THE INFLUENCE OF AN OPTICAL RECEIVING SYSTEM ON STATISTICAL CHARACTERISTICS OF A LIDAR SIGNAL

V.E. Zuev, V.A. Banakh, V.L. Mironov
The Institute of Atmospheric Optics, Siberian
Branch, USSR Academy of Sciences, Tomsk, 634055
U S S R

The effects connected with correlation of direct and backward waves propagating through the same randomly inhomogeneous media can be observed along the paths with reflection in a turbulent atmosphere[1-3]. In particular, the mean intensity of the reflected wave can increase in comparison with the wave propagating in the forward direction at a doubled distance; the intensity fluctuations can become stronger and so on. These effects depend on the strength of optical turbulence β_o^2 ($\beta_o^2 = 1.23 C_n^2 k^{7/6} \ell^{11/6}$, C_n^2 is the structure characteristics of the index of air refraction, k is the wave number, ℓ is the path length), as well as on the diffraction sizes $\Omega = ka^2/\ell$, $\Omega_{\chi} = ka_{\chi}^2/\ell$ of the exit apertures of the source $2a$ and of the reflector $2a_{\chi}$, respectively.

However, as shown in Refs.[4-6] the focusing of radiation reflected with a receiving telescope leads, in some cases, to the fact that the dependence of amplification effects on the parameters Ω and Ω_{χ} becomes essentially different. This should be taken into account when analyzing the lidar signals.

1. The Effect of Backscattering Amplification

The following relation[2,3] is fulfilled

$$\langle I^R(x_o,\vec{e})\rangle = \frac{|U_o|^2}{(k\ell)^4} \left(1 + B_{I,S}(x,\vec{e})\right) \tag{1}$$

for a mean spherical-wave intensity scattered by a "point" reflector. Here $\langle I^R(x_o,\vec{e})\rangle$ is the distribution of the reflected wave mean intensity in the plane of the source exit aperture $x' = x_o$, U_o is the initial wave's amplitude, $B_{I,S}(x,\vec{e})$ is the normalized correlation function of the spherical-wave intensity in the reflector's plane $x' = x$.

It follows from Eq.(1) that in the strictly backward direction ($\vec{r} = 0$) there is amplification of the mean intensity by the value determined by variance of the direct spherical wave intensity $\sigma_{I,S}^2 = B_{I,S}(x,0)$. In the region of weak fluctuations, when the parameter $\beta_o^2 < 1$, $\sigma_{I,S}^2 = 0.4\beta_c^2$ and $\langle I^R(x_o,0)\rangle$ increases by the value $(|U_o|^2/(k\ell)^4) \cdot 0.4\beta_o^2$ [1] in comparison with propagation in a homogeneous medium.

If, however, the spherical wave after reflection is received with a telescope, then, at sufficiently large sizes of the objective ($\Omega_{\chi} = ka_{\chi}^2/\ell \gtrsim 0.1$), the mean intensity amplification effect $\langle I^R(\ell,\vec{\rho})\rangle$ is weakened, as the observation plane ℓ approaches the plane ℓ^* of the sharp receiving-lens image[6]. In the plane ℓ^* it fully disappears.

In the region of strong fluctuations $(\beta_0^2 \gg 1)\, \sigma_{I,s}^2 = 1 + 2.7\beta_0^{-4/5}$ and, hence, at a telescope entrance, the reflected spherical wave intensity ($\Omega \ll \beta_c^{-12/5}$) increases by a factor of more than two in the direction $\vec{r} = 0$. If the reflector is irradiated by a source with the aperture $\Omega \gg \beta_c^{-12/5}$, then the amplification of mean intensity at a telescope entrance is small. It is determined by the value of asymptotically small terms of the order of $\beta_c^{-4/5}$.

It follows from the asymptotical expression for the function of the second-order mutual coherence of the reflected-wave field $\Gamma_2^R(x_0,\vec{\ell},\vec{\rho})\, (\langle I^R(x_0,\vec{\ell})\rangle = \Gamma_2^R(x_0,\vec{\ell},0))$ at $\beta_0^2 \gg 1$ [1,6] that, when $\Omega \gg \beta_0^{-12/5}$, not only the term $O(\beta_0^{-4/5})$ but also the term of higher order of smallness $O(\beta_0^{-12/5})$ is responsible for the correlation of direct and reflected waves. It describes the so-called "far correlations" of the reflected field [1] and has a significant (of the order of $\sqrt{L/k}\,\beta_0^{6/5}$) scale of decrease in the plane transverse to the direction of propagation. This circumstance allows the effective focusing of the reflected radiation to be made if the sizes $2a_\ell$ of the receiving lens satisfy the condition $\Omega_\ell \gg \beta_0^{-12/5}$. Really, in the focus of such a lens the mean intensity increases by a factor of more than two in comparison with the intensity of the wave propagating along the path of a doubled length [1,4].

Thus, if in the plane of the entrance telescope lens there is no mean intensity amplification at $\beta_0^2 \gg 1$, $\Omega \gg \beta_0^{-12/5}$, then in the lens focus such an amplification arises. However, focusing of a spherical wave reflected with a lens with sizes $\Omega_\ell \gg \beta_0^{-12/5}$ at $\beta_0^2 \gg 1$ results in the fact that the larger than doubled mean intensity increase occurring at a telescope entrance disappears in the plane of sharp image of the receiving lens [6] just in the same way as at weak fluctuations.

2. Amplification of Intensity Fluctuations

As shown in [2,3], the significant amplification of strong ($\beta_0^2 \gg 1$) intensity fluctuations occurs only when scattering is on a point scatterer ($\Omega_\ell \ll \beta_0^{-12/5}$). In this case the saturation level of relative variance of the reflected radiation intensity is five, if the reference wave is spherical, and three if it is plane ($\Omega \gg \beta_0^{12/5}$). When the reflectors have the sizes $\Omega_\ell \gg \beta_0^{-12/5}$, the increase of the relative intensity variance is observed in the asymptotically small terms $O(\beta_0^{-4/5})$ only, and the saturation level $\sigma_{I,R}^2$ equals unit as in the case of direct propagation [2,3].

The focusing of reflected radiation with the telescope results in variation of the value of intensity fluctuations. In particular, the saturation level of the plane-wave intensity fluctuations scattered with a point reflector increases from the value $\sigma_{I,R}^2 = 3$ at a telescope entrance to the value $\sigma_{I,F}^2 = 5$ in a focal plane [4,5].

It should be noted that if a spherical-wave field is

focused after reflection, then the saturation level of the relative intensity variance in the lens focus turns out to be lower than that in the plane of the lens itself [4,5].

These variations, however, are of local character. When the observation plane is displaced from a focus along the optical-system axis ($\ell \neq F_\ell$), the relative variance of the reflected radiation intensity takes again the same values as in the entrance-lens plane [5].

References

1. Yu.A.Kravtsov, A.I.Saichev. - Usp.Fiz.Nauk, 1982, v.237, ed. 3, p.501-527.
2. Signals and Noises in Laser Sounding /Orlov V.M. et al. Moscow, Radio i Svyaz, 1985.
3. V.P.Aksenov, V.A.Banakh, V.L.Mironov. - J.Opt.Soc. Am. A, 1984, vol.1, N3, p.263-274.
4. V.P.Aksernov, V.A.Banakh, V.M.Buldakov et al.- Optics Letters, 1984, vol.10, N4, p.107-109.
5. V.P.Aksernov, V.A.Banakh, V.M.Buldakov et al. - Kvant. Elektron., 1985, v.12, N10, p.2136-2140.
6. V.A.Banakh, V.L.Mironov, I.N.Smalikho. - In: VII All-Union Symposium on Laser and Acoustic Sounding of the Atmosphere. Abstracts of Papers, Part I, Tomsk,1984, p.41-44.