EXPERIMENTAL STUDY OF THE BACKSCATTERING INTENSIFICATION EFFECT AND INTENSITY FLUCTUATIONS OF A BEAM REFLECTED FROM A SPECULAR SURFACE

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We present some experimental results on studying the backscattering intensification effect and intensity fluctuations of a spherical wave reflected from a flat mirror. It is found that the increase in the average intensity of the reflected wave takes place for strong intensity fluctuations. The experimental results are compared with the theoretical calculations. It is shown that the amplification of the intensity fluctuations is consistently manifested for weak fluctuations and in passing from weak to strong intensity fluctuations.

The backscattering intensification effect in the strictly backward direction[1–3] and the amplification of relative intensity fluctuations[2,3] occur when the waves are reflected from the objects located in a randomly inhomogeneous medium. The degree to which these effects manifest depends on the level of turbulence, on diffraction characteristics of the optical wave and of the reflector, and on the relation between the transport time of optical inhomogeneities across the path and the time of their propagation in forward and backward directions.

In the turbulent atmosphere the backscattering intensification effect was observed when a spherical wave was reflected from a rough surface,[4] for a plane wave it took place in the presence of a phase screen placed near a specular surface.[5] The experimental support for the predicted intensification effect due to the reflection of a spherical wave from a specular disk[3] has not yet been obtained up to date. It should be noted that the theoretical calculations have an asymptotic character, strictly speaking, they can describe this effect sufficiently well for weak or "saturated" intensity fluctuations. Spatial localization of the effect of amplification of the intensity fluctuations has been studied for weak intensity fluctuations alone.[6]

To establish the backscattering intensification effect due to the reflection from a flat infinite specular disk, the experiments were carried out in the real atmosphere. In a randomly inhomogeneous medium one can observe both the "absolute" backscattering intensification (increase in the intensity against a medium without refractive index fluctuations) and the "relative" intensification (increase in intensity of reflection in the strictly backward direction against with the lateral reflection). Since the turbulence always occurs on the ground atmospheric paths, the quantitative study of the "relative" intensification effect can be conveniently made.

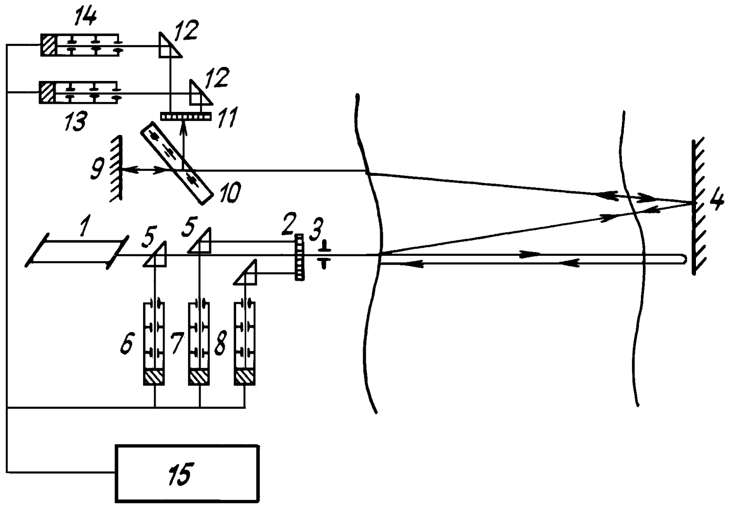

FIG. 1. Diagram showing the experimental configuration.

The experiment was carried out in summer of 1989 and 1990 on a horizontal path with an even underlying surface. The path length at the first stage in 1989 was 400 m and at the second stage in 1990 it was increased up to 800 m. Diagram of the experimental configuration is shown in Fig. 1.

The radiation of the He–Ne laser *1* at the wavelength $\lambda = 0.63$ μm with the power $P = 50$ mW was sent to the atmosphere through the aperture in the plate *2* and the shaping aperture *3*. The aperture *3* with diameter a = 1.0 mm was placed to obtain a quasispherical wave from

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the laser (the wave parameter of the source was larger than 100). After the beam has passed through the turbulent layer of the atmosphere, it falls within the reflector *4* mounted on a heavy support located at a distance $L_1 = 400$ m from a measurement pavilion. The design of the support and the holder excluded possible vibrations of the reflector caused by severe gusts and by shock oscillations of the Earth's surface. In the measurements, a high–quality flat specular disk 500 m in diameter was used as a reflector. This made it possible to complete interception of the incident beam.

The experiment was carried out with two configurations. In the first case in 1989 the beam reflected from the mirror *4* entered the receiving channel and the length L of the direct path was equal to 400 m. In the second case in 1990 a V–shaped path was exploited and the beam reflected from the mirror *4* was directed toward the mirror *9* 300 mm in diameter which was inserted in the measurement pavilion. In front of the mirror *9* the semitransparent plate *10* was placed for recording the signals needed for the calculation of the cross–correlation function $B_I(\rho)$ of the incident radiation on the direct path, where ρ is the distance between the photodetectors in a horizontal plane. To record the signals, two photodetectors *13* and *14* were placed and the distance between them being changed during the measurements. The signals for the photodetectors were shaped with the system of horizontally located diaphragms 0.8 mm in diameter, inclosed in the plate *11* spaced at a distance of 3 mm and specular prisms *12*. The distance was measured by displacing the photodetector *14*.

Both in the first and second variants the radiation reflected from the mirror *4* entered the receiving channel incorporating the plate *2*, specular prisms *5*, and the photodetectors *6*, *7*, and *8*. The plate *2* had a set of equidistantly spaced apertures 0.8 mm in diameter for receiving the signals at different distances from the optical axis of the source. The central diaphragm 2 mm in diameter was intended to transmit the radiation in the forward direction. The placed–below diaphragm shaped a signal for the fixed photodetector *6* which served as a reference one during the experiment. The diaphragms being on the right and left sides of the central diaphragm shaped signals for the photodetectors *7* and *8*. Adjustment to a specified distance from the axis was accomplished by moving the photodetectors *7* and *8* fixed on the tables with micrometer screws. To reduce the level of background illumination, the photodetectors were equipped with shields having input diaphragms. Diffusive scatterers were inserted in front of the input windows of all photodetectors to avoid possible changes in sensitivity of the moving photodetectors in the process of measurements.

Thus, when the location of the photodetectors *7*, *8*, and *12* changed, it was possible to record the signal distribution in the plane perpendicular to the direction of beam propagation as well as the signals bearing the information about the cross–correlation function of the intensity fluctuations along the direct propagation path with a discrete step of 3 mm. The minimum distance from the optical axis of the source was 3 mm and the maximum one was 21 mm. The reference receiver recorded the signal at a distance of 3 mm from the optical axis of the beam. In the experiment the PMT–79 photomultipliers were used as photodetectors.

The electric signals from the output amplifiers of the PMT were fed into the instrumentation–programmed system *15* (see Ref. 7), where, after low–frequency filtration (cutoff frequency was 2.5 kHz), they were digitized and stored on magnetic tape using a code magnetic storage elements (CMSE) with the following characteristics: dynamic range was 72 dB, discretization frequency in each channel was 4 kHz. The on–line processing of the recorded realizations with subsequent calculation of the mean value and variance in each channel was carried out during the measurements while the complete statistical analysis was performed on a stationary system under laboratory conditions. More than a hundred of 50–second and a hundred of 30–second realizations were recorded and processed during the measurements.

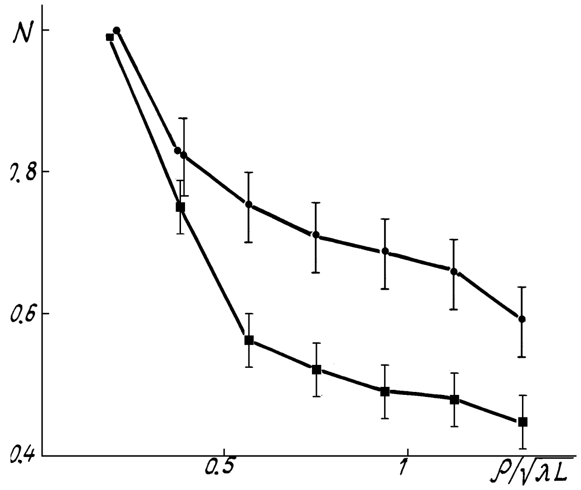

FIG. 2. Distribution of the normalized intensity $N(\rho) = I(\rho)/I_{ref}$ *in the receiving plane (dots stand for* $\beta_0 \simeq 2.0–3.5$ *and squares stand for* $\beta_0 \simeq 4.0–5.2$*).*

Simultaneously with the record on the CMSE, pressure, humidity, and temperature were measured along the path as well as the mean and fluctuational components of the wind velocity in the direction perpendicular to the propagation path with the help of an acoustic anemometer[8] located at a distance of 100 m from the measurement pavilion. In addition to the basic path, another path was exploited to determine the structure characteristic of the refractive index C_n^2 and to calculate the parameter $b_0 = [1.23\, C_n^2\, k^{7/6}(2L_2)^{11/6}]^{1/2}$ which describe the level of turbulence along the path $2L_2$, where $k = 2\pi/\lambda$ is the wave number.

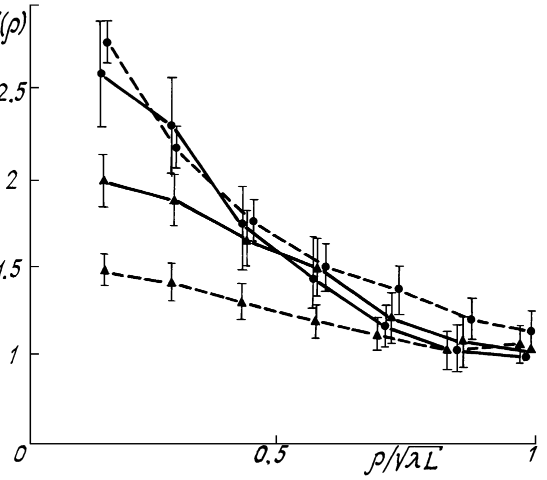

FIG. 3. Distribution of the intensification factor $N(\beta)$ *(triangles stand for* $\beta_0 \simeq 3.0–3.3$ and *dots stand for* $\beta_0 \simeq 5.4–5.7$, *dashed curves denote* $N(\rho) = \hat{B}_I(\rho) + 1$ *and solid curves denote* $N(\rho) = I(\rho)/\mathrm{I}_{\mathrm{ref}}$.

Shown in Figs. 2 and 3 are the measurements of relative amplification of the average intensity $I(\rho)$ and the intensity fluctuations $\beta^2(\rho)$ of a spherical wave for different values of the parameter β_0, where ρ is the distance between the point of reception and the optical axis of the beam in the image plane and L is the distance from the source to the reflector. The vertical segments in the figure denote the spread of experimental data points. The average intensity $I(\rho)$ and its relative variance $\beta^2(\rho)$ in the moving channels were normalized to the corresponding values of I_{ref} and β^2_{ref} in the reference channel.

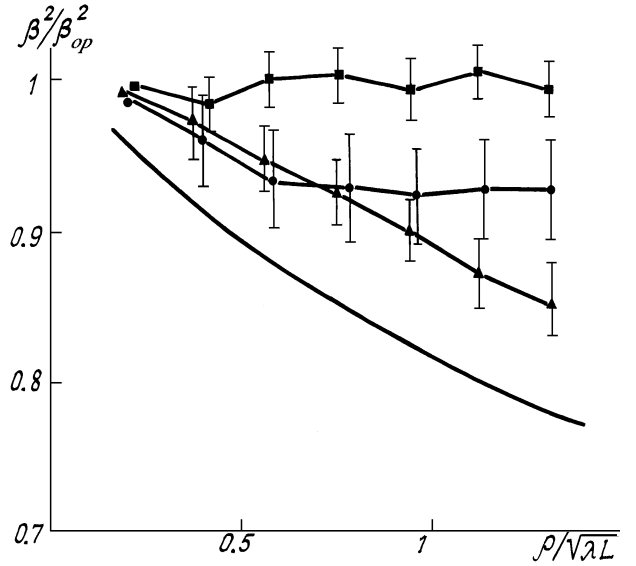

FIG. 4. Distribution of the normalized relative variance $\beta^2(\rho)/\beta^2_{\mathrm{ref}}$ *in the receiving plane (triangles stand for* $\beta_0 \simeq 0.7–1.2$, *dots stand for* $\beta_0 \simeq 2.0–3.5$, *and squares stand for* $\beta_0 \simeq 4.0–5.2$).

As can be seen from Fig. 2, the amplification factor for the average intensity $N(\rho) = I(\rho)/I_{\mathrm{ref}}$ is clearly manifested for strong fluctuations and depends on β_0. The value of $N(\rho)$ increases with increase of the level of turbulence along the path and for $\beta_0 \simeq 5.0$ the ratio $I(\rho)$ at $\rho = 3$ mm to the corresponding value of the intensity at a distance of the first Fresnel zone $\rho = (\lambda L)^{1/2}$ attains 2.5. Figure 3 shows the plots of experimental comparison for the backscattering intensification factor $N(\rho) = I(\rho)/I_{\mathrm{ref}}$ (solid curves) with the average intensity at $\rho = (\lambda L)^{1/2}$ taken as a reference value and the backscattering intensification factor which, following the theory, is described by the dependence $N(r) = \hat{B}_I(r) + 1$ (see Ref. 1), denoted by the dashed curves, where $\hat{B}_I(r)$ is the correlation function of the direct beam intensity on the reflector normalized to the average intensity on the reflector. As can be seen from the comparison of the plots, the data are in good agreement for $\beta_0 \simeq 5.4–5.7$ and agree somewhat worse for $\beta_0 \simeq 3.0–3.3$.

Shown in Fig. 4 is the distribution of the normalized relative variance of the intensity fluctuations in the image plane $\beta^2(\rho)/\beta^2_{\mathrm{ref}}(3\ \mathrm{mm})$ for different values of the parameter β_0. Solid curve shows the result of theoretical calculation by the smooth perturbation method.[6]

It can be seen from the figure that the effect of amplification of fluctuations in the case under study occurs only for weak fluctuations within the limits of the first Fresnel zone and becomes insignificant when $\beta_0 \simeq 4.0–5.2$. This result agrees well with the experimental behavior of the amplification coefficient of the intensity fluctuations $K = \beta(0)/\beta_{\mathrm{d}}(2L)$, where $\beta^2_{\mathrm{d}}(2L)$ is the relative variance of the intensity fluctuations on the direct path.

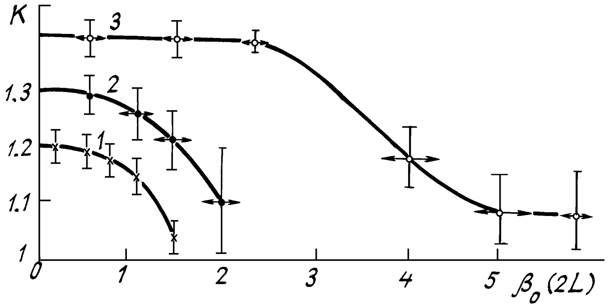

FIG. 5. The amplification coefficient of the reflected wave fluctuations $K = \beta(0)/\beta_{\mathrm{ref}}(2L)$ *vs the parameter* $\beta_0(2L)$: *1) plane wave, 2) narrow collimated beam, and 3) spherical wave.*

The results were obtained based on the measurements anologous to those performed in Ref. 6. It follows from the data that amplification of the intensity fluctuations of a spherical wave becomes weak on the path with reflection for $\beta_0 \simeq 5.0$. Thus our experiments indicated the existence of the effect of amplification of the average intensity and the intensity fluctuations due to backward reflection from a specular disk of large diameter. At the same time, the effect of amplification of the average intensity is most pronounced for strong turbulence when the parameter $\beta_0 \geq 2.0$, while the most noticeable amplification of the fluctuations takes place for weak turbulence when $\beta_0 < 1.0$.

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