Speckle Reduction Solutions

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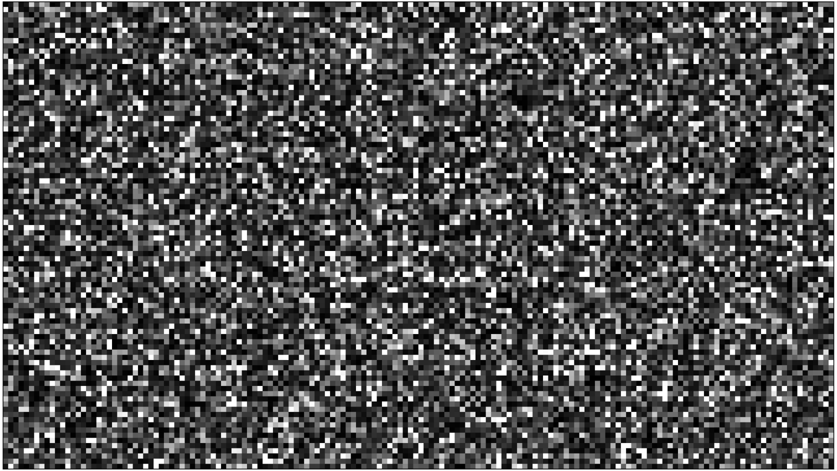
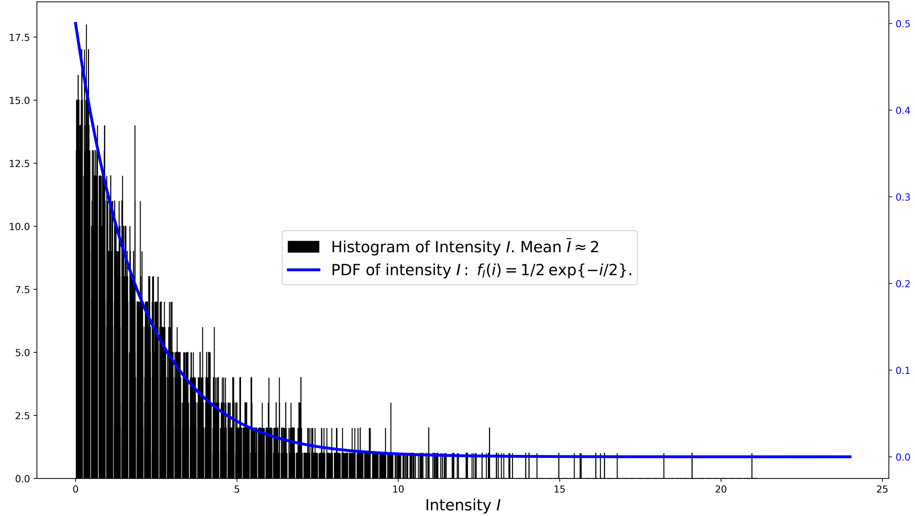
Speckle

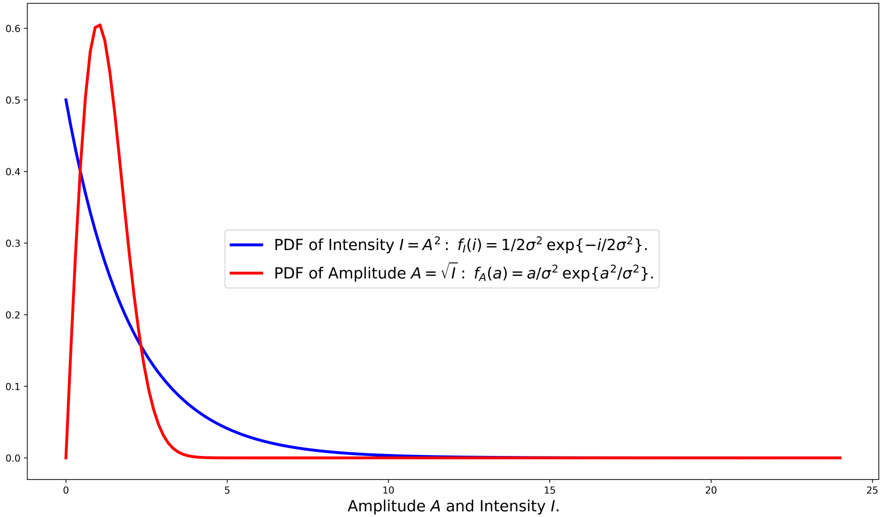


Noise-like pattern arising from constructive and destructive interference.

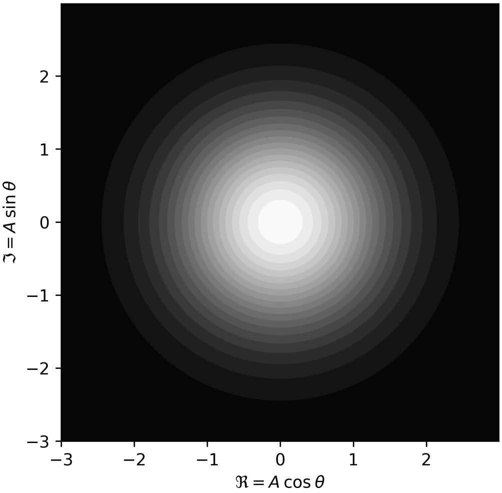
Intensity distribution

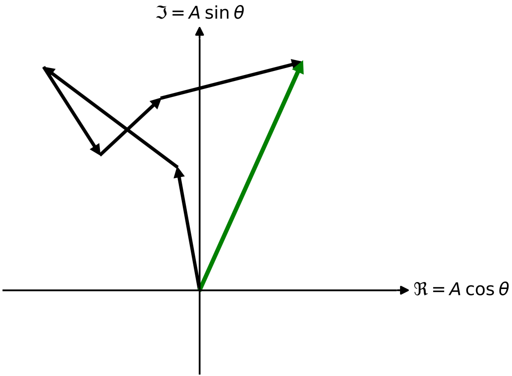


Intensity and amplitude PDFs



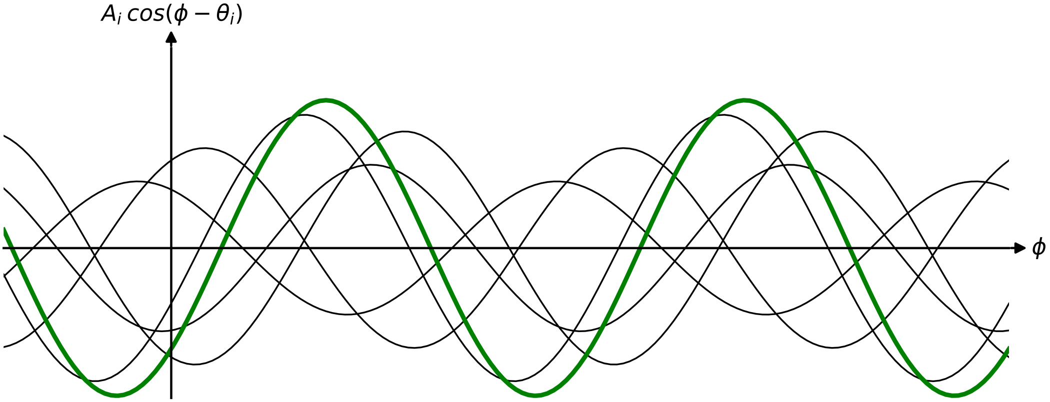
Complex amplitude PDF



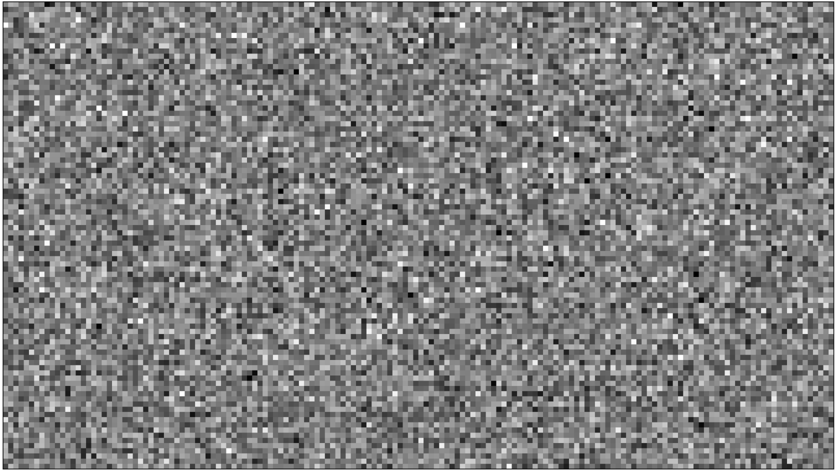


$$f_{\Re,\Im}(\mathfrak{re}, \mathfrak{im}) = \frac{1}{2\pi\sigma^2}\ \exp\{-\frac{\mathfrak{re}^2+\mathfrak{im}^2}{2\sigma^2}\}\ \textit{where}\ \sigma^2 = \sigma_\Re^2 = \sigma_\Im^2.$$

Amplitude summation

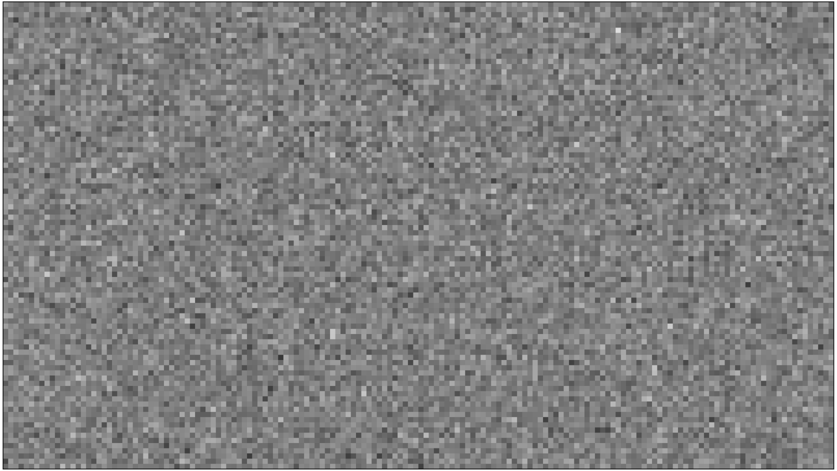


Intensity summation



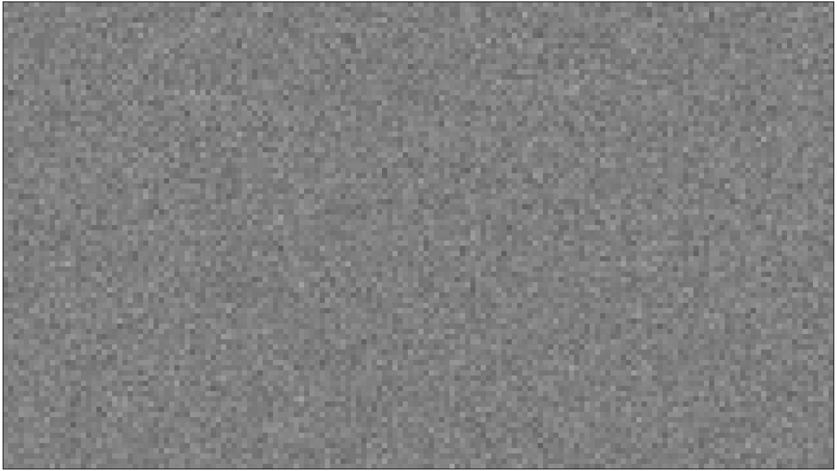
Mean of $N = 256$ *uncorrelated speckle patterns.* $C_S = \sigma_I/\bar{I} \approx 6.25\% = 1/\sqrt{N}$.

Intensity summation



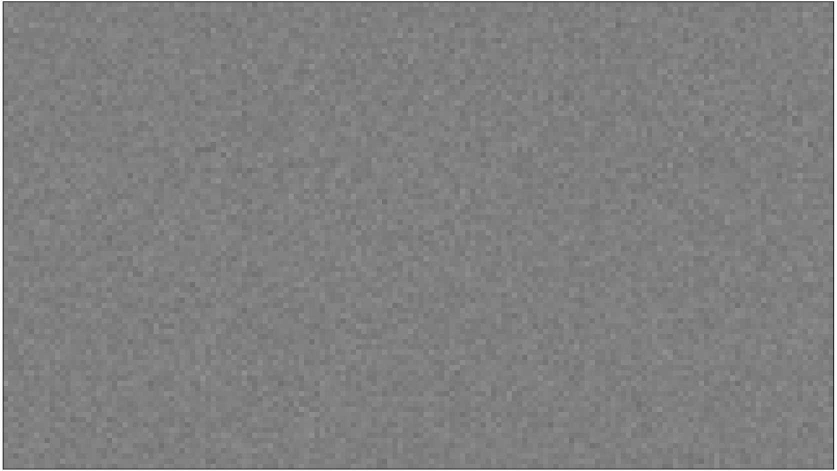
Mean of $N = 1,024$ *uncorrelated speckle patterns.* $C_S \approx 3.12\% = 1/\sqrt{N}$.

Intensity summation



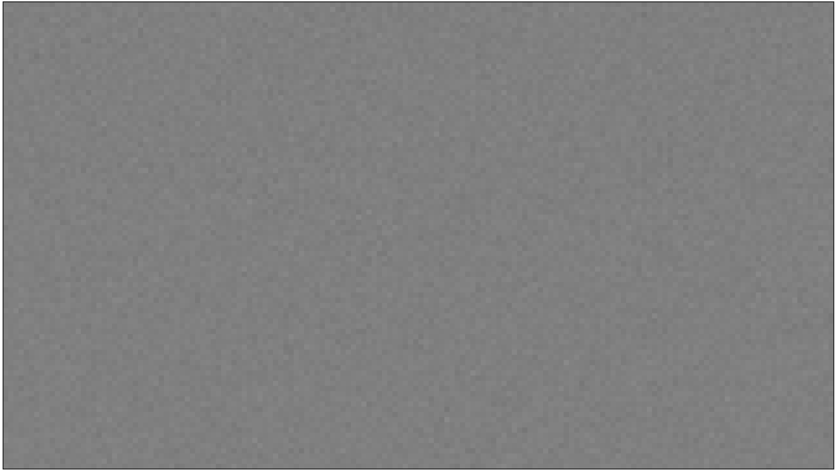
Mean of $N = 4,096$ *uncorrelated speckle patterns.* $C_S \approx 1.56\% = 1/\sqrt{N}$.

Intensity summation



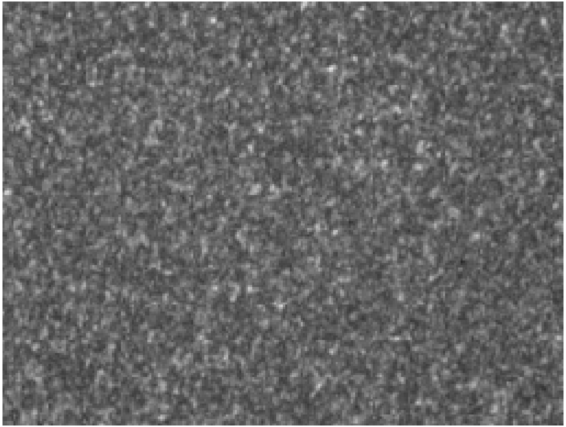
Mean of $N = 16,384$ *uncorrelated speckle patterns.* $C_S \approx 0.8\% = 1/\sqrt{N}$.

Intensity summation

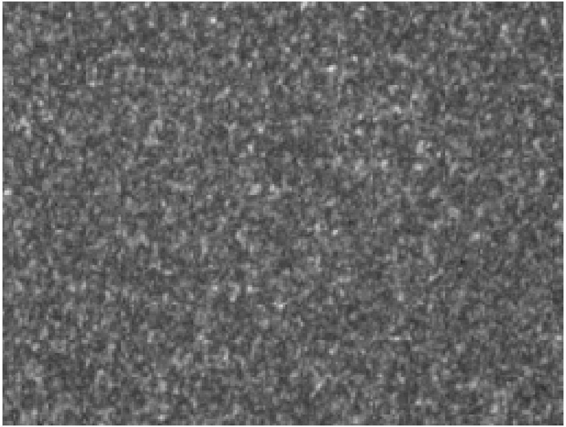


Mean of $N = 65,536$ *uncorrelated speckle patterns.* $C_S \approx 0.4\% = 1/\sqrt{N}$.

Insufficient angular separation of mutually-incoherent pulses

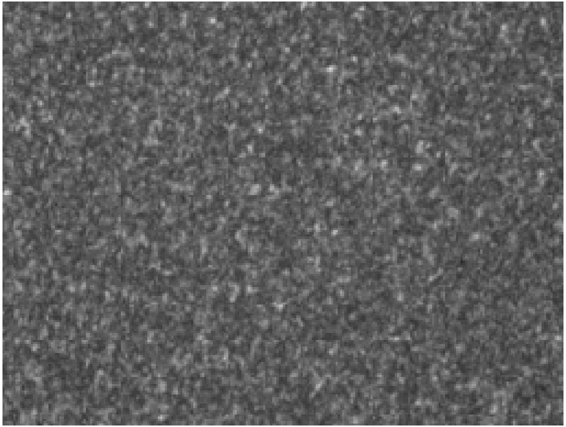


Single 22 ns *pulse speckle pattern,*
$C_S \approx 24\%$.

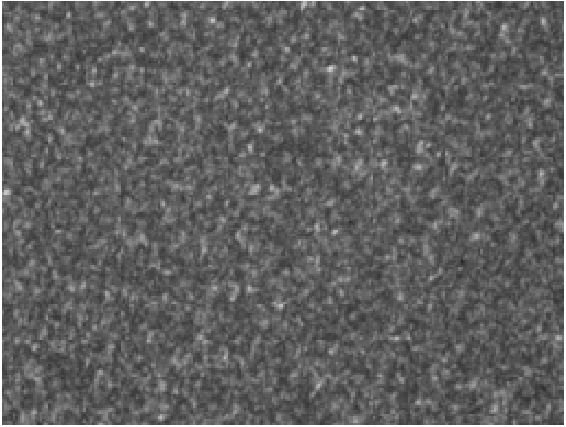


Mean of 100 *different* 22 ns *pulse speckle patterns,*
$C_S \approx 24\%$.

Insufficient angular separation of mutually-incoherent pulses

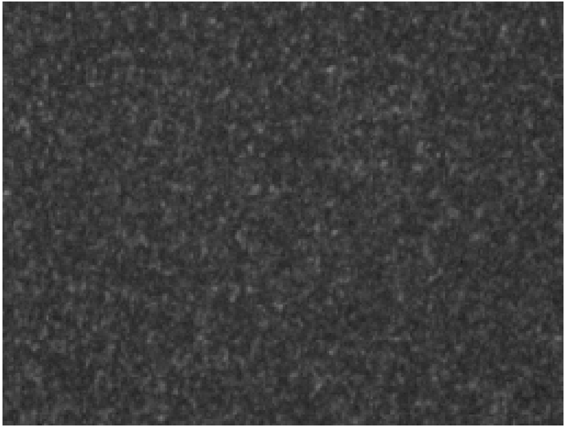


Single 14 ns *pulse speckle pattern,*
$C_S \approx 24\%$.

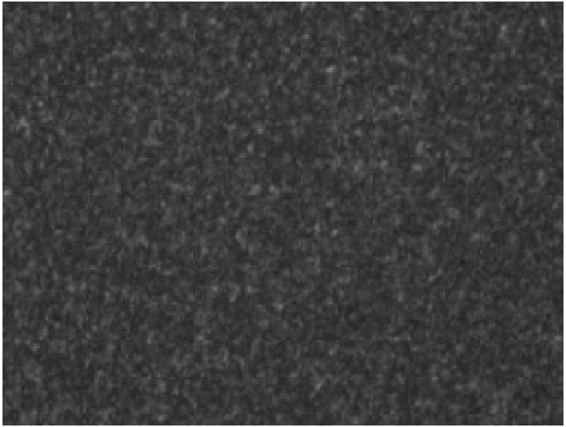


Mean of 100 *different* 14 ns *pulse speckle patterns,*
$C_S \approx 24\%$.

Insufficient angular separation of mutually-incoherent pulses



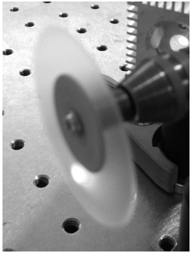
Single 6 ns *pulse speckle pattern,*
$C_S \approx 20\%$.



Mean of 100 *different* 6 ns *pulse speckle patterns,*
$C_S \approx 20\%$.

Moving diffusers

Well-known approach to the generation of uncorrelated speckle patterns over time.



Typical rotating implementation.

Moving diffusers

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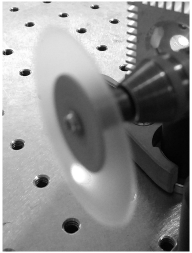
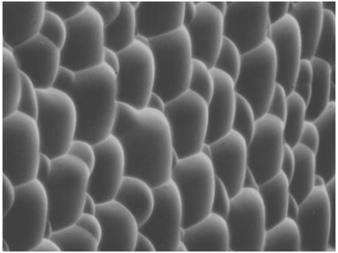


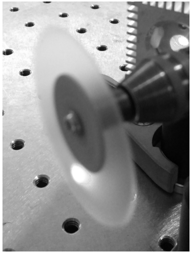
Typical rotating implementation.



"Efficient" refractive diffusers diffract at microlens apertures.

Moving diffusers

Well-known approach to the generation of uncorrelated speckle patterns over time.



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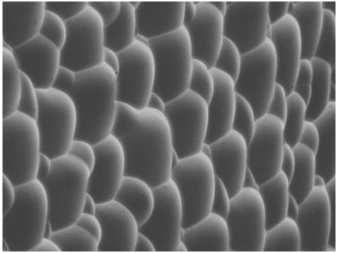

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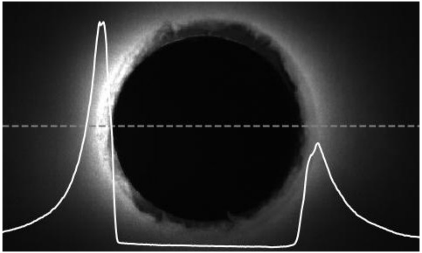
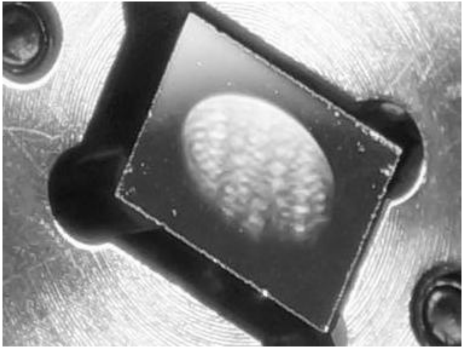


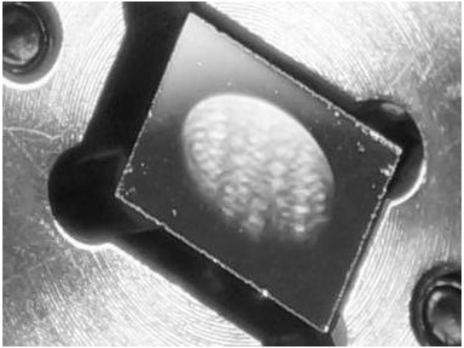
Intensity profile from 2 ×"2 deg" *diffusers outside* 4 deg *aperture.*

DYOPTYKA deformable mirror

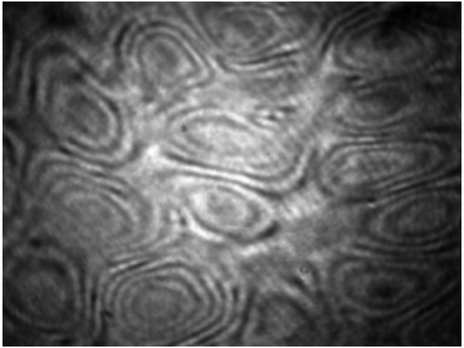


Randomly-distributed surface deformations at frequencies up to tens of MHz.

DYOPTYKA deformable mirror



Randomly-distributed surface deformations at frequencies up to tens of MHz*.*



Microscope interferometer fringes resulting from convex and concave surface deformations.

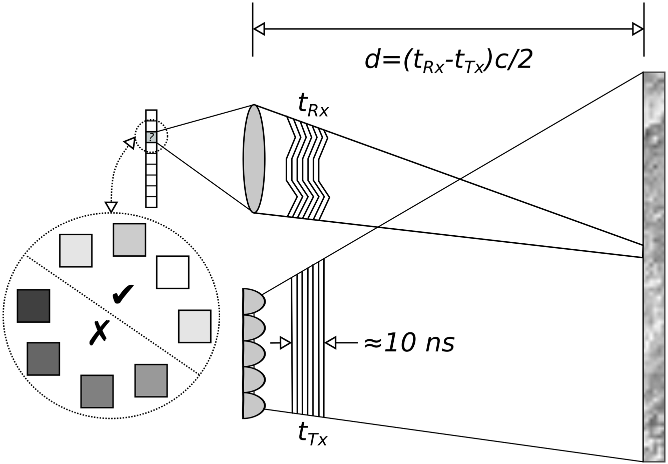
DYOPTYKA publications

- Speckle reduction within nanosecond-order pulse widths for **flash lidar** applications.
- Homogenization **without scattering** of laser illumination.
- **Phase randomization** for spatio-temporal averaging of unwanted interference effects arising from coherence.
- Dynamic illumination for spatio-temporal integration of unwanted interferences in **holographic displays**.
- Directional **illumination** with homogenisation of laser incidence on remote phosphor.
- **Beam quality**-preserving speckle reduction for scanned laser displays.
- **Light guide plate** illumination with blue laser and quantum dot emission.
- A compact, **low cost**, phase randomizing device for laser illuminated displays.
- Light guide plate illumination by laser through **optical fiber**.
- Speckle reduction for illumination with lasers and stationary, heat sinked, **phosphors**.
- Speckle reduction with **multiple** laser pulses.
- Speckle reduction within a **single** one microsecond laser pulse.
- Speckle mitigation in laser-based projectors.
- Speckle reduction for laser-illuminated **picoprojectors**.

Customer applications

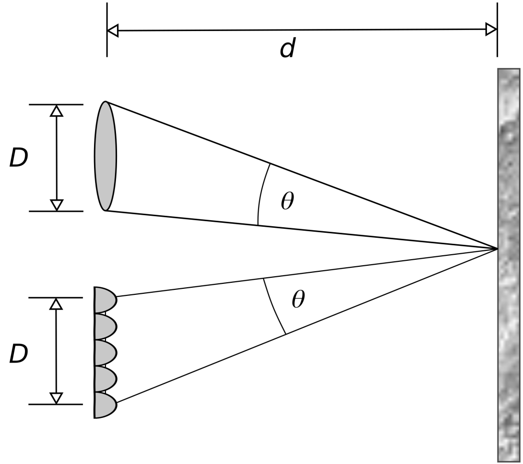
- Cinema projectors.
- Mobile device projectors.
- Front-projection television.
- Rear-projection television.
- Aerospace head-up display.
- Automotive head-up display (DLP, LCOS.)
- Holographic display for augmented reality.
- Optical coherence tomography.
- Sensor calibration (LWIR.)
- Lithography (DUV.)
- Interferometry.
- Spectroscopy.
- Microscopy.
- Metrology.

Direct time-of-flight camera



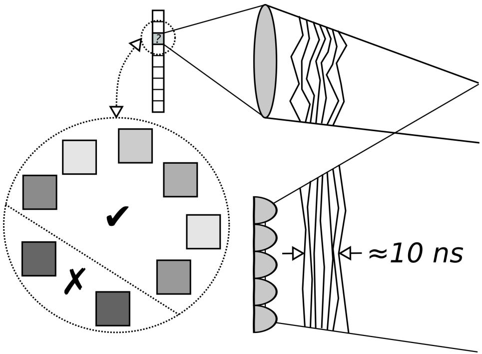
Dark speckle causes non-detection of Rx pulse at some pixels.

VCSEL array sources



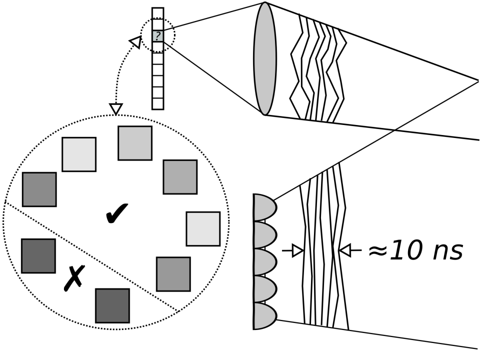
Array dimensions similar to camera pupil diameter.

Speckle reduction *within* single pulse durations

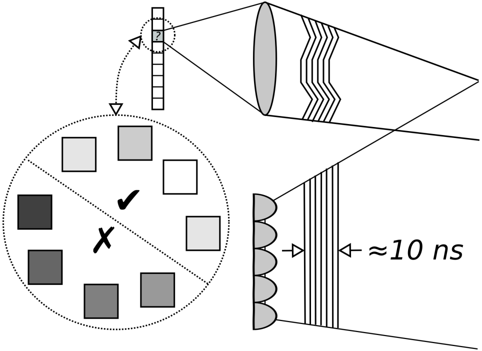


Randomize T_X pulse wavefronts so that R_X wavefronts less correlated.

Speckle reduction *within* single pulse durations

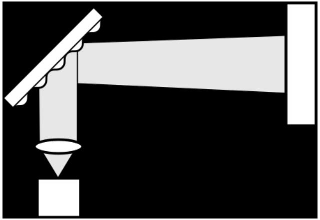


Randomize T_X pulse wavefronts so that R_X wavefronts less correlated.



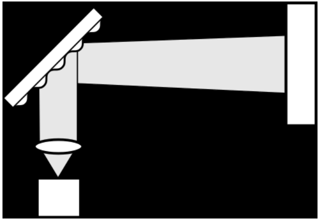
R_X pulse wavefronts highly correlated to rough surface.

Apparatus configuration #1

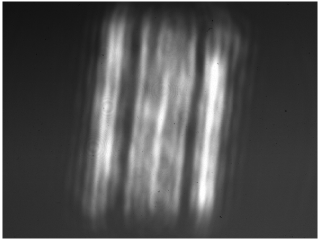


LD, DM, BP.

Apparatus configuration #1

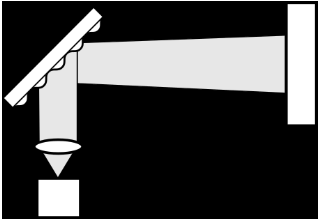


LD, DM, BP.

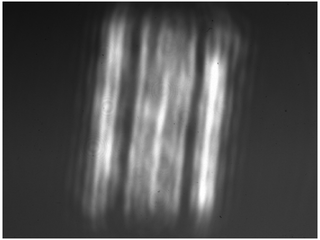


LD emission, DM inactive.

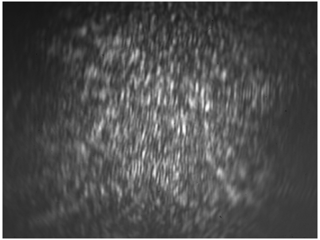
Apparatus configuration #1



LD, DM, BP.

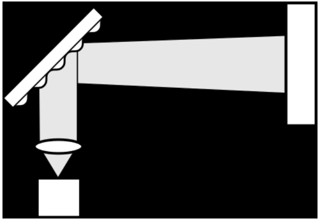


LD emission, DM inactive.

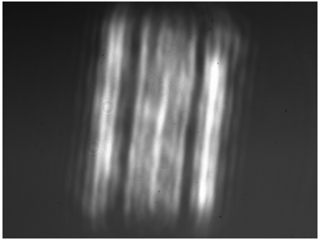


LD 6 ns *pulse, DM active.*

Apparatus configuration #1



LD, DM, BP.



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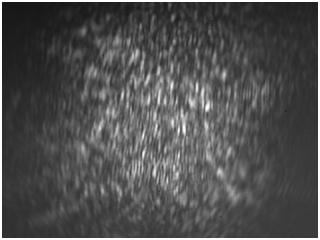
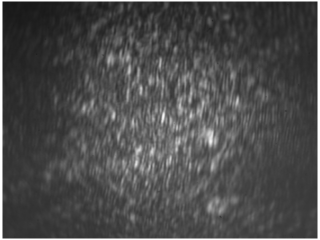
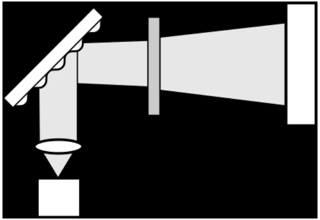


LD 6 ns *pulse, DM active.*



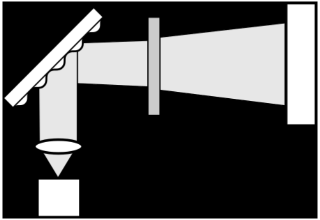
LD 6 ns *pulse, DM active.*

Apparatus configuration #2

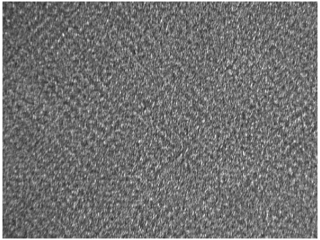


LD, DM, ED, BP.

Apparatus configuration #2

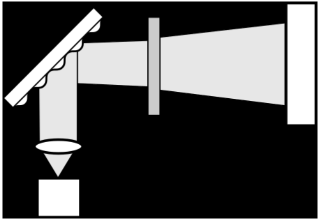


LD, DM, ED, BP.

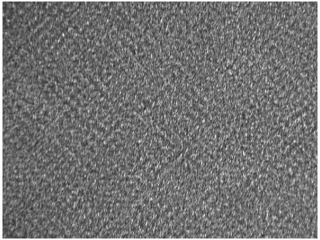


ED pattern, DM inactive.

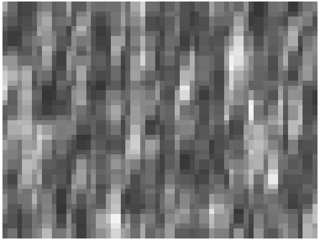
Apparatus configuration #2



LD, DM, ED, BP.

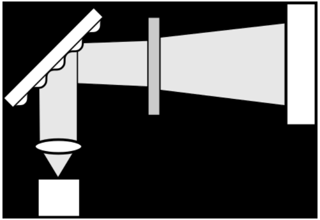


ED pattern, DM inactive.

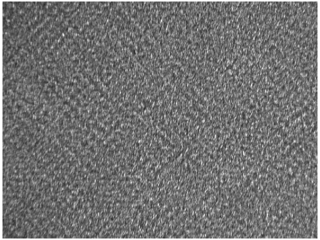


Region, 6 ns *pulse, DM inactive.*

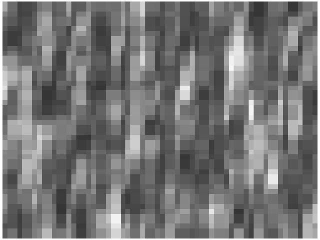
Apparatus configuration #2



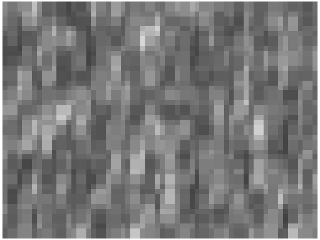
LD, DM, ED, BP.



ED pattern, DM inactive.

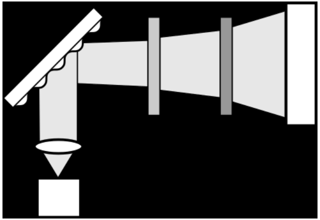


Region, 6 ns *pulse, DM inactive.*



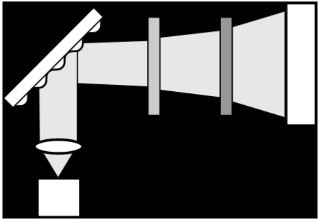
Region, 6 ns *pulse, DM active.*

Apparatus configuration #3

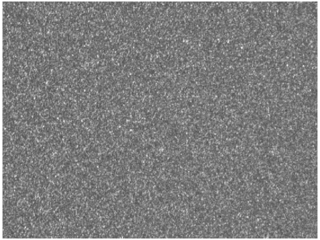


LD, DM, ED, GG, BP.

Apparatus configuration #3

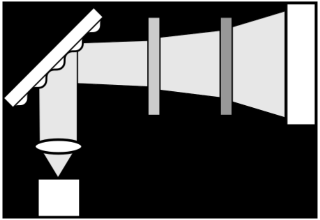


LD, DM, ED, GG, BP.

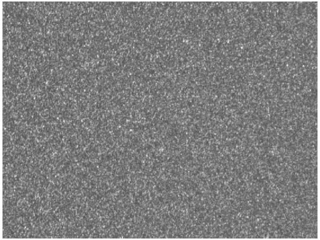


GG pattern, DM inactive.

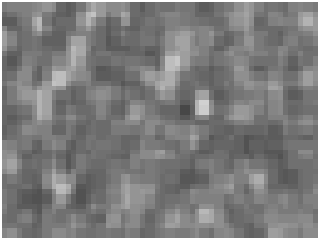
Apparatus configuration #3



LD, DM, ED, GG, BP.

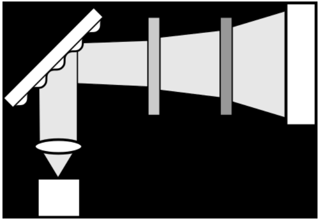


GG pattern, DM inactive.

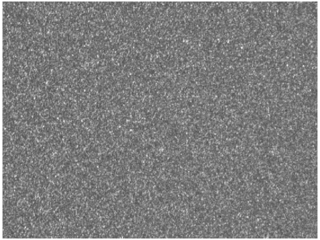


LD 6 ns *pulse, DM inactive.*

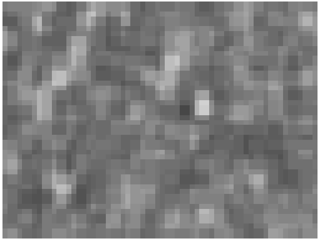
Apparatus configuration #3



LD, DM, ED, GG, BP.



GG pattern, DM inactive.



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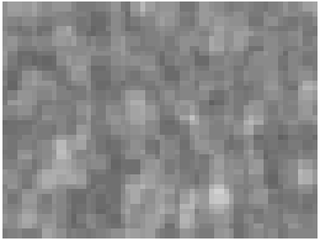
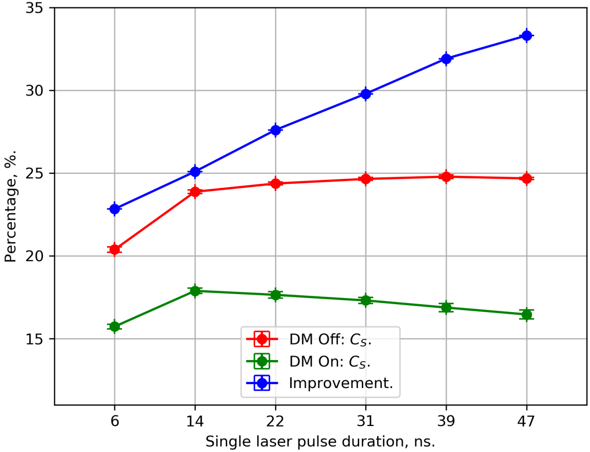


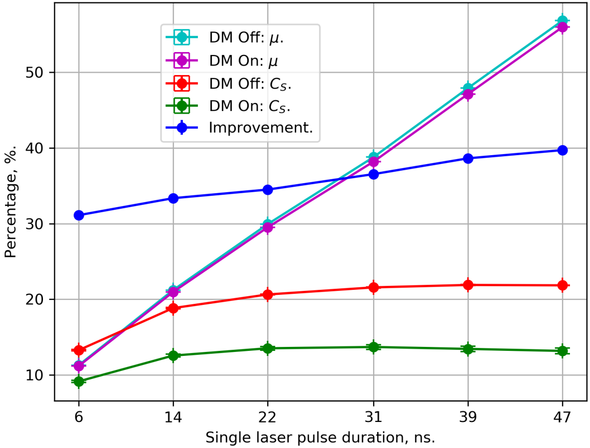
LD 6 ns *pulse, DM active.*

Speckle reduction within single pulse durations



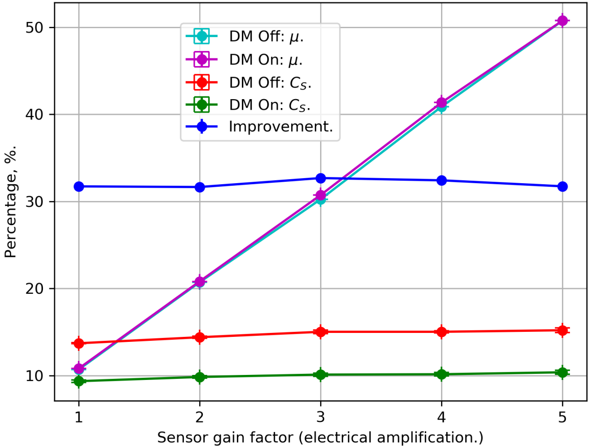
For 100 different pulse images for each duration.

Verification for sensor sensitivity*



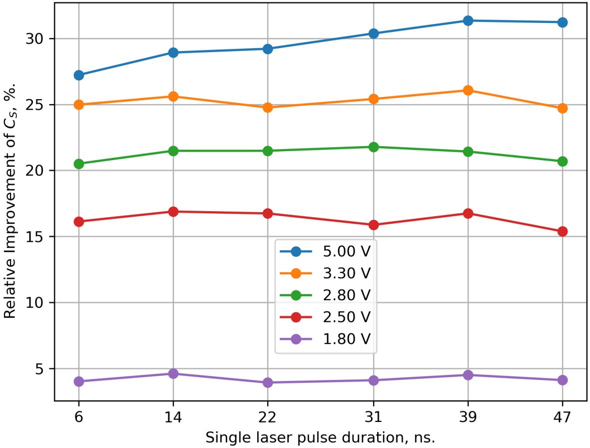
For 100 different pulse images for each duration.

Verification for sensor gain*



For 100 different 6 ns *pulse images for each gain factor.*

Verification for DM wave amplitudes**



For 100 different pulse image pairs for each duration.

Conclusions for time-of-flight

- Relative improvement of $> 20\%$ to speckle contrast ratio demonstrated and verified for $\geq 6\,\mathrm{ns}$ pulse durations.

- Should improve spatial resolution . . .
  by reducing the need for averaging within a range image.

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Thank You!

Please contact me to discuss:

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