NUMERICAL SIMULATION OF PHASE CHARACTERISTICS OF THE REFLECTED WAVES IN THE ATMOSPHERE

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We simulate numerically the propagation of waves reflected from a specular object of finite size through the turbulent atmosphere. Phase fluctuations of a Gaussian beam are analyzed, concentrating attention on the effects of amplification of phase fluctuations.

Studying amplitude and phase characteristics of the reflected waves is an important problem because of the necessity, first, to solve applied problems, such as the problems in adaptive optics, and, second, to study the physics of interaction of the propagating radiation with the inhomogeneous medium.

The adaptive systems which are based on the reciprocity principle and which receive the waves reflected from an object or from a special wave reflector, use optical feedback. In particular, the phase conjugate systems control the transmitting system by measuring the phase of such a reflected wave. Thus, it is necessary to study the phase characteristics of the wave, which has passed twice one and the same atmospheric path in the forward and backward directions, in order to design such adaptive systems for atmospheric optics.

Among the theoretical approaches to such problems, numerical simulation of wave propagation through the inhomogeneous media starts to play an important role in addition to the analytic methods. On a supercomputer one may study those ranges of variability of the parameters of atmospheric turbulence, which are hardly available to the analytic techniques, as well as take into account the finite physical size of the reflectors, vary within wide limits the function of illumination of the object, its reflectivity, etc.

Previous theoretical publications devoted to the phase characteristics of the reflected waves were based on the smooth perturbation method and the Huygens–Kirchhoff method.[1,2] Here we present the results of numerical simulation of wave propagation through the turbulent atmosphere given that the wave is reflected from a specular reflector of finite size.

The equation of quasioptics for a scalar monochromatic wave can be written as

$$\frac{\partial U}{\partial Z}=\frac{1}{2}\left[\frac{\partial^2}{\partial X^2}+\frac{\partial^2}{\partial Y^2}+k^2 n\right]U,$$

where n are the fluctuations of the field of refractive index. It was solved by modified splitting method employing the FFT mixed–radix algorithm. The field of the reflected wave was found from the solution of this equation with the opposite sign of z, and with the boundary conditions that take into account the reflection function. Fluctuations of the refractive index of the medium were generated on a computer as a sequence of two–dimensional phase screens, with their spectral density being the power–law function, δ-correlated over z.

Amplitude–phase characteristics of the direct and the reflected waves, particularly the transverse distribution of the average intensity, of the variance of the intensity fluctuations, and of the structural function of a phase were studied by the statistical simulation method averaging these parameters over realizations of the solution of the dynamic part of the problem. The number of such realizations was varied from 30 to 120 depending on the intensity of fluctuations.

The main goal of these computations was to study the fluctuational characteristics of phase of a Gaussian beam, first of all, the effect of amplification of phase fluctuations on the path with reflection. The calculated characteristic is the structural characteristic of phase, calculated both in the plane of the reflector and in the receiving plane, which coincides with the plane of the transmitter. The ratio of these two functions describes the effect of amplification of phase fluctuations.

Calculations were carried out for various intensities of turbulence for a circular specular reflector, whose radius was equal to that of one or two Fresnel's zones. These coefficients of amplification of phase fluctuations are shown in Figs. 1 and 2.

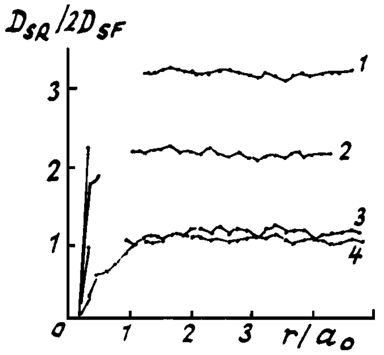

FIG. 1. The coefficient of amplification of the phase fluctuations vs the distance betweeen the observation points. The radius of the reflector is equal to one Fresnel's zone.

Analyzing these results, the following should be noted:

– the behavior of the coefficient of amplification of phase fluctuations depends on the distance between the observation points, the intensity of turbulence, and the size of the reflector;

– the saturation of amplification of phase fluctuations can be seen for observation points located at $r > 2a_0$;

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– the amplification curve has two typical sections: that of a power–law increase, and the plato;

– within the plato the coefficient of amplification characterizes the ratio of the corresponding variances of phase fluctuations;

– no amplification of phase fluctuations can be seen on the path with reflection in the case of strong intensity fluctuations $D_{SR} \cong 2D_{SF}$ (curves *3* and *4* in Figs. 1 and 2);

– in the case of weak intensity fluctuations (see curve *1*, Figs. 1 and 2), the phase fluctuations are stronger for the reflector of smaller size (for $\gamma > a_0$), and for shorter separation distances (for $\gamma < 0.5a_0$) the rate of amplification is also faster for the reflector of smaller size;

– in the case of moderate fluctuations ($b_0^2 = 0.6$–0.7, curve *2*) the behavior of the amplification curve is similar to that for weak fluctuations.

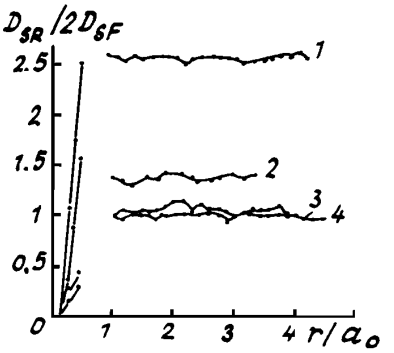

FIG. 2. The coefficient of amplification of the phase fluctuations vs the distance between the observation points. The radius of the reflector is equal to two Fresnel zones.

The table below lists the corresponding serial numbers of curves and the intensity of turbulence β_0^2 and the ratio of Fried's correlation radius r_0 to the initial beam radius a_0.

The question is whether we may adequately compare our results with those obtained previously? It is a difficult question, because, for example, in Ref. 1 the reflection from an infinite reflector was analyzed by the approximate smooth perturbation method. Thus only curves *1* in Figs. 1 and 2 may be adequately compared with the results of Ref. 1. It can be seen from curves *1* that amplification decreases with increase of the size of the reflector. In our opinion, in the case of weak fluctuations the amplification will be equal to 2 for an infinite reflector. Decreasing the size of the reflector (up to a limiting size of a speckle point) we will obtain amplification of the order of 10/3.

TABLE I

Figures	Curves	γ_0/a_0	b_0^2
1	1	1.11	0.11
	2	0.39	0.62
	3	0.18	2.31
	4	0.16	3.20
2	1	0.81	0.18
	2	0.37	0.69
	3	0.27	1.24
	4	0.18	2.88

However, a more detailed and correct comparison of the results of analytic computations with our numerical simulations is needed for more serious conclusions. This will be the subject of our next work.

REFERENCES

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3. P.A. Konyaev, in: *Applied Mathematical Software* (Novosibirsk, Nauka, 1984).