External dimensions (WxHxD)	~25x25x4	mm
Weight LSR	~5	g
Mechanical interface	screws	

Electrical specifications

Power supply (micro-USB or solder pads)	5	VDC
Power consumption (with std. electronics)	2500	mW

Optical specifications

Diffusion angle (FWHM)	8.5	°
Diffusion angle incl. static diffuser (FWHM)	12 ²	
Transmission wavelength	430-680	nm
Transmission	> 98 (coated), > 94 (uncoated)	%
Depolarization	< 0.1 % (to be confirmed)	%
Material	Fused Silica / Borosilicate	
Damage threshold		W/cm ²
Oscillation frequency	350	Hz
Scratch/dig	60/40	
Oscillation amplitude (peak to peak) typical	0.4	mm

Environmental specifications

Storage temperature range	[-40,+85]	°C
Operating temperature range	[0,+60]	°C

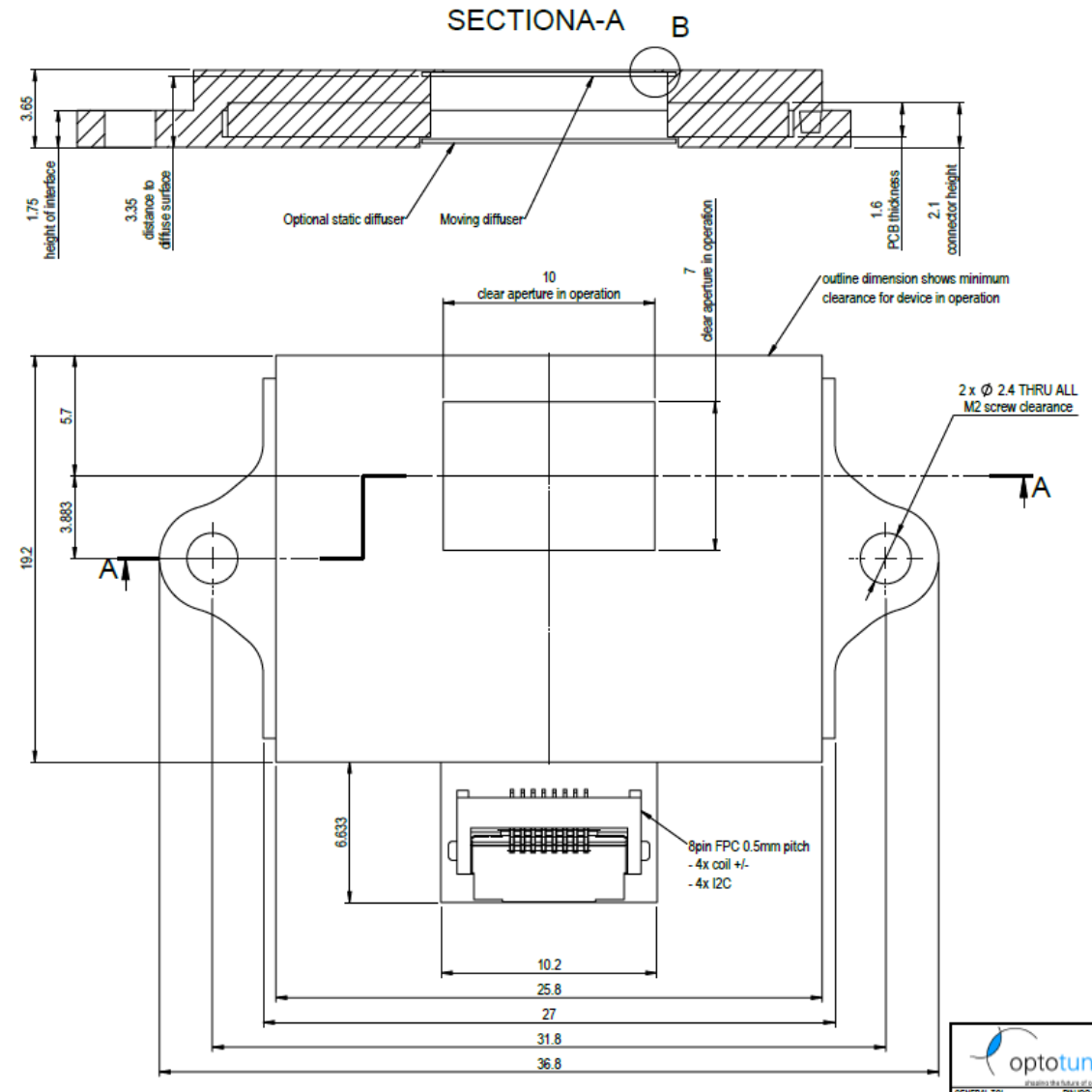
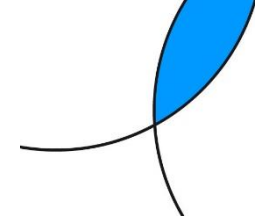
Standard products

LSR-10-9S-T1-VIS-E	Single dynamic diffuser (type 1) with 9° diffusion angle, VIS coated, including electronics
LSR-10-12D-T1-VIS-E	Dynamic and static diffuser (type 1) with 12° total diffusion angle, VIS coated, including electronics

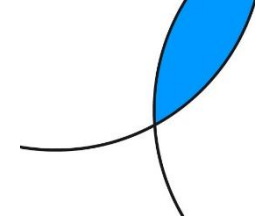
[\[1\]](#) **100-230 VAC to 5 VDC micro-USB power supply available**

[\[2\]](#) **Other diffuser angles and non-Gaussian diffusers on request**

LSR-10 – preliminary drawing



Speckle pattern comparison (10 ms exposure time)

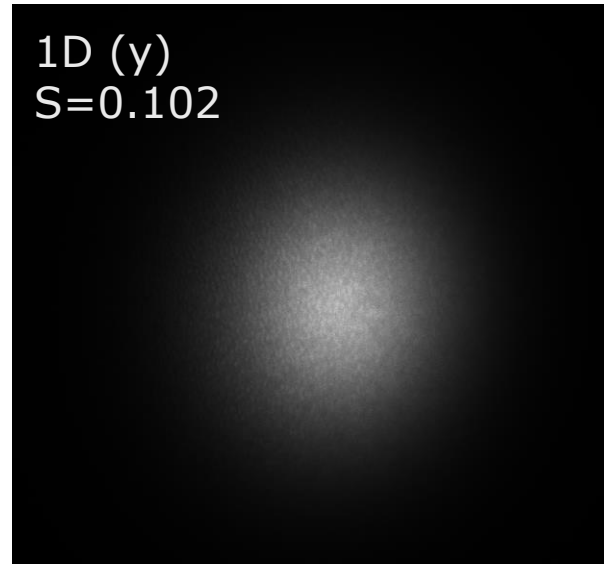


LSR-10

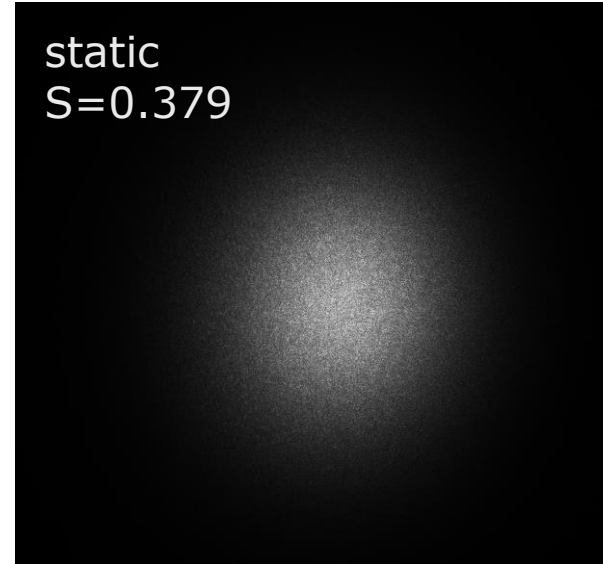
2D
S=0.077



1D (y)
S=0.102

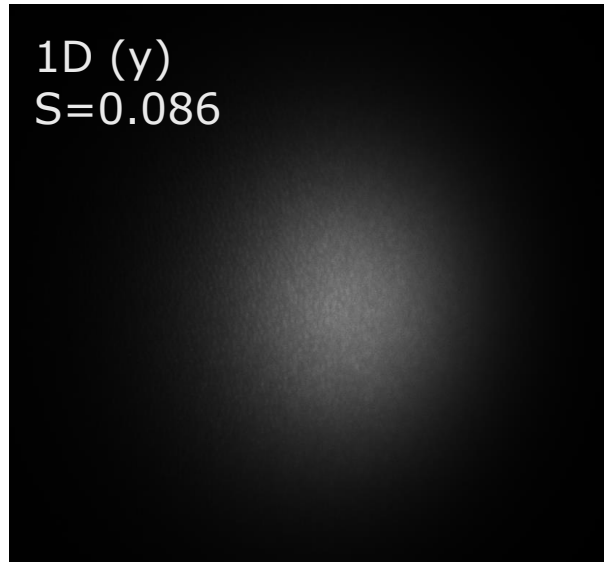


static
S=0.379

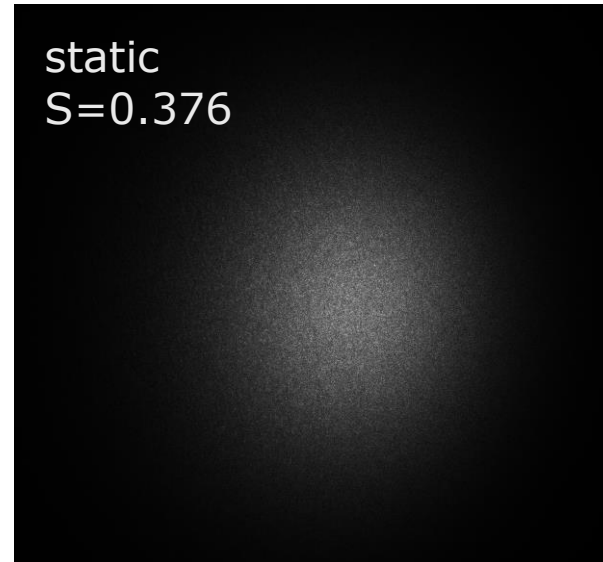


LSR-4C

1D (y)
S=0.086

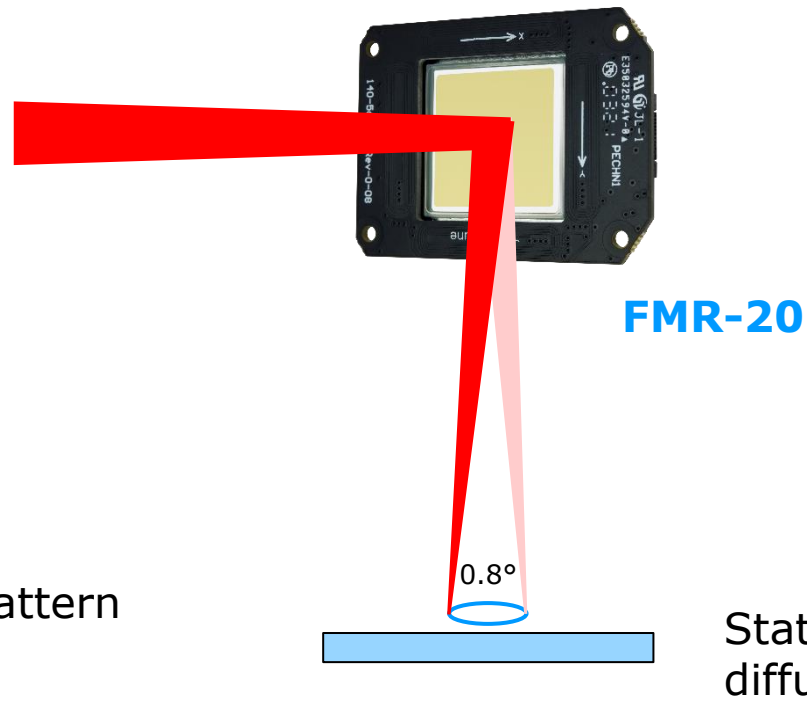
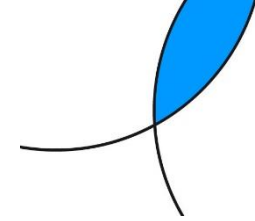


static
S=0.376



- **2D vs 1D:** slightly better despeckling with 2D oscillation, but difficult to discern from the 1D case visually
- **Dynamic vs static:** dynamic despeckling clearly performs better
- **LSR-10 vs LSR-4C:**
 - static: similar performance, as expected for the same type of diffuser
 - dynamic: LSR-10 yields better despeckling in 1D than LSR-4C
 - the LSR-4C window seems to have lower transmission

Fine steering mirror (FMR) for de-speckling



Benefits:

- Compact
- Long lifetime
- Fast
- Precise
- Programmable pattern



FMR-20

Mirror size	20 x 20 mm
Mechanical tilt angle (p-p)	0.4°
Motion pattern	2D programmable
Bandwidth	250 Hz @ 0.26° p-p
Mirror coating	Au, dielectric, custom
Laser wavelength	UV, VIS, NIR, IR
Laser power	Several kW*
Position feedback	Open loop
External sensor for feedback	Can be added
Power consumption	< 4W
Size (width x height x depth)	47 x 35 x 3.65 mm
Weight	9 g

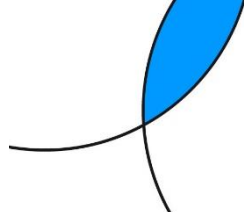
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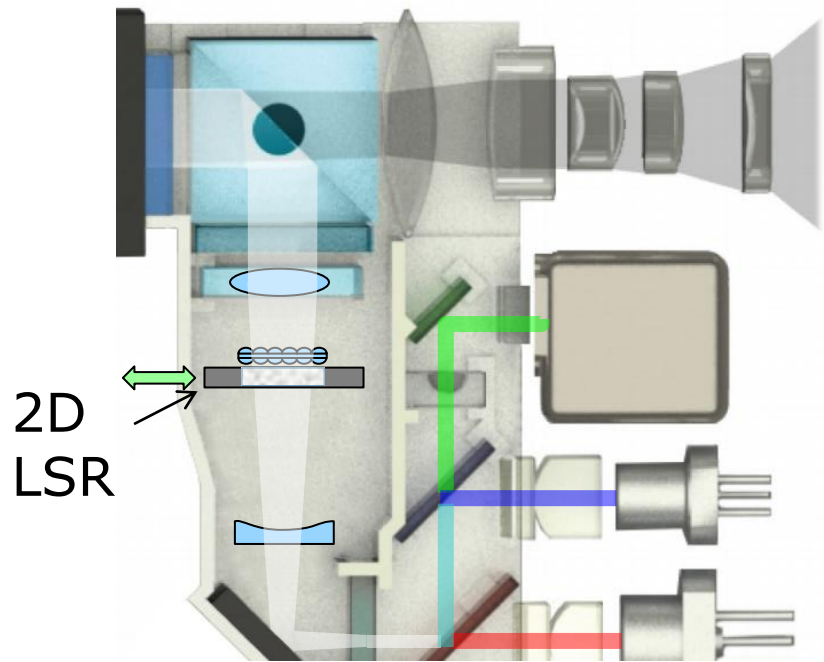
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LSR solutions for pico-projectors

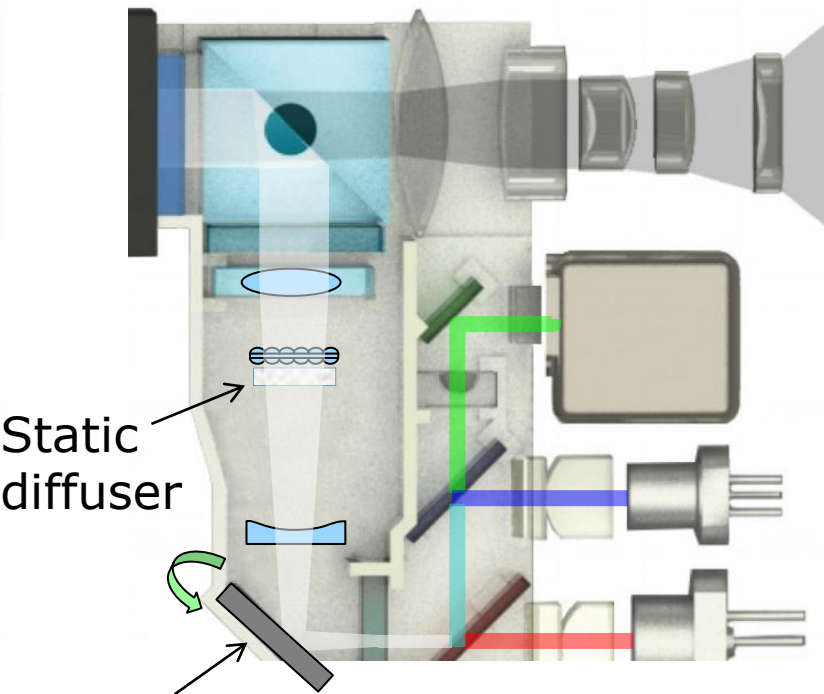


2D LSR before FEL



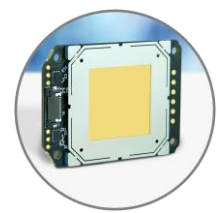
2D
LSR

Fast steering mirror + static diffuser

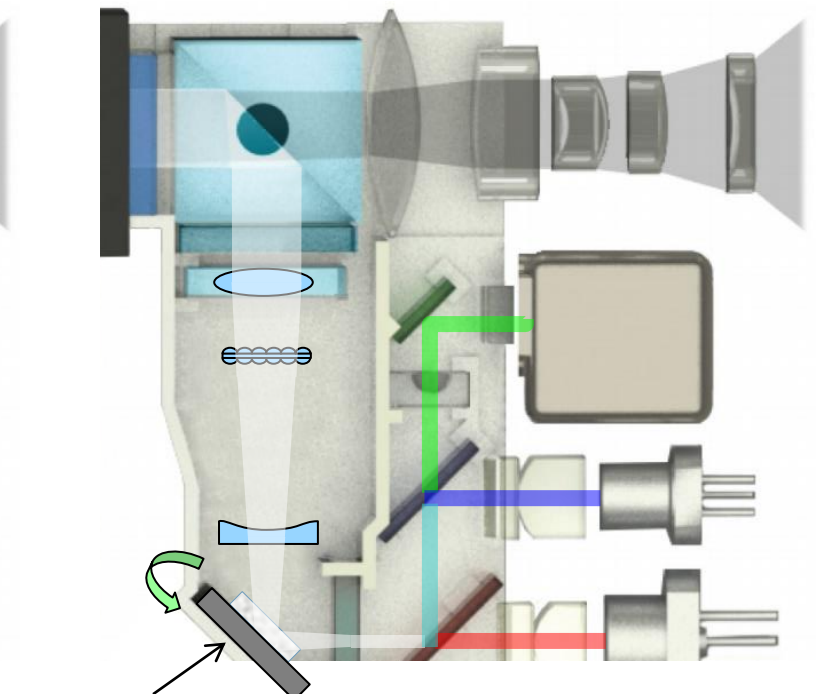


Static
diffuser

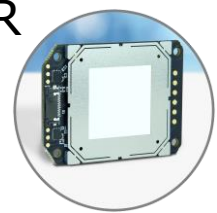
FMR



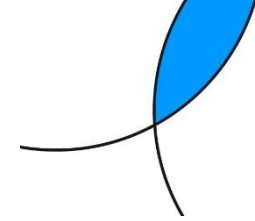
Reflective diffuser on fast moving mirror



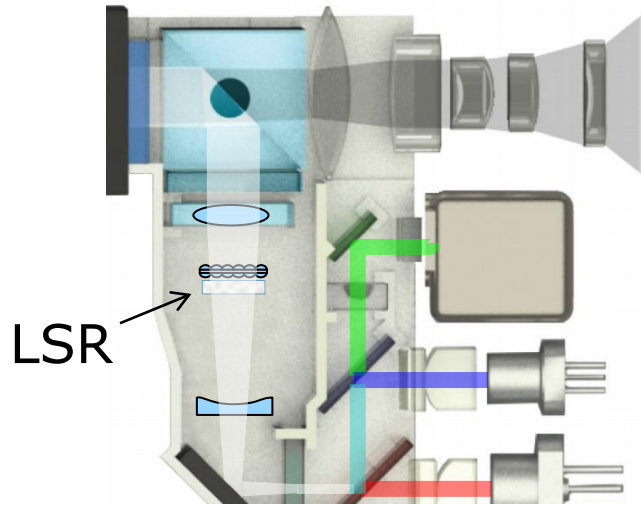
Reflective
LSR



Optotune provides a different solution for each laser-based HUD type



LSR in light path

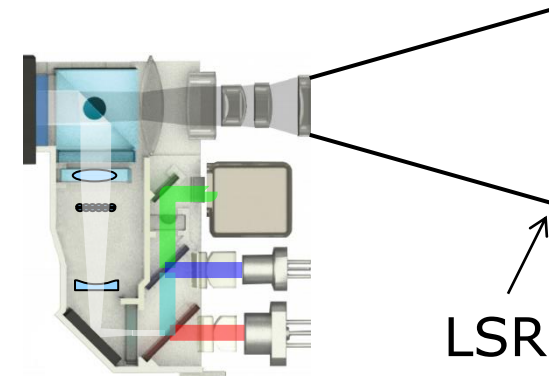


- 5x5mm aperture
- LSR placed before homogenizer
- Std products available



Standard LSR

LSR in image plane

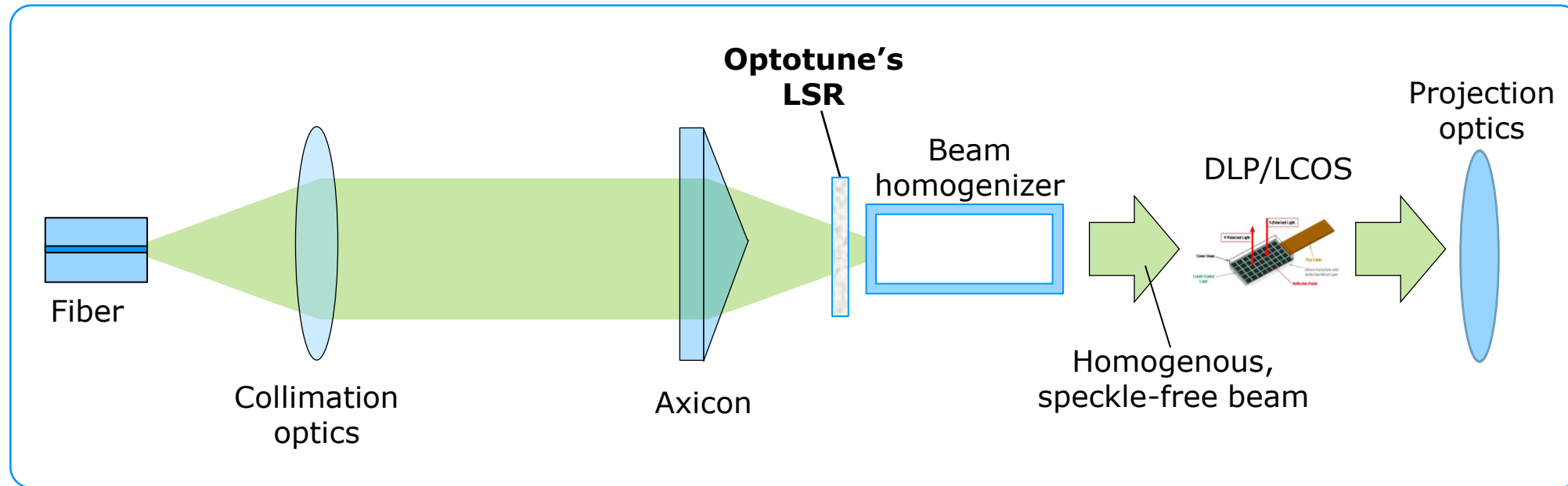


- 20x50mm aperture
- Best speckle reduction (no subjective speckles)
- Basic technology available (reluctance force), but customization required



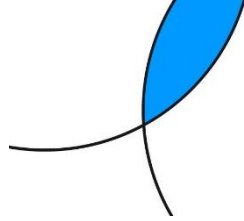
Customized LSR

Example: Light engine for laser projector

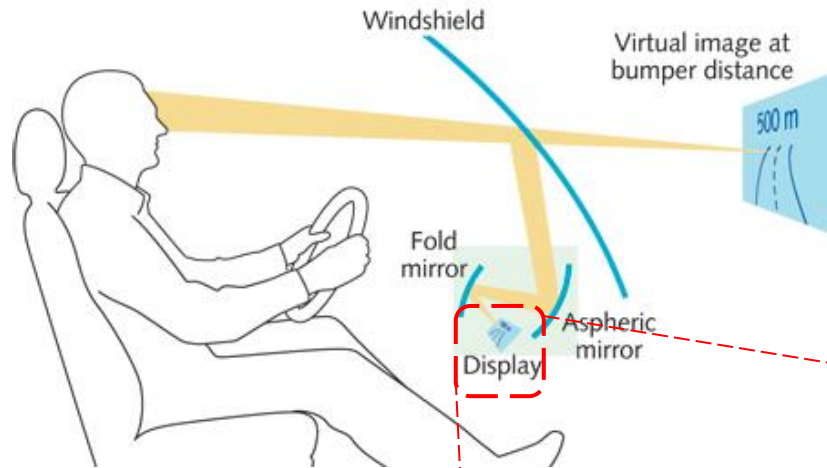


- Effective speckle reduction has been shown using
 - an axicon as a focusing lens
 - Optotune's LSR
 - directly followed by a beam homogenizer
- Such a setup is compact, cost-saving and easy to align

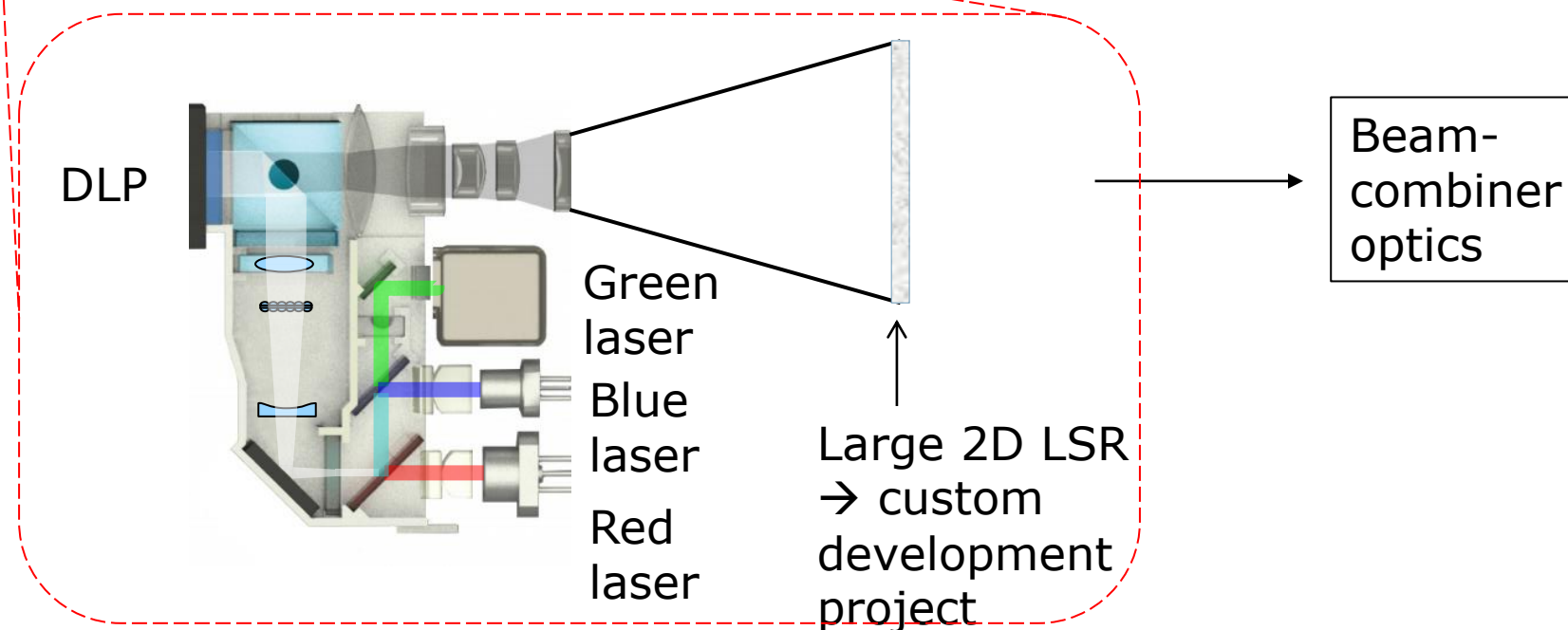
LSR in intermediary image plane of a HUD



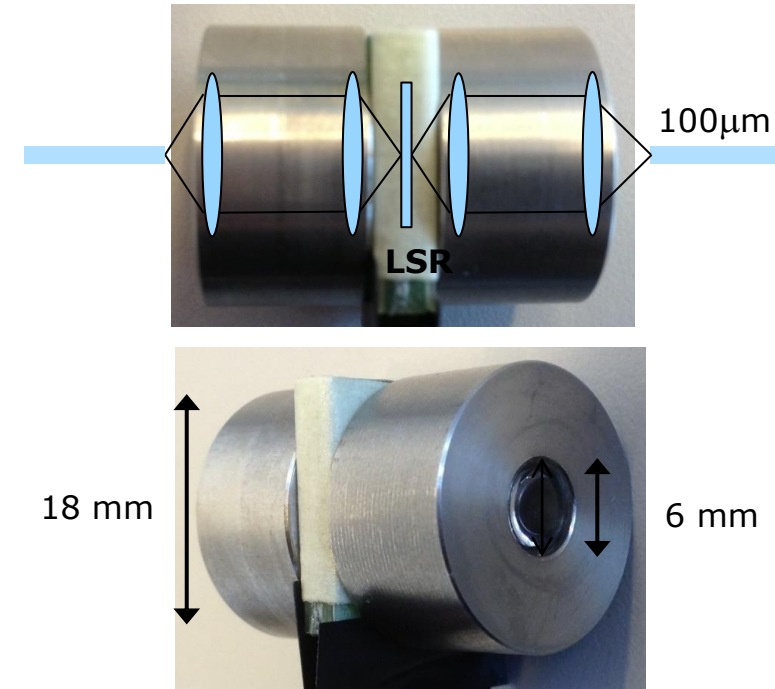
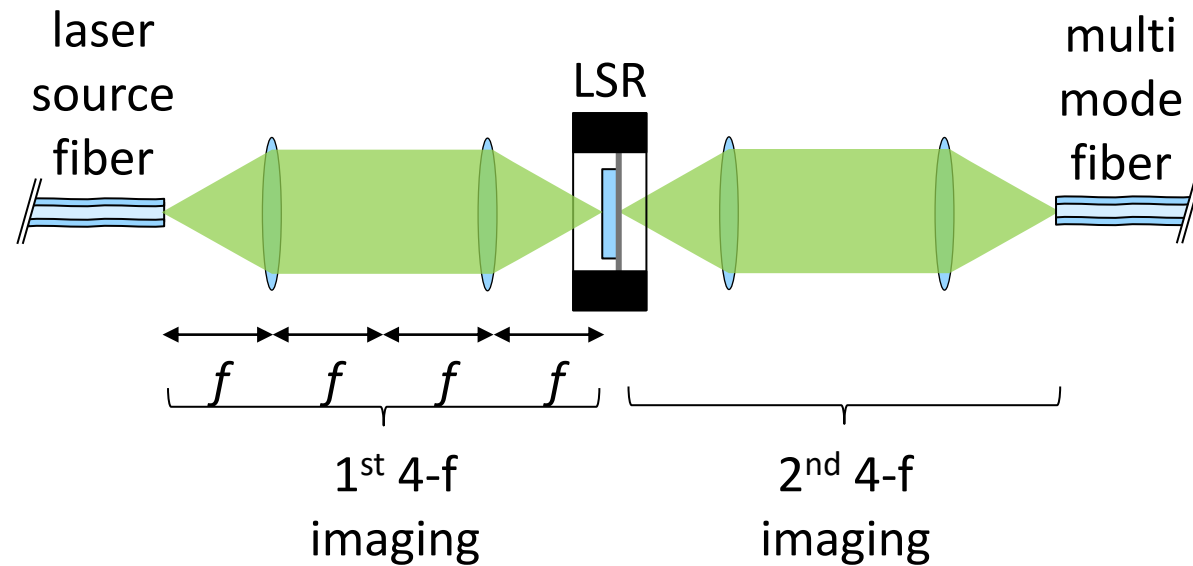
How does a head-up display work?



Place LSR in intermediate image plane ("shaking screen")



Fiber coupling: best layout is to image a spot on the diffuser



- Spot size on diffuser < diameter of fiber core
- No static diffuser allowed

- Speckle reducer: LSR-5-17-17S-VIS with single 17° diffuser
- Fiber: 100mm core, 0.5 NA
- Off-the-shelf glass asphere



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