Speckle Noise In TDLS

A.I. Nadezhdinskii

DLS LAB

A. M. Prokhorov General Physics Institute of RAS
38 Vavilov str., 119991 Moscow, Russia.
E-mail: Nad@nsc.gpi.ru

Abstract

In [1] it was shown that fundamental limit of sensitivity due to Diode Laser (DL) quantum noise can be achieved in TDLS when resonance molecular absorption is considered. This corresponds to minimum detectable absorption below 10-7 for 1 sec averaging time.

At present time one of promising modification of DL based system are systems installed on vehicles, helicopters, airplanes, etc. detecting scattered laser light from topography reflector. When we've started investigation of sensitivity of such systems presence of additional noise was observed reducing sensitivity more than 1000 times.

Characteristic feature of such systems is presence of scattered light from topography reflector and relative system movement with respect to the reflector. Without movement no additional noise was observed. As the origin of this noise, speckle pattern of scattered light was assumed.

Speckle pattern of scattered light will be analyzed and modeled. Experimental investigations of additional noise will be presented and compared will predictions of analysis and modeling.

[1] A.Nadezhdinskii, in TDLS 2005, Abstracts of papers, Florence, Italy, 2005, p.66.

Presence of additional noise

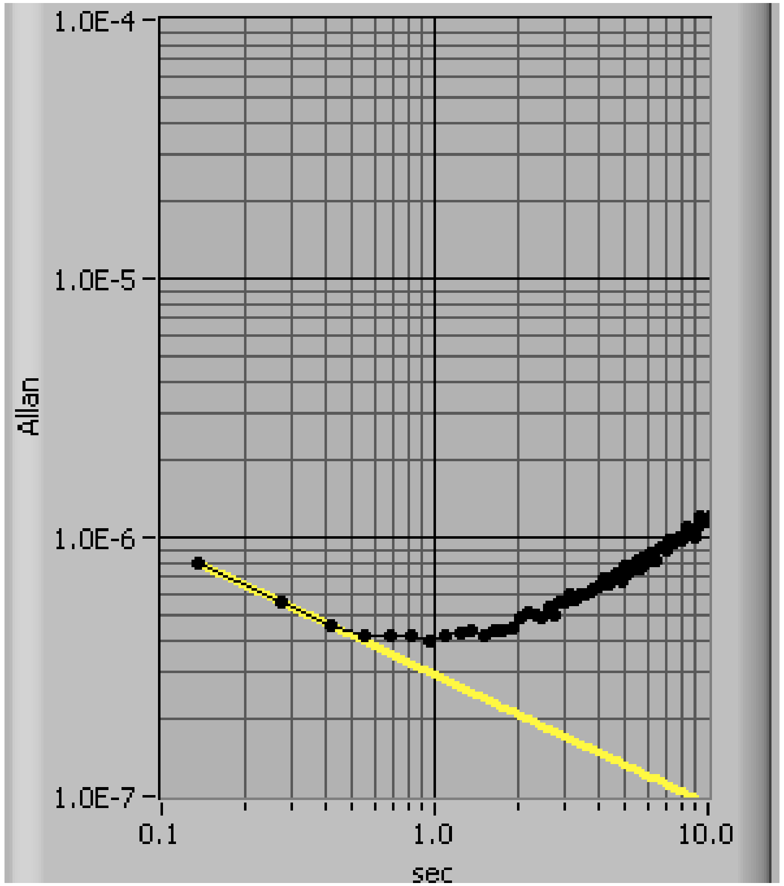
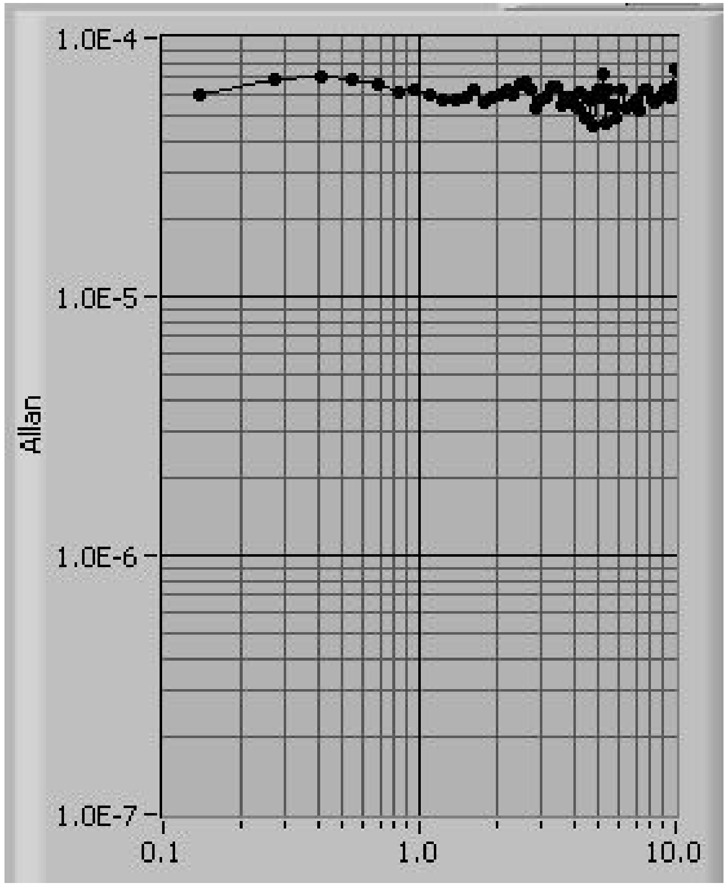


Fig.1 Examples of Allan plots of relative photo-current noise - Di/i for traditional TDLS scheme (left) and system with topography reflector (right)



Conclusions:

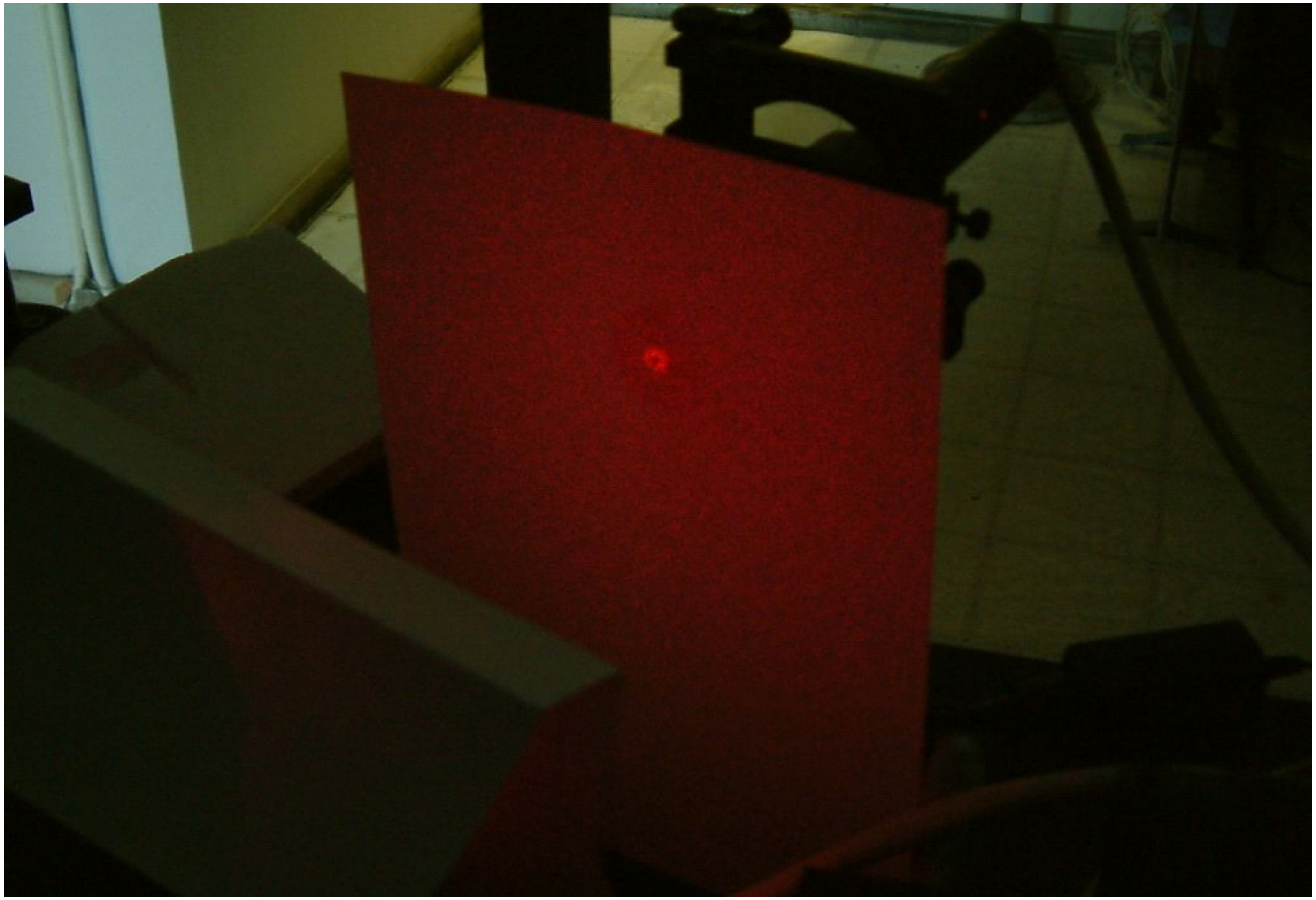
1. Because of additional noise presence more than 2 orders of sensitivity were lost
2. Additional noise looks like flicker one

Goal: to identify the noise origin and to suppress it.

Speckle pattern

Assumption:

Additional noise is due to movement of speckle pattern determined by scatted laser light



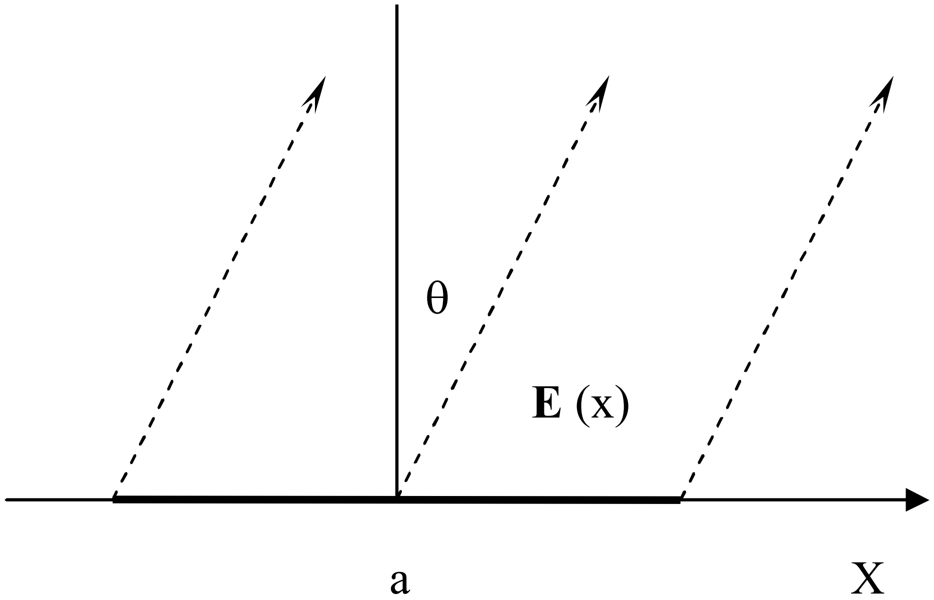
Speckle pattern view for He-Ne laser light scattered by sheet of white paper

Up to author knowledge, for the first time this type of noise for TDLS system with topography reflector was considered in [2].

[2] R.Wainner, B.Green, M.Allen, M.White, J.Stafford-Evans, R.Naper, Appl.Phys., B75, 249-254 (2002)

Speckle pattern formation

Speckle pattern is result of scattered light interference



Near and far field of scattered light: E(x) and E(θ), respectively

$$E(x) = r(x)\exp\left[i\Delta\varphi(x)\right]E_0$$

$$E(\theta) = \int_{-a/2}^{a/2} E(x)\exp\left[ikx\sin(\theta)\right]dx$$

Angular dependence of scattered light

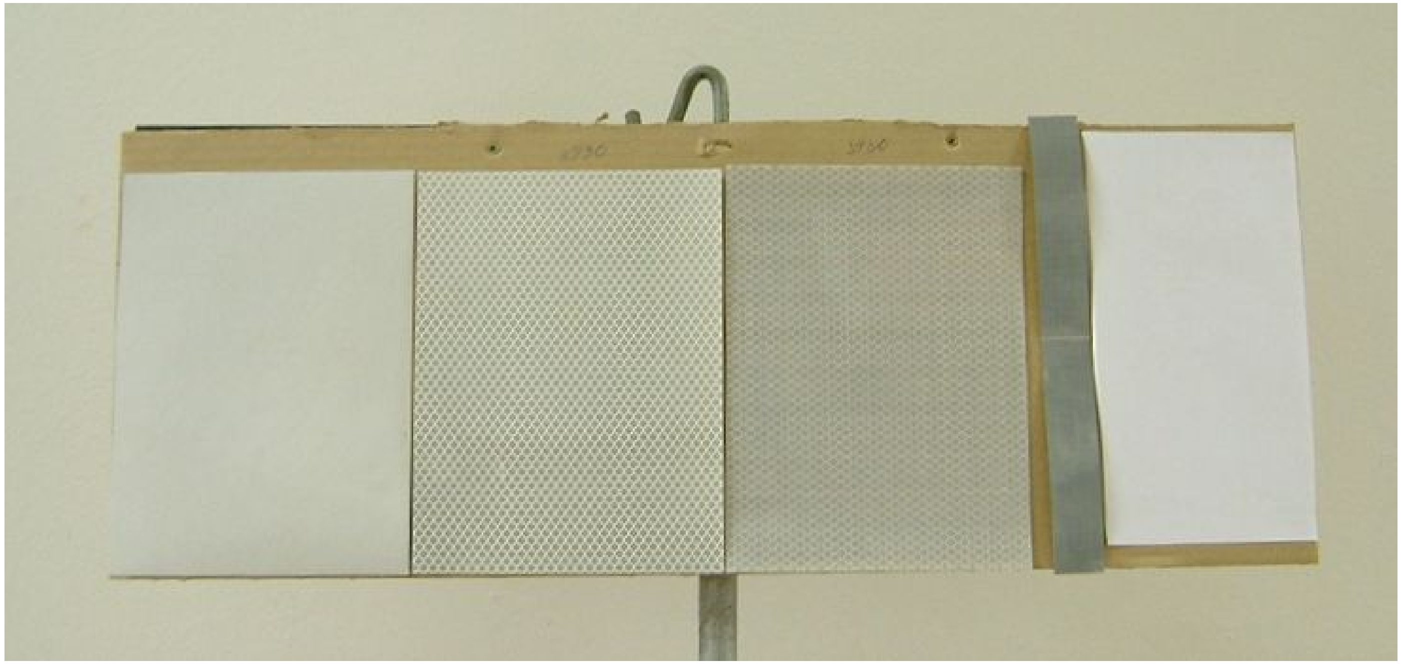
$$I(\theta) = 2\,\mathrm{Re}\int_{-a/2}^{a/2} dx \int_{-a/2}^{a/2} E(x)E(y)\exp\left[ik(y-x)\sin(\theta)\right]dy$$

Diagram of scattered light

$$\langle I(\theta)\rangle = |E_0|^2 \, 2\,\mathrm{Re} \int_{-a/2}^{a/2} dx \int_{-a/2}^{a/2} F(x,y) \exp[ik(y-x)\sin(\theta)]dy$$

$$F(x,y) = \langle r(x)r(y)\exp[i\Delta\varphi(y) - i\Delta\varphi(x)]\rangle$$

Scattered light diagram is FFT of near field correlation function – F



View of tested reflector films

Table. 1 Identification of used reflector films

#	Identification	Description	Parameters
1	Series 3200	Micro glass balls which encapsulated in gauzy polymer layer	Diameter – 40 μ
2	Series 4090	An optical element are microprisms, which are encapsulated in rhomb-shaped capsules and from outer face they covered with gauzy polymer layer.	Size 100*170 μ
3	Series 3930	Film optical elements produced by «full cube» technology. Elements are microprisms, which are encapsulated in rhomb-shaped capsules and from outer face they covered with gauzy polymer layer.	
4	Film from USA		130 μ
5	White paper sheet		

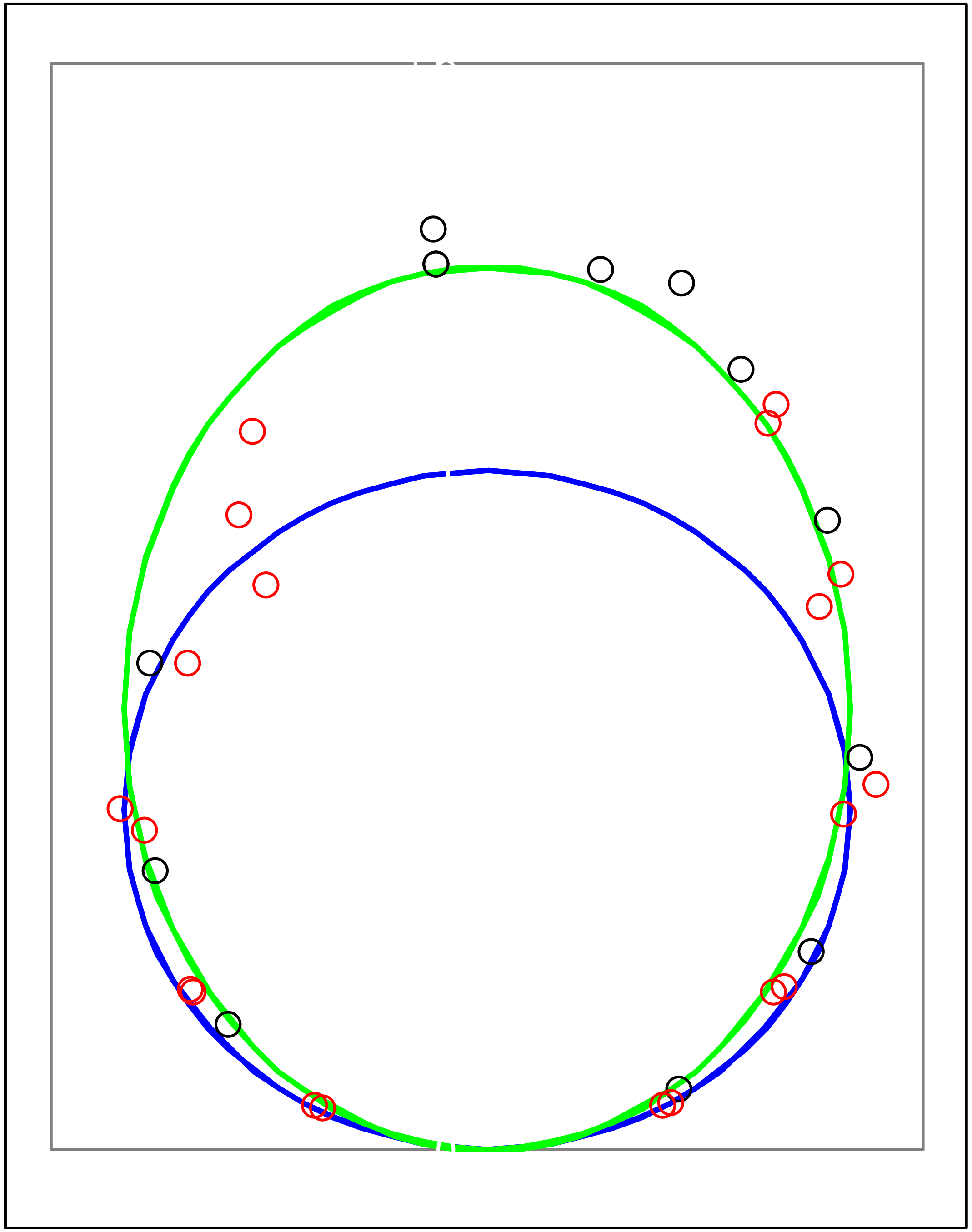


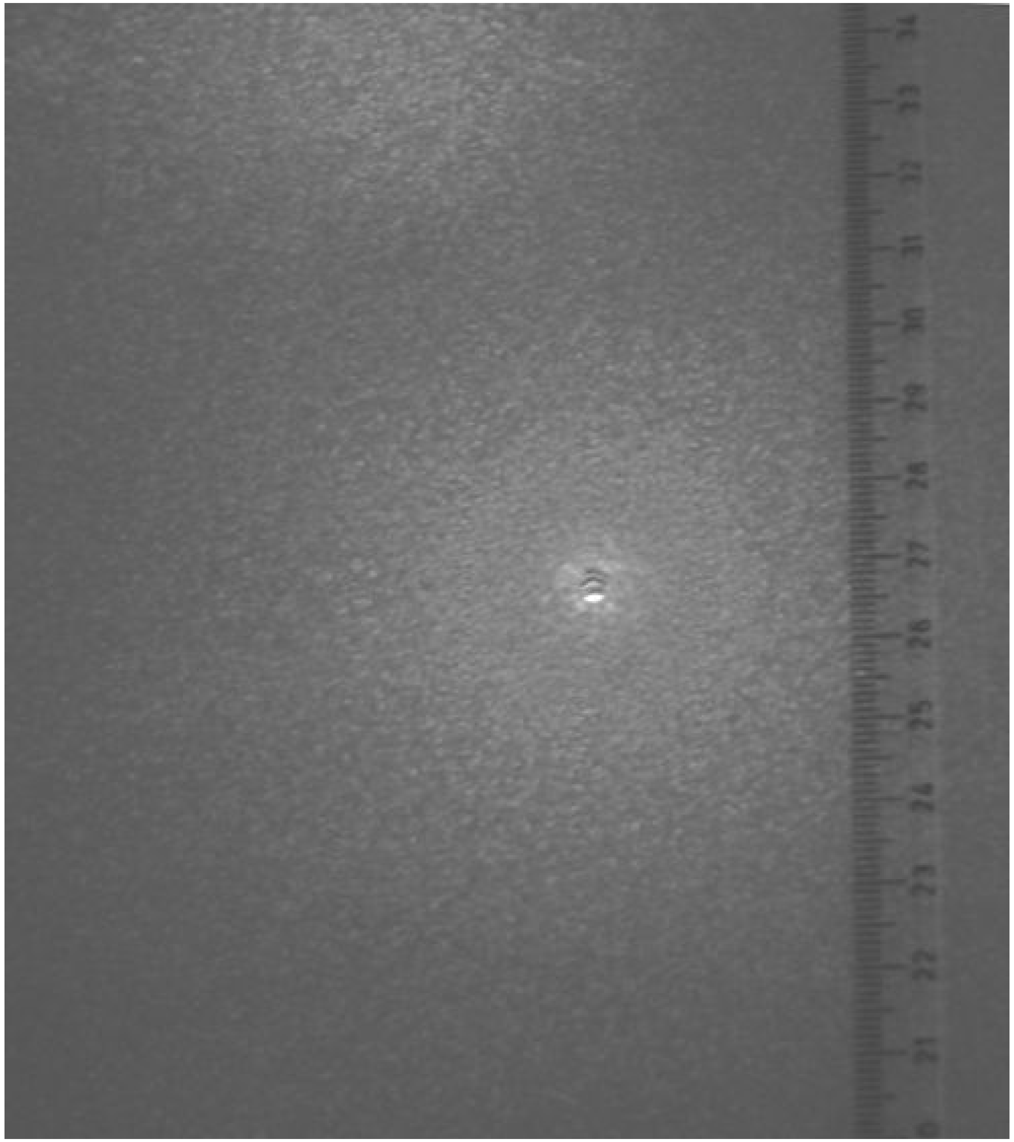
Diagram of scattered light

DL radiation scattering diagram for DL radiation with λ = 1.6 μ by white paper surface. Blue line corresponds to isotropic scattering.

Scattering diagram is close to isotropic one:

Hence, near field correlation function of white paper has characteristic dimension close to **1.6** μ

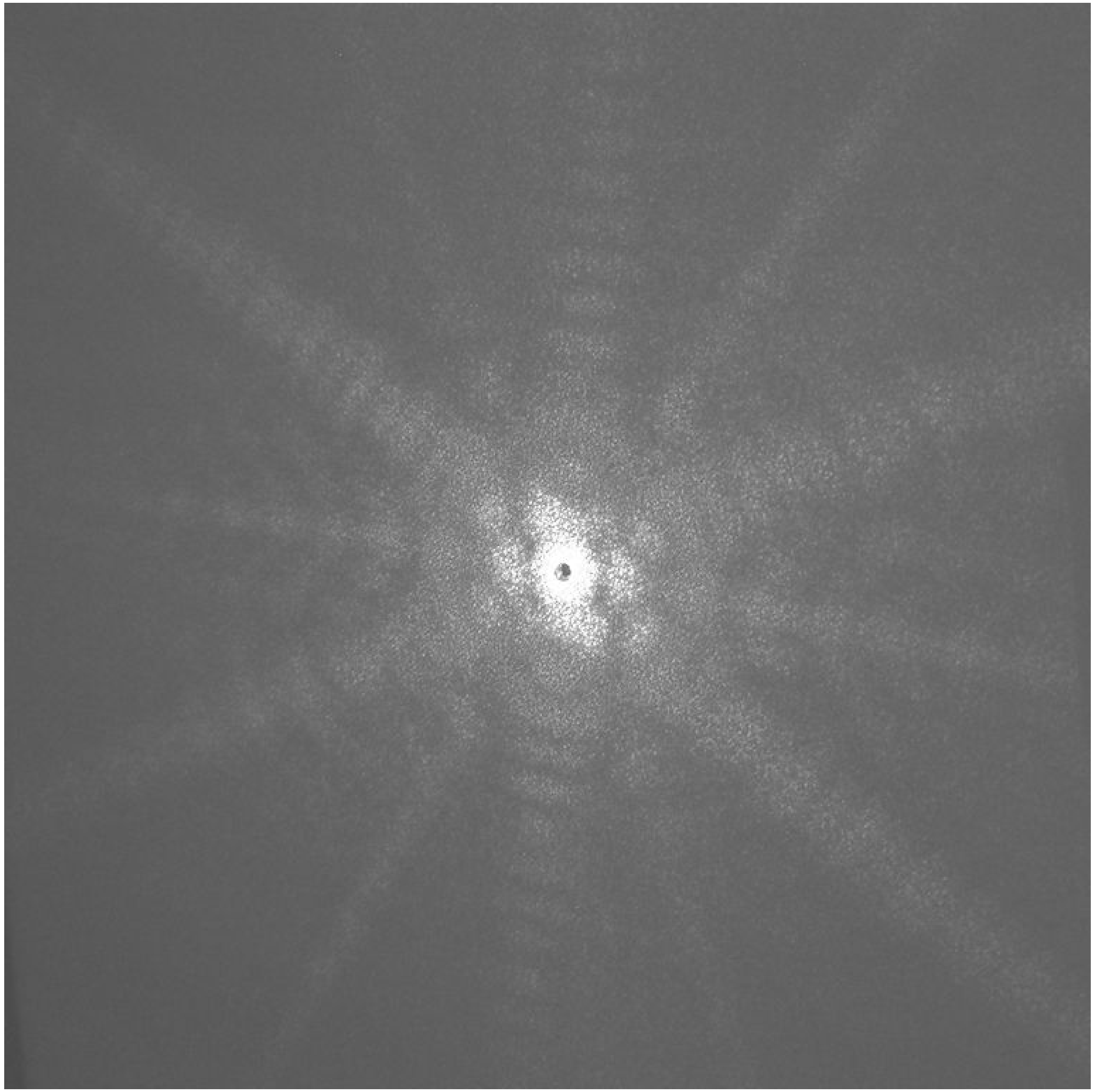
Diagram of scattered light



Scattering diagram for sample №1.

Diagram of scattered light demonstrates structure typical for diffraction on hole. In this case it is diffraction on 40 μ glass ball of the film. Speckle pattern is also observable.

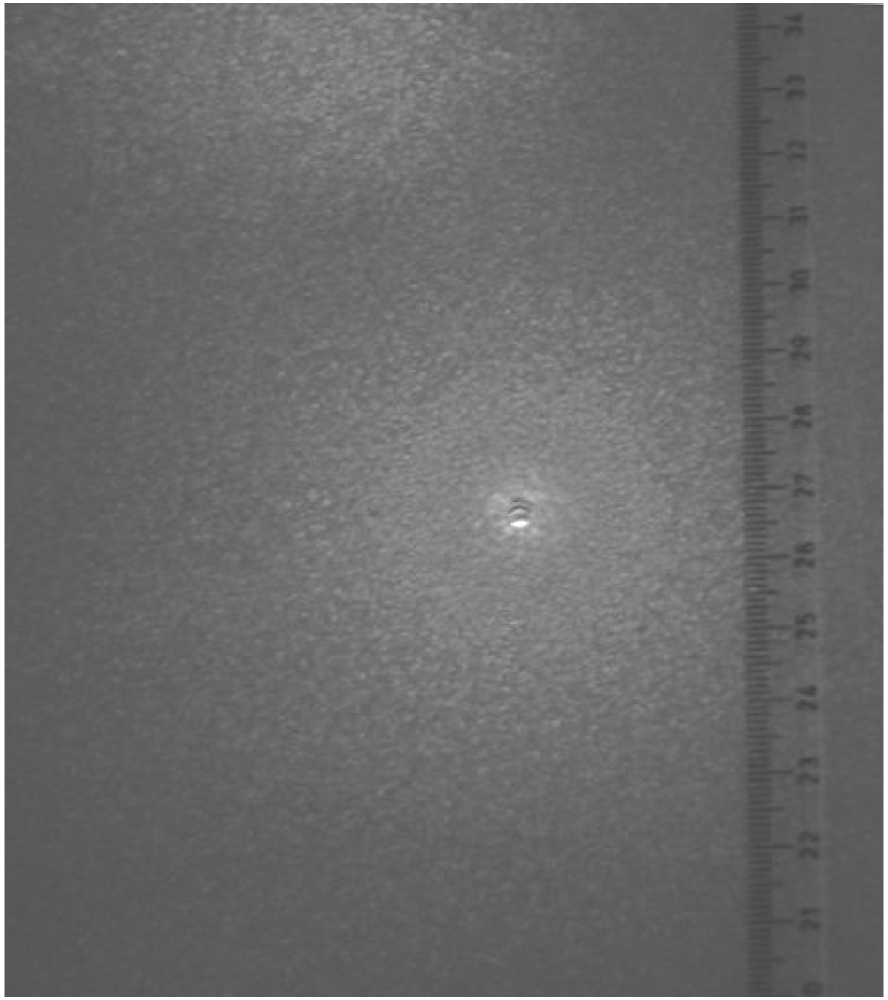
Diagram of scattered light



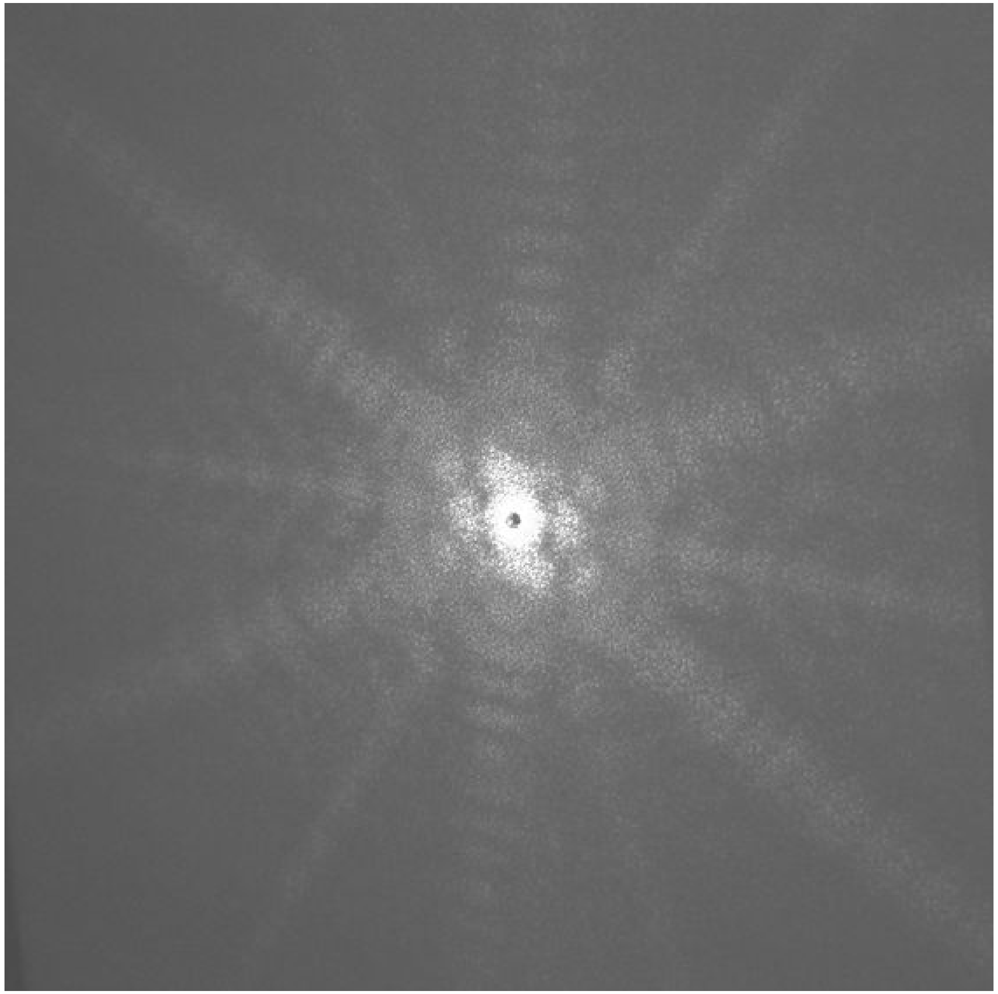
Scattering diagrams for the sample №4.

Diagram of scattered light demonstrates specific structure having 6 order symmetry – six intensive rays. It is due to light diffraction by microprism (cubic corner). Microprism periodic structure of the film leads to periodic structure of rays because of interference (similar to grating). Deviation from the periodicity for larger distances produces Speckle pattern.

Diagram of scattered light



Scattering diagram for sample №1.

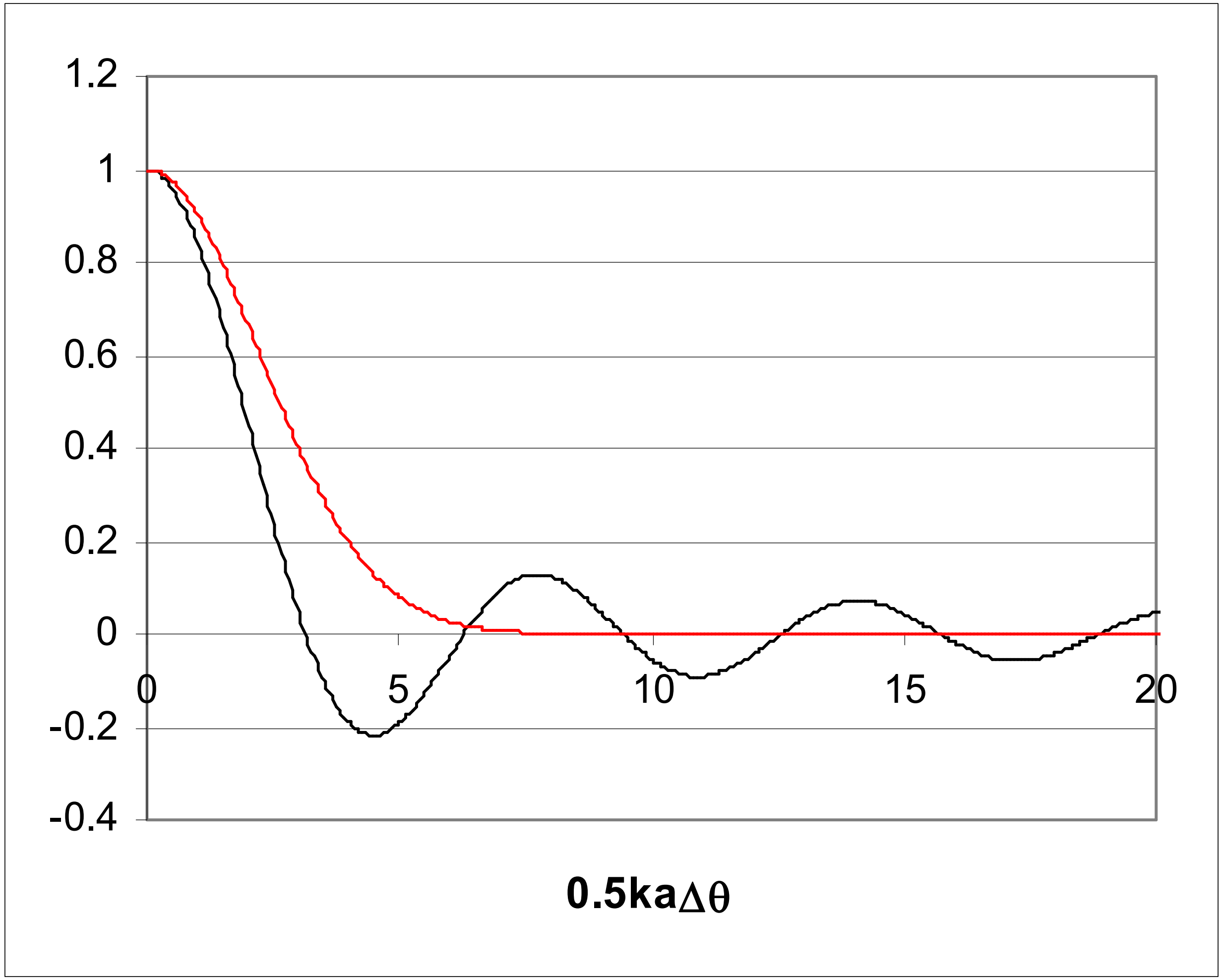


Scattering diagrams for the sample №4.

Diagram of scattered light are totally different.
However, speckle pattern can be easily observed

Speckle dimension

$$\left\langle E(\theta)E^*(\theta+\Delta\theta)\right\rangle = \left|E_0\right|^2\left\langle r^2\right\rangle 2\,\mathrm{Re}\int_{-a/2}^{a/2}\exp\left[ikx\Delta\theta\right]dx = 2a\left|E_0\right|^2\left\langle r^2\right\rangle\frac{\sin\left[0.5ka\Delta\theta\right]}{0.5ka\Delta\theta}$$



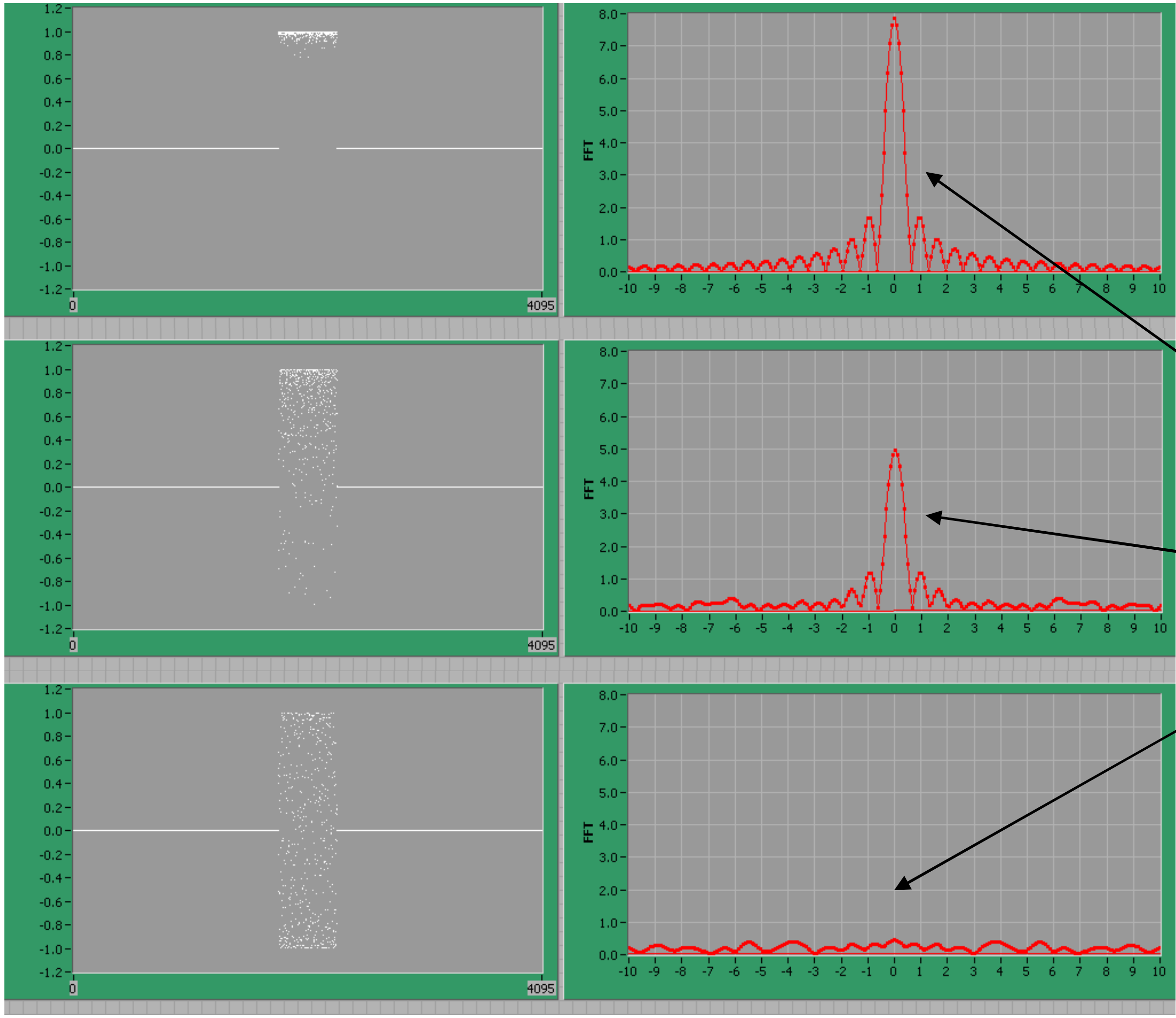
Far field correlation function is determined by diffraction of near field pattern

Rectangular and Gaussian light intensity distribution on reflector: black and red, respectively

Speckle pattern modeling

$$\langle I(\theta)\rangle = |E_0|^2\, 2\,\mathrm{Re}\int_{-a/2}^{a/2} dx \int_{-a/2}^{a/2} F(x,y)\exp[ik(y-x)\sin(\theta)]dy$$

$$F(x,y) = \langle \exp[i\Delta\varphi(y) - i\Delta\varphi(x)]\rangle$$



One-dimension scattering model with random phase distribution

Ideal reflection with diffraction on slit

Intermediate situation

Diffusion scattering, speckle pattern

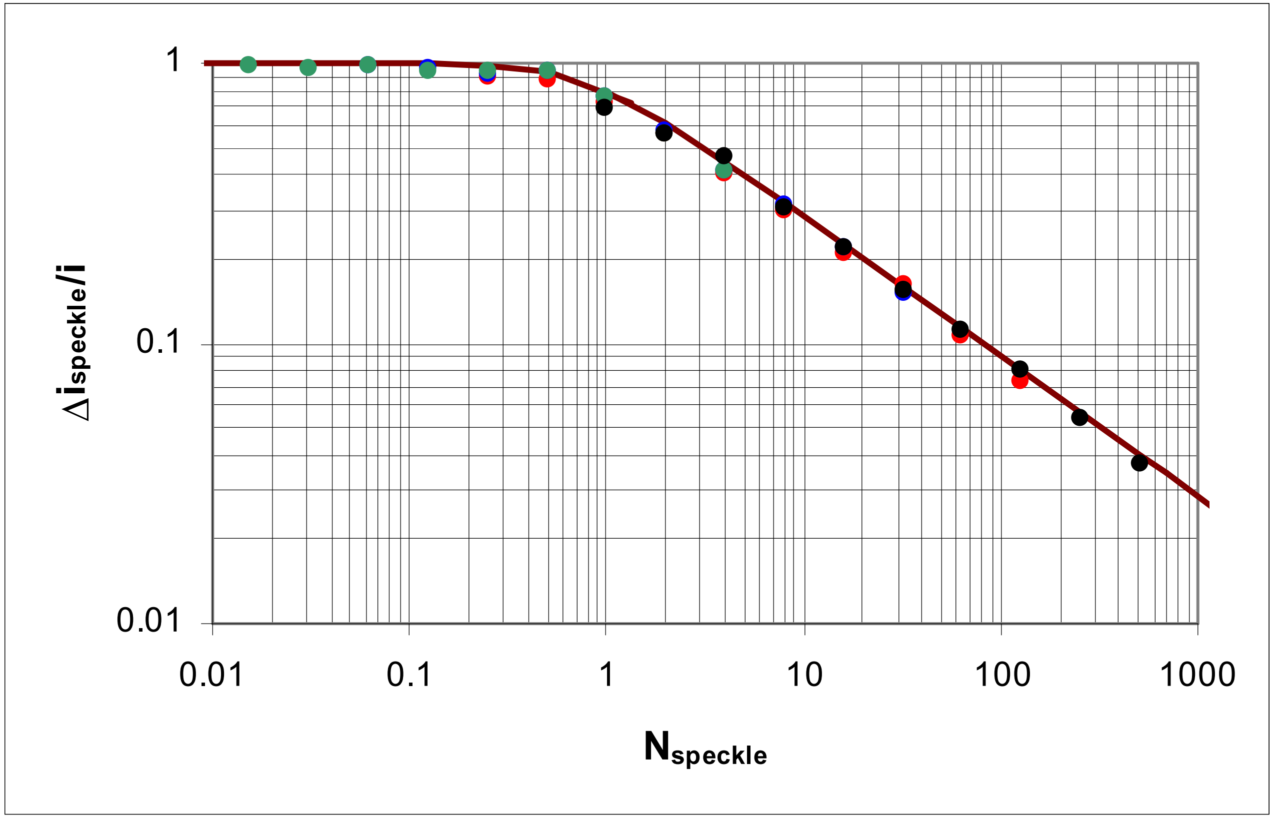
Near (left) and far (right) field diagrams for phase std – 0.2, 1, 5

Speckle noise modeling

$$2\,\mathrm{Re}\int_{-\theta_0/2}^{\theta_0/2} E(\theta)E^*(\theta)d\theta = 2\,\mathrm{Re}\int_{-a/2}^{a/2} dx \int_{-a/2}^{a/2} E(x)E^*(y)dy \left\{\frac{\sin[0.5k(y-x)\theta_0]}{0.5k(y-x)}\right\}$$ Photocurrent - i

Speckle pattern is determined by following parameters:

L – distance between TR and receiving optics; a – laser beam dimension on TR; D – diameter of receiving optics; l – laser wavelength



$N_{speckle}$ – mean speckles number in receiving optics aperture

One dimension

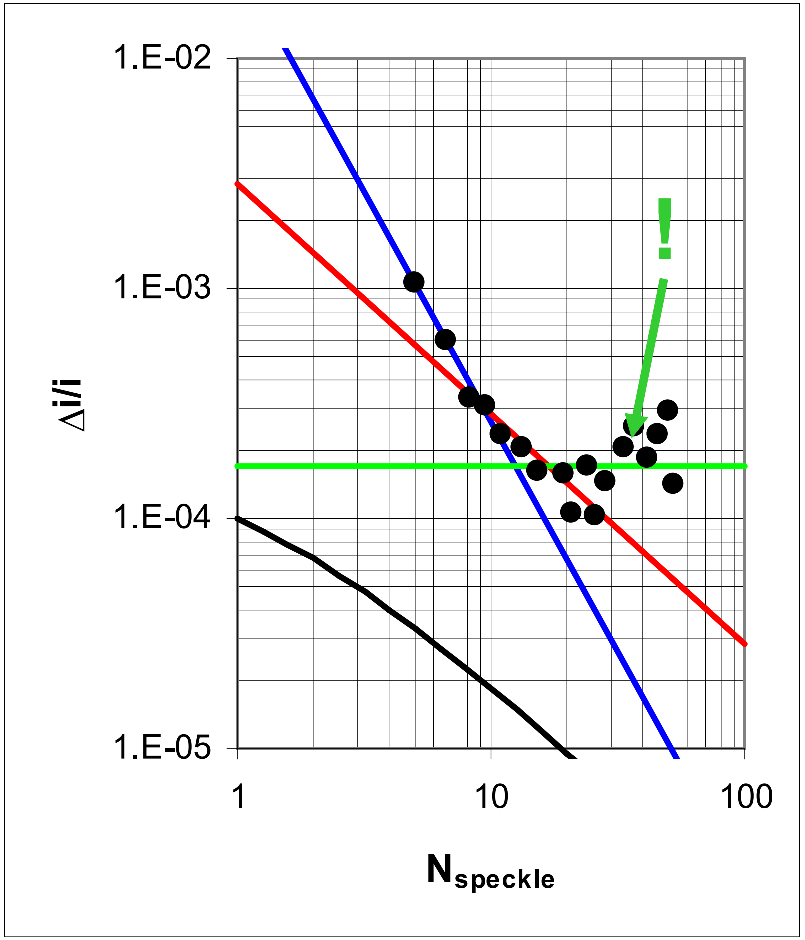
$$\frac{\Delta i_{speckle}}{i} = \sqrt{N_{speckle}} = \sqrt{\frac{2\lambda L}{Da}}$$

Two dimensions

$$\frac{\Delta i_{speckle}}{i} = \sqrt{N_{speckle}} = \frac{2\lambda L}{Da}$$

Experimental investigation of additional noise for DL based system with TR

Experimental setup

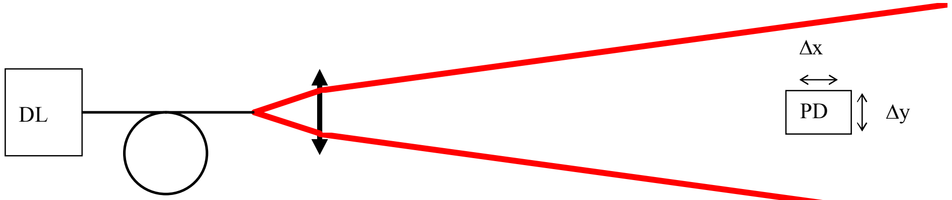


Relative photocurrent noise dependence on speckles number in receiving aperture.

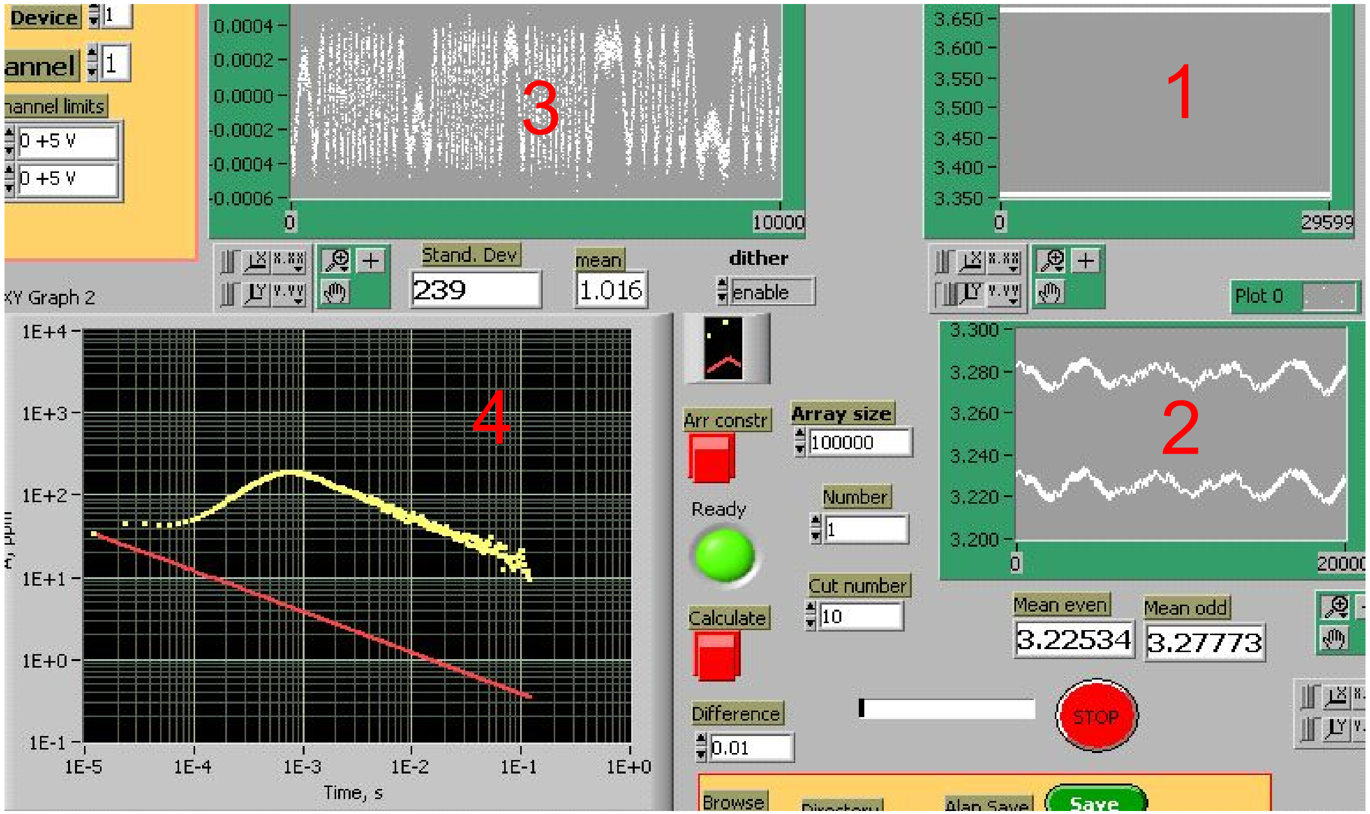
Speckle noise modeling prediction is shown by black line, blue line – thermal noise of preamplifier resistor, red line – photocurrent shot noise

Additional noise in DL based systems with TR does not depend on N. Hence, it is not due to speckle noise of DL light scattered by TR. This noise is forming on TR itself

Time dependence of additional noise



Scheme of experimental setup installed on office table. Vibration was initiated by operating ventilator



1. DL current
2. PD signal
3. Even-odd ratio
4. Allan plot

This behavior can be explained only if DL far field diagram has fine structer.

See separate poster