TURBULENT FLUCTUATIONS OF DETECTOR PHOTOCURRENT POWER IN COHERENT LIDAR SYSTEMS

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Behavior of the relative variance of the turbulent fluctuations of detector photocurrent power is analyzed for CW and pulsed coherent lidars and different schemes of matching the wave fronts in optical heterodyning. It is shown that fluctuations of the photocurrent power occur for high spatial resolution of a single–mode heterodyne detector. The magnitude of these fluctuations is proportional to the turbulent intensity fluctuations of sounding radiation. The proportionality factor depends on the receiver field of view and decreases with its increase.

1. INTRODUCTION

The atmospheric turbulence is one of the main factors decreasing the potential of coherent lidar systems. This factor causes the amplitude and phase distortions of the optical radiation propagating through the atmosphere, resulting in the amplitude and phase fluctuations of photocurrent. By now the influence of the phase fluctuations of scattered optical radiation on the operating efficiency of coherent lidar has been much studied. For example, due to the phase fluctuations of scattered wave and the linear character of heterodyne reception, the average field vanishes, and the average photocurrent of coherent lidar correspondingly vanishes.[1] The average photocurrent power can serve as the information–bearing parameter, i.e., valid signal at reception of random optical fields. Its behavior is determined by the behavior of the second–order mutual coherence function. It was shown in Ref. 2 that degradation of coherence of scattered radiation, which depends primarily on the phase fluctuations of optical wave, resulted in the decrease of the average photocurrent power. Therefore, to measure the parameters of a medium at high efficiency, the radius of the input aperture of a receiving telescope of coherent lidar may not exceed the coherence radius typical of the wave scattered in the turbulent atmosphere. This result was widely used in the development of coherent lidar systems.[1,3]

In addition to the phase fluctuations, the intensity fluctuations of scattered radiation are a distorting factor, which strongly affects the operating efficiency of the coherent lidar. The information on the intensity fluctuations is contained in the fourth–order coherence function. This function determines the behavior of the photocurrent power fluctuations or, what is the same in our case, the fluctuations in the valid signal. In our opinion, the turbulent fluctuations in the valid signal have still received only insufficient study, and the intensity fluctuations of scattered radiation are ignored in the development of the heterodyne lidar systems.[1,3] Only the experimental evidence that these fluctuations depend strongly on the atmospheric turbulence on the path "lidar–scattering volume" were reported in Ref. 4. The lack of theoretical results in this area as well as incidentally of the comprehensive experimental study makes the solution of two problems difficult. The first problem is to interpret the lidar sounding data. When measuring the atmospheric parameters, the turbulent fluctuations in the valid signal are the source of errors. Hence, the study of turbulent fluctuations in the valid signal will allow us to estimate the measurement error and to choose proper experimental conditions. The second problem is remote sensing of the parameters of atmospheric turbulence. The fluctuations in the valid signal may be considered as the useful information about physical processes on a sounded path. Thus relationships connecting the state of the medium and fluctuations in the valid signal will allow us to measure the parameters of atmospheric turbulence.

The present paper is devoted to the study of the behavior of the relative variance of the photocurrent power turbulent fluctuations of CW and pulsed coherent lidars for different schemes of wave front matching. The single–mode and multimode regimes of detection, most often used in practice for optical heterodyning, are considered.[1]

2. MATHEMATICAL MODEL OF PHOTOCURRENT OF COHERENT LIDARS

Figure 1 depicts the scheme of wave front matching for optical heterodyning in coherent lidar systems. In the single–mode detection regime (Fig. 1*a*) the scattered radiation field $u_s(\mathbf{r}, t)$ and the reference heterodyne field $u_r(\mathbf{r})$ are focused onto the photodetector sensitive element with one lens.[1] The photocurrent complex amplitude is given by the formula

$$j_c = \eta \int M(\mathbf{r})\, u_r^*(\mathbf{r})\, u_s(\mathbf{r}, t)\, dS , \qquad (1)$$

where η is the photodetector sensitivity, $M(\mathbf{r})$ is the amplitude transfer function of the receiving telescope, and dS is an element of its area.

In the multimode detection regime (Fig. 1*b*) the scattered radiation field is focused with the lens onto the photodetector, and the reference laser heterodyne field is incident on the photodetector through the mixing plate bypassing the lens.[1] The multimode detection regime is known as heterodyning by the Airy disk technique. An expression for the photocurrent complex amplitude, analogous to Eq. (1), has the form

$$j_c = \eta \int M(\mathbf{r})\, u_r^*(\mathbf{r})\, u_s(\mathbf{r}, t) \exp\left(-\frac{i\kappa\mathbf{r}^2}{2F}\right) dS , \qquad (2)$$

where F is the focal distance of the receiving telescope.

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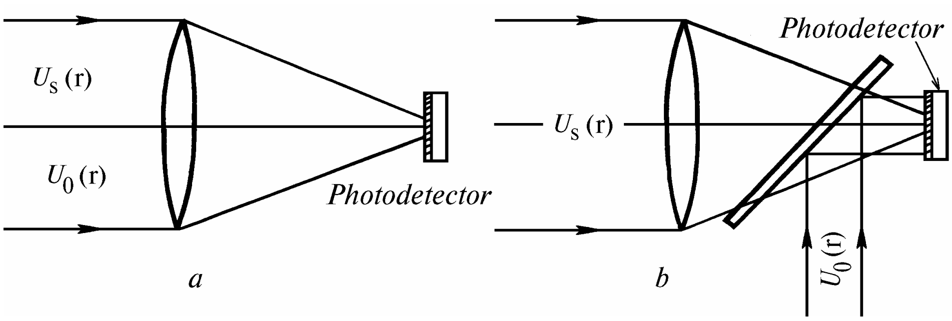

FIG. 1.

It is clear from Eqs. (1) and (2) that the photocurrent complex amplitudes differ in the exponential factor entering into the integrand. It leads to the different physical properties of heterodyne receivers.

It is known[1] that for best matching in heterodyne reception of the optical radiation backscattered by an ensemble of particles, a spherical wave with the wave front radius being equal to that of the regular component of incident radiation

$$u_r(\mathbf{r}) = u_r \exp\left(-\frac{i\kappa\mathbf{r}^2}{2z} + i\kappa\mathbf{n}_0\,\mathbf{r}\right), \quad (3)$$

must be used as a reference heterodyne field, where u_r is the amplitude, z is the path length, and $\mathbf{n}_0$ is the unit vector specifying the direction of arrival of the reference wave.

We will use in the further investigations the expressions for the field of optical radiation backscattered in the turbulent atmosphere with the discrete disseminations, which were obtained in Ref. 5

$$u_s(\mathbf{r}, t) = 2i\kappa \sum_{m=1}^{N} A_m\, G_t(\mathbf{r}, \mathbf{r}_m)\, u_{it}^p\left(\mathbf{r}_m, t - \frac{1}{c}\,|\mathbf{r} - \mathbf{r}_m|\right), \quad (4)$$

$$u_{it}^p(\mathbf{r}_m, t) = 2i\kappa \int \beta\left(t - \frac{1}{c}\,|\mathbf{r}_m - \mathbf{r}|\right) G_t(\mathbf{r}_m, \mathbf{r})\, u_{0i}(\mathbf{r})\, ds, \quad (5)$$

where $G_t(\mathbf{r}_m, \mathbf{r})$ is the Green's function for the turbulent medium, A_m is the scattering amplitude of an individual particle, $\mathbf{r}_m$ is the mth–particle coordinate, N is the total number of particles, $\beta(t)$ specifies the shape of sounding pulses, $u_{0i}(\mathbf{r})$ describes the initial distribution of the source field, and ds is the element of source area. Formulas (4) and (5) are valid for the CW optical radiation, when $\beta(t) = \mathrm{const}$, and for the pulsed radiation, when $\beta(t) \neq \mathrm{const}$ and pulse duration 10^{-2} s $\ll \tau_p \ll 10^{-1}$±10^{-3} s (see Ref. 5).

Equations (1)–(5) are starting relations used to calculate the relative variance of the turbulent fluctuations in photocurrent power for the CW and pulsed coherent lidars. It is assumed in the paper that in the case of CW coherent lidar the length of a scattering volume is determined by the length of the volume in which particles are localized (the typical dimensions of particle cloud, smoke plume, etc.). When receiving the scattered pulsed radiation, the longitudinal dimensions of the scattering volume are determined by the pulse duration, and the particles are not localized in space.

3. TURBULENT FLUCTUATIONS OF PHOTOCURRENT POWER

Let us define the relative variance of the fluctuations of photocurrent power for two cases which can be experimentally realized. In the first case the heterodyne receiver measures the coherent and incoherent components of the intensity fluctuations of scattered radiation field. In this case the relative variance of the photocurrent power fluctuations is determined by the expression

$$\sigma^2 = \frac{\langle\, \overline{|j_c|^4}\,\rangle}{\langle\, \overline{|j_c|^2}\,\rangle^2} - 1\,. \quad (6)$$

Here the bar atop denotes an ensemble averaging, and the angular brackets denote an averaging over the turbulent fluctuations of the refractive index. In the second case, the heterodyne receiver measures only the incoherent component of the intensity fluctuations of scattered radiation field. The relative variance of the incoherent fluctuations of photocurrent power takes the form

$$\sigma_{ic}^2 = \frac{\langle\, \overline{|j_c|^2}^{\,2}\,\rangle}{\langle\, \overline{|j_c|^2}\,\rangle^2} - 1\,. \quad (7)$$

It is clear from Eqs. (6) and (7) that these definitions differ by the order of averaging of the observed quantity and correspond to different experimental conditions.[4] In the first case the photocurrent power fluctuations contain the intensity fluctuations of scattered radiation field caused by the particle ensemble and turbulent medium. In the second case the photocurrent power fluctuations contain only the turbulent intensity fluctuations of incident field, whereas the receiver does not measure the intensity fluctuations occurring due to the particle ensemble.

When receiving the scattered pulsed radiation, the photocurrent of the coherent lidar is the photocurrent pulse train. The turbulent medium is the reason of distortions in the coherent lidar photocurrent. If the pulse repetition period obeys the condition 10^{-12} s $\ll \tau_r \ll 10^{-1}$–10^{-3} s and the pulse duration varies in the interval 10^{-12} s $\ll \tau_p \ll 10^{-1}$–10^{-3} s, only the envelope of pulse train is randomly distorted. It is this case which is considered when the scattered pulsed radiation is received. Thus the relative variances of the fluctuations in photocurrent power determined by Eqs. (6) and (7) characterize the actual turbulent fluctuations of the envelope of the photocurrent pulse train.

The relative variance of the photocurrent power fluctuations is expressed in terms of the second–order mutual coherence function

$$\Gamma_{2s}(\mathbf{r}_1, \mathbf{r}_2; t) = < \overline{u_s(\mathbf{r}_1, t)\, u_s^*(\mathbf{r}_2, t)} >$$

and of the fourth–order mutual coherence function

$$\Gamma_{4s}(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3, \mathbf{r}_4; t) = < \overline{u_s(\mathbf{r}_1, t)\, u_s^*(\mathbf{r}_2, t)\, u_s(\mathbf{r}_3, t)\, u_s^*(\mathbf{r}_4, t)} >$$

by the following formulas:

$$< \overline{|j_c|^2} > = \eta^2 \int M(\mathbf{r}_1)\, M^*(\mathbf{r}_2)\, u_r^*(\mathbf{r}_1)\, u_r(\mathbf{r}_2) \times$$

$$\times\, \Gamma_{2s}(\mathbf{r}_1, \mathbf{r}_2; t)\, dS_1\, dS_2 , \quad (8)$$

$$< \overline{|j_c|^4} > = \eta^4 \int M(\mathbf{r}_1)\, M^*(\mathbf{r}_2)\, M(\mathbf{r}_3)\, M^*(\mathbf{r}_4)\, u_r^*(\mathbf{r}_1)\, u_r(\mathbf{r}_2) \times$$

$$\times\, u_r^*(\mathbf{r}_3)\, u_r(\mathbf{r}_4)\, \Gamma_{4s}(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3, \mathbf{r}_4; t)\, dS_1\, dS_2\, dS_3\, dS_4 , \quad (9)$$

in the single–mode detection regime, and by the formulas

$$< \overline{|j_c|^2} > = \eta^2 \int M(\mathbf{r}_1)\, M^*(\mathbf{r}_2)\, u_r^*(\mathbf{r}_1)\, u_r(\mathbf{r}_2) \times$$

$$\times \exp\left[-\frac{i\kappa}{2F}\left(\mathbf{r}_1^2 - \mathbf{r}_2^2\right)\right] \Gamma_{2s}(\mathbf{r}_1, \mathbf{r}_2; t)\, dS_1\, dS_2 , \quad (10)$$

$$< \overline{|j_c|^4} > = \eta^4 \int M(\mathbf{r}_1)\, M^*(\mathbf{r}_2)\, M(\mathbf{r}_3)\, M^*(\mathbf{r}_4)\, u_r^*(\mathbf{r}_1)\, u_r(\mathbf{r}_2) \times$$

$$\times\, u_r^*(\mathbf{r}_3)\, u_r(\mathbf{r}_4) \exp\left[-\frac{i\kappa}{2F}\left(\mathbf{r}_1^2 - \mathbf{r}_2^2 + \mathbf{r}_3^2 - \mathbf{r}_4^2\right)\right] \times$$

$$\times\, \Gamma_{4s}(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3, \mathbf{r}_4; t)\, dS_1\, dS_2\, dS_3\, dS_4 \quad (11)$$

for heterodyning by the Airy disk technique. The relative variance of the incoherent photocurrent power fluctuations is determined in terms of the second–order mutual coherence function and incoherent component of the fourth–order mutual coherence function

$$\Gamma_{4s}^{ic}(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3, \mathbf{r}_4; t) = < \overline{u_s(\mathbf{r}_1, t)\, u_s^*(\mathbf{r}_2, t)\, u_s(\mathbf{r}_3, t)\, u_s^*(\mathbf{r}_4, t)} >$$

by the relationship which is derived from Eqs. (8)–(10) after the substitution

$$\Gamma_{4s}(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3, \mathbf{r}_4; t) \to \Gamma_{4s}^{ic}(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3, \mathbf{r}_4; t) .$$

The mutual coherence functions of the second and fourth orders and the incoherent component of the fourth–order coherence function were calculated by the independent averaging over the ensemble of particles and over the turbulent fluctuations of the refractive index. It is necessary to know the probability distribution laws for the turbulent fluctuations of the refractive index as well as for the random coordinates $\mathbf{r}_m$. The refractive index turbulent fluctuations were assumed to be the Markovian δ – correlated Gaussian random process with zero mean.[6] Due to the incoherent scattering of optical radiation by the ensemble of particles, the single–particle $W_1(\mathbf{r}_m)$ and the binary $W_2(\mathbf{r}_m, \mathbf{r}_n)$ probability densities are needed for the calculations. These densities were determined in the present paper by the following way:

$$W_1(\mathbf{r}_m) = 1/V , \quad (12)$$

$$W_2(\mathbf{r}_m, \mathbf{r}_n) = W_1(\mathbf{r}_m)\, W_1(\mathbf{r}_n) , \quad (13)$$

where V is the volume which contains the particles.

When the above–enumerated constraints are imposed and $N \gg 1$, the averaging operations in Eq. (6) yield the following relation between the relative variance of the photocurrent power fluctuations and the relative variance of the incoherent fluctuations of this power:

$$\sigma^2 = 1 + 2\sigma_{ic}^2 . \quad (14)$$

It is clear from Eq. (14) that the relative variance of the photocurrent power fluctuations is the sum of two terms. The first term describes the fluctuations in the output signal in the absence of the random pulsations of the refractive index on the sounded path. The second term describes the turbulent fluctuations of the output signal.

In calculating the relative variance σ_{ic}^2 it was additionally assumed that the size of the illuminated spot is smaller than the transverse dimensions of the scattering volume V, the longitudinal dimensions of this volume are smaller than the path length z, and the turbulence on the sounded path is weak. The relative variance of the incoherent fluctuations in the photocurrent power for perfect matching of wave fronts of reference heterodyne and scattered radiation and the amplitude transmission function of the receiving telescope of the form $M(r) = M_0 \exp(-2r^2/R^2)$ takes the form

$$\sigma_{ic}^2 = \frac{1}{2\pi(\varphi/\varphi_0)^2} \int \exp\left(-\frac{r^2}{2(\varphi/\varphi_0)^2}\right) B_I(\rho_I\, r; z)\, d^2r , \quad (15)$$

where $B_I(r; z)$ is the correlation function of the intensity fluctuations of sounding radiation, ρ_I is the correlation length of these fluctuations, φ is the field–of–view angle of the heterodyne receiver, $\varphi_0 = \rho_I/z$ is the angular size of dark or bright spot in the speckle pattern formed in the scattering volume due to the random pulsations of the refractive index on the sounded path of length z, M_0 is the amplitude factor, and R is the receiving aperture radius.

For further consideration it is useful to introduce a function characterizing the effect of averaging over the aperture of the receiving telescope

$$G(\varphi) = \sigma_{ic}^2(\varphi) \,/\, \sigma_{ic}^2(0) . \quad (16)$$

This function shows how many times the relative incoherent fluctuations of photocurrent power of the coherent lidar with the finite field of view are weaker than these fluctuations in the receiver with δ–shaped directional pattern.

Let us write down the following asymptotic expressions for the aperture averaging of the receiving telescope when the spectral power density of turbulent fluctuations of the refractive index obeys the two–thirds law[6] for a wide collimated beam ($\Omega_D \gg 1$):

$$G(\varphi)=\begin{cases}1+6.28(\varphi/\varphi_0)^2-12.6(\varphi/\varphi_0)^{5/3}+o\big((\varphi/\varphi_0)^2\big)\,, & \varphi\ll\varphi_0\,,\\ 0.0728(\varphi/\varphi_0)^{7/3}+o\big((\varphi/\varphi_0)^{7/3}\big)\,, & \varphi\gg\varphi_0\end{cases} \quad (17)$$

and for a quasispherical wave ($\Omega_D \ll 1$)

$$G(\varphi)=\begin{cases}1+2.94(\varphi/\varphi_0)^2-6.06(\varphi/\varphi_0)^{5/3}+o\big((\varphi/\varphi_0)^2\big)\,, & \varphi\ll\varphi_0\,,\\ 0.204(\varphi/\varphi_0)^{7/3}+o\big((\varphi/\varphi_0)^{7/3}\big)\,, & \varphi\gg\varphi_0\,.\end{cases} \quad (18)$$

In Eqs. (17) and (18) $\varphi_0 = \sqrt{z/\kappa}/z$ and $\Omega_D = \kappa D^2/z$ is the Fresnel number of the radiating aperture. Figure 2 shows the results of numerical calculation of the receiving telescope averaging factor $G(\varphi)$ for the spectral power density of the refractive index turbulent fluctuations which obey the two–thirds law.[6] Curve *1* corresponds to a quasispherical wave, curve *2* corresponds to a wide collimated beam.

It is clear from Eqs. (14)–(18) as well as from Fig. 2 that the fluctuations of coherent lidar photocurrent power are determined solely by the intensity fluctuations of the sounding radiation and occur when the spatial resolution of the receiver is high. The turbulent intensity fluctuations occurring in the process of optical wave propagation from the scattering volume to the receiver as well as the correlation between the intensities of forward and backward waves are averaged over the volume V. When the coherent lidar with δ–shaped directional pattern is used, the relative variance of photocurrent power incoherent fluctuations is equal to the relative variance of sounding radiation intensity fluctuations, i.e., $\sigma^2_{\text{ic}}(0) = \sigma^2_I$. When the field of view of coherent lidar increases, these photocurrent fluctuations are partially averaged, and the relative variance of incoherent photocurrent power fluctuations becomes proportional to the relative variance of sounding radiation intensity fluctuations: $\sigma^2_{\text{ic}}(\varphi) = G(\varphi)\,\sigma^2_I$. Thus the coherent lidar wth sufficiently high spatial resolution can be used to measure the intensity fluctuations of sounding radiation. Recall that for the two–thirds law the relative variance of sounding radiation intensity fluctuations in the case of a quasispherical wave is $\sigma^2_I = 0.492 C^2_n\, \kappa^{7/6}\, z^{11/6}$ and for a wide collimated beam $\sigma^2_I = 1.23 C^2_n\, \kappa^{7/6}\, z^{11/6}$, where C^2_n is the structure constant of the refractive index fluctuations.[6]

This phenomena can be interpreted physically in the following way. The sounding radiation propagates through a layer of the turbulent atmosphere and produces the speckle pattern in the form of a system of dark and light spots in the scattering volume. Typical angular size of such spots is equal to φ_0. Therefore, the power fluctuations of photocurrent of the heterodyne receiver occur when the receiving system resolves one dark or bright spot. As φ increases, a great number of dark and bright spots fall within the field of view of heterodyne receiver resulting in averaging of the turbulent fluctuations in the square modulus of complex coherent component of the net energy flux.

In the single–mode detection regime the field–of–view angle of coherent lidar is determined by the formula $\varphi = 1/\kappa R$, and the angular size of the dark or bright spot is $\varphi_0 = \sqrt{z/\kappa}/z$ given that the spectral power density of the turbulent fluctuations of the refractive index obeys the two–thirds law. Hence the condition of occurrence of the turbulent fluctuations of photocurrent power for the given regime has the form $\kappa R^2/z \gg 1$. Thus the power fluctuations of photocurrent in coherent lidar for the single–mode detection regime occur solely in the near diffraction zone of the receiver.

The condition of occurrence of turbulent fluctuations in photocurrent power for the single–mode detection regime differs from the analogous conditions in the problem of averaging over the receiving aperture of a square–law photodetector when recording the optical radiation which has passed the path once,[6] and in the problem of averaging over the field–of–view diaphragm of a lidar with incoherent signal detection.[7] As follows from Refs. 6 and 7, the photocurrent fluctuations occur as the photodetector receiving aperture decreases (in the case of recording of the optical radiation which has passed the path once) and as the diameter of the field diaphragm of the lidar with incoherent signal detection decreases, while the fluctuations of the received field are smoothed out when these parameters increase. For the coherent lidar the turbulent fluctuations in photocurrent power occur as the aperture of the receiving telescope increases while the fluctuations in the intensity of received field are smoothed out when the aperture decreases. At first glance, this contradicts conventional notion of the aperture effect. For example, the mechanisms of occurrence of turbulent fluctuations of the photocurrent power in coherent lidar and in lidar with incoherent signal detection are determined by the inequality $\varphi \ll \varphi_0$. For the coherent lidar $\varphi \sim 1/R$, while for the lidar with incoherent signal detection the field–of–view angle is proportional to the radius of the field diaphragm. Thus the reverse dependences of the field of view on the radii of the receiving aperture of coherent lidar and of the field diaphragm of lidar with incoherent signal detection eliminate this paradox.

In heterodyning by the Airy disk technique, the receiver field–of–view angle is $\varphi = R/F$. The condition of occurrence of the turbulent fluctuations $\varphi \ll \varphi_0$ can be written in the form $\kappa R^2/F \ll F/z$. Taking into account that the technique is effective when the relationship $\kappa R^2 \gg F$ is fulfilled, we come to a conclusion that the multimode detection regime should be insensitive to the turbulent conditions of propagation on the sounding path $z \gg F$.

4. CONCLUSION

Let us compare the obtained results with the experimental data published in Ref. 4. The experiment was performed with the input aperture radius $R = 2.8$ cm, the path length $z = 1.06$ km, and $\kappa = 6\cdot 10^5$ m^{-1}. The authors of Ref. 4 measured the degree of random modulation of heterodyne receiver photocurrent within the limits 18–52%.

It follows from Eqs. (14)–(18) that the fluctuations of the output signal power of heterodyne receiver depend on the turbulent conditions on the sounding path. The theoretical estimate of the degree of random modulation of photocurrent obtained on the basis of Eqs. (14)–(18) with the use of Fig. 2 yields 0–50%. All these show the good agreement between theory and experiment. Unfortunately, the behavior of photocurrent turbulent fluctuations of the CW and pulsed heterodyne lidars has still received only insufficient experimental study; therefore, a comparison in more detail is impossible at present.

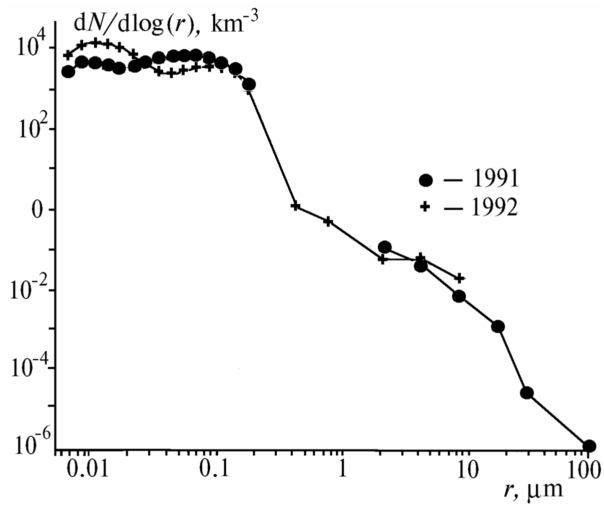

FIG. 2.

The result obtained in the paper can be applied to the solution of the problems arising in the use of coherent lidar system in practice. In sounding of the atmospheric parameters the measurement error will be determined by the relative variance of the output signal turbulent fluctuations among other factors. In heterodyning by the Airy disk technique the measurement error is not pronounced on the real paths ($z \gg F$). For the single–mode detection regime the degree of random modulation of photocurrent of the order of 50% and more can be observed on the paths shorter than 10 and 300 km for receiving aperture radii of 7.5 and 50 cm, respectively. The given parameters are considered to be optimal for the coherent lidar system intended for ground paths and for sounding from space.[4] These radii correspond to the spatial resolution of coherent lidars $\varphi = 2{\cdot}10^{-5}$ and $\varphi = 3{\cdot}10^{-6}$. Thus in sounding of the atmospheric parameters with high spatial resolution the measurement error arises which can influence essentially the accuracy of the measurable parameters.

We note that the condition of absence of photocurrent power turbulent fluctuations $\kappa R^2/z \ll 1$ or $R \ll \sqrt{z/\kappa}$ is more stringent in practice than the condition of degradation of scattered optical radiation coherence $R \ll \rho_c$. Here ρ_c is the coherence radius of the scattered optical radiation. Consequently, in the cases in which the photocurrent power turbulent fluctuations affect strongly the measurement error, the input aperture radii should be chosen smaller than those which are widely used in the development of coherent lidar system.[1,3]

Let us discuss the results obtained in the present paper as applied to the problem of developing the techniques for sounding of the parameters of atmospheric turbulence based on measurement of scattered field intensity fluctuations. The results show that the problem is reduced to the development of coherent lidar with high spatial resolution. It is possible only in the single–mode detection regime. The techniques using the coherent lidar are the most promising means of sounding of the parameters of the atmospheric turbulence as compared with the techniques based on the measurement of the scattered field intensity fluctuations harnessing incoherent detection.[7] Indeed, even for the input aperture of the receiving telescope $R = 2.8$ cm the spatial resolution of lidar is sufficient to measure the degree of random modulation of the order of 50% on the path of length $z = 1.06$ km. Further increase of the sounding range is obtained by increasing the input aperture. It is possible up to $R = 7.5$ cm for the coherent lidar systems intended for the ground paths and up to $R = 50$ cm for sounding from space without a considerable decrease of the signal–to–noise ratio. A specific feature peculiar to pulsed coherent lidar systems is that the pulse repetition period must satisfy the condition 10^{-12} s $\ll \tau_r \ll 10^{-1}$–10^{-3} s. At present the solution of the problem on the development of coherent lidar system is in an advanced stage. Therefore, going to the development of coherent techniques for sounding of the parameters of atmospheric turbulence from measurement of the scattered field intensity fluctuations should present no engineering problems.

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