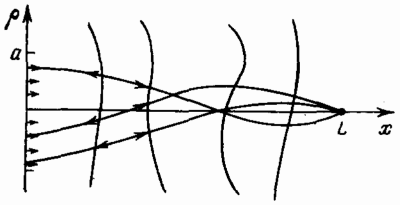

FIG. 2

reversed component in the field of the reflected wave. For example, suppose a collimated beam of radius a and complex amplitude $u(\rho)$ is radiated in the $x = 0$ plane and at a distance L from the source plane a point reflector (Fig. 2) is located in the multiple ray propagation region for the source wave, such that $N = \sigma/\rho_k \gg 1$ (where ρ_k is the source wave's radius of coherence in the vicinity of the scatterer and $\sigma = L/k\rho_k$ is the characteristic transverse deflection of the ray from its trajectory in a homogeneous medium). If $a > \rho_k$ then in the vicinity of the source the reflected wave will contain a reversed component with the average amplitude of approximately $v_0(\boldsymbol{\rho}) \approx (\rho_k/a)^2 u^*(\boldsymbol{\rho})$. If $a \leqslant \rho_k$ the reversed component is focused, leading to the enhancement of the reflected wave intensity in the vicinity of the source. When $a > \rho_k$ this enhancement of intensity can also be observed in the focal plane of a lens positioned to coincide with the source: the lens will effectively focus the weak, but spatially strongly coherent reversed comonent of the scattered wave. Let us emphasize that given $N \gg 1$ the reflected component reversed with respect to the source wave will be present in all space between the source and the reflector, albeit far from the source its spatial coherence, like the coherence of the incident wave, will be weak. Also, multichannel coherence effects analogous to partial reversal should exist in regularly-inhomogeneous media, as well as in the case of waves reflected from complex shapes in a homogeneous medium.

The reciprocity of waves that causes the partial reversal effect also governs the behavior of waves reflected from phase conjugation systems, such as phase front reversal (PFR) mirrors. We note some of the features of this phenomenon in the example of a wave point source (light spot) from a reflected in a turbulent medium from a PFR mirror of radius a, located at a distance L from the source. If $a > \sigma$, the directivity diagram of the PFR mirror $\sim 1/ka$ will be smaller than the coherence angle ρ_k/L and the distortions introduced into the reflected wave by the turbulence will be almost fully compensated by the mirror. The reflected wave will be focused to a spot of radius L/ka in the plane of the source. If $a < \sigma$, we do not have a full compensation of the effect of the inhomogeneous medium. If $N \gg 1$ in the latter case, the mean intensity of the reflected wave in the plane of the source will consist of a sharp intensity peak of the reversed component superimposed on a broad ($\sim \sigma$) plateau. The peak's radius will be $\sim \rho_k < L/ka$. The indicated narrowing of the intensity peak can be treated in terms of the turbulent medium broadening the effective dimensions of the PFR mirror to a radius $\sim \sigma$.

[1] A. I. Saichev, Izv. Vyssh. Uchebn. Zaved., Ser. Radiofiz. **21**, 966 (1978) [Radiophys. Quantum Electron. **21**, (1978)]; Radiotekh. Elektron. **27**, 1961 (1982) [Radio. Eng. Electron. (USSR) **27**, (1982)].

[2] A. V. Polovinkin and A. I. Saichev, Izv. Vyssh. Uchebn. Zaved., Ser. Radiofiz. **24**, 433 (1981) [Radiophys. Quantum Electron. **24**, (1978)]; Radiotekh. Elektron. **29**, 193 (1984) [Radio Eng. Electron. (USSR) **29**, (1984)].

[3] A. B. Krupnik and A. I. Saichev, Izv. Vyssh. Uchebn. Zaved., Ser. Radiofiz. **24**, 1234 (1981) [Radiophys. Quantum Electron. **24**, (1981)].

[4] Yu. A. Kravtsov and A. I. Saichev, Usp. Fiz. Nauk **137**, 501 (1982) [Sov. Phys. Usp. **25**, 494 (1982)]; Zh. Eksp. Teor. Fiz. **83**, 532 (1982) [Sov. Phys. JETP **56**, 291 (1982)]; Double Passage of Waves in Randomly Inhomogenous Media (in Russian), Preprint IRE Akad. Nauk SSSR No. 20 (198), Moscow, 1984.

[5] A. N. Malakhov, A. V. Polovinkin, and A. I. Saichev, Izv. Vyssh. Uchebn. Zaved., Ser. Radiofiz. **26**, 579 (1983) [Radiophys. Quantum Electron. **26** (1983)].

[6] Kh. S. Akhunov and Yu. A. Kravtsov, Izv. Vyssh. Uchebn. Zaved., Ser. Radiofiz. **26**, 635 (1983) [Radiophys. Quantum Electron. **26** (1983)].

[7] A. B. Krupnik, Radiotekh. Elektron. **30**, 625 (1985) [Radio Eng. Electron. (USSR) **30** (1985)].

L. A. Apresyan and D. V. Vlasov. *Strong double passage effects in laser probing of the upper ocean layer.* The great promise of airborne lidar systems in the probing of the upper ocean layer (UOL) is due to the availability of clear reference signals due to molecular scattering in the water column (particularly spontaneous Raman scattering (SRS)) which can be studied in the laboratory. Reference signals enable us to measure "impurities per water molecule" irrespective of the lidar type and aircraft, and hence to compare quantitatively the data gathered by different systems. Field experiments on the laser probing of the UOL, carried out by the AOL team[1] (U.S.) on the "Chaika" airborne lidar[2] (Institute of General Physics, USSR Academy of Sciences) as well as a number of other teams, turned up anomalous resuls which could not be explained by the widely used echo-signal parameter measurement model and thus cast doubt on certain important measurement techniques. An analysis of these results led us to the conclusion that there are strong echo-signal fluctuations due to the focusing and defocusing that occurs during the double passage of radiation through the disturbed air-water interface.

In the standard model the time base of the SRS reference signal should fall monotonically with increasing depth. Experiments[1,2] however measured nonmonotonic distortions and giant bursts in the SRS signal. Hoge and Swift measured a strong correlation of echo-signal fluctuations with local disturbances in the UOL.[1] When measuring echo-signal fluctuations from two depths, Vlasov obtained a strong anticorrelation in several ensemble realizations (Fig. 1). These, as well as other anomalous experimental results, suggest that surface disturbances must be taken into account when we interpret the results of UOL laser probing. Generally, the echo-signal power $P_S(z_S)$ from isotropic scatterers in the z_S plane behaves as $P_S(z_S) \propto \int I_L I_S d^2\rho_S$ where, omitting the proportionality constant, we have I_L and I_S as the radiation intensities at the scattering point $z_S, \boldsymbol{\rho}_S$) for a unit source and a receiver acting as a unit source, respectively. Because of the integration over ρ_S the measured power P_S

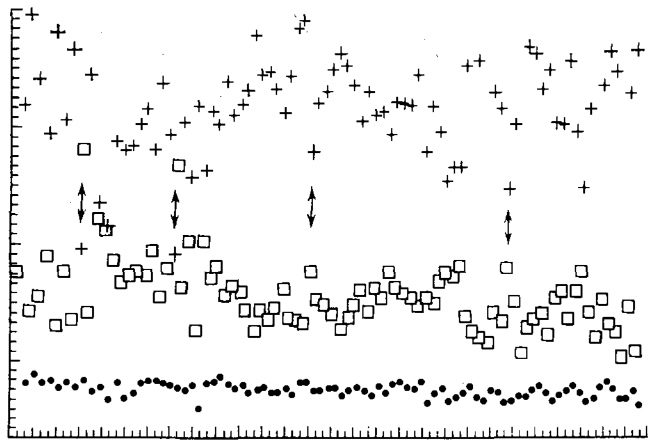

FIG. 1. Experimental echo-signal power readings from two depths (1–22 m; 2–11 m) along the flight path.[2] Arrows mark pairs of points exhibiting clearest anticorrelation.

(z_S) is always averaged over small-scale intensity fluctuations $I_{L,S}$ whose correlation scale is much smaller than the characteristic dimensions of the intersection between the irradiated and observation regions. At the same time, $P_S(z_S)$ remains a strongly fluctuating quantity due to large-scale fluctuations which alter the cross section of the beam.

After some simplifying approximations the disturbed interface can be approximately modeled as a flat phase screen; radiation is treated in the small-angle approximation of wave theory. Then, for various models of the interface disturbance, we can evaluate the experimentally important enhancement factor $\Gamma(z_S)$, defined as the ratio between $P_S(z_S)$ and the signal power for an ideal, flat interface $P_0(z_S)$. Higher statistical moments of $\gamma(z_S)$ can also be evaluated. In the "single lens" approximation, an imhomogeneity large compared to the beam cross section is modeled by a thin lens,

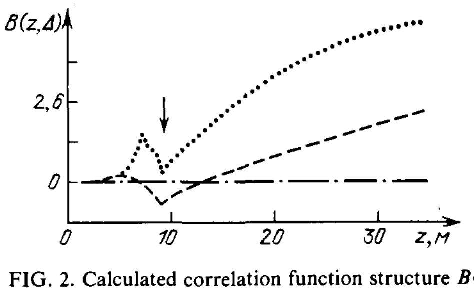

FIG. 2. Calculated correlation function structure $B(z,\Delta)$ for sinusoidal surface disturbance.[2] Arrow marks the minimum focusing depth (~ 9 m). Dashed line corresponds to $\Delta = 8$ m; points correspond to $\Delta = 2$ m.

i.e., a quadratic phase corrector. Then we can derive an analytic expression for $\Gamma(z_S)$ in the case of Gaussian beams, and hence the required statistical moments $\langle \Gamma^n(z_S) \rangle$.

In order to distinguish large-scale and small-scale fluctuations, it is convenient to redefine the enhancement factor $\Gamma(z_S)$ as a product of the focusing factor $\gamma_F(z_S) = P_{SP}/P_{SO}$ and a backscattering enhancement factor $\gamma_M(z_S) = P_S/P_{SP}$, where γ_F describes the case of separated reception and reflects the independent averaging of I_L and I_S over small-scale fluctuations. For combined reception and identical receiver and source characteristics, the focusing factor is of the order of magnitude $\Sigma_0(z_S)/\Sigma(z_S)$—$\Sigma(z_S)$ and $\Sigma_0(z_S)$ are the beam cross section with and without focusing—and can be greater or smaller than unity. The $\gamma_M(z_S)$ is always greater than unity for combined reception: it describes backscattering enhancement due to small-scale intensity fluctuations.

In Fig. 2 we illustrate the normalized correlation function of the enhancement factor $\Gamma(z_S)$ for two depths

$$B(z,\ \Delta) = \frac{\langle \Gamma(z+\Delta)\,\Gamma(z)\rangle}{\langle \Gamma(z+\Delta)\rangle \langle \Gamma(z)\rangle}$$

given a sinusoidal surface disturbance with a random phase (here the angle brackets refer to statistical averaging over large-scale fluctuations). The existence of a region of negative B is significant: it may explain the anticorrelation of experimental measurements from two depths (Fig. 1) reported in Ref. 2. In fact, the anticorrelation is due to the existence of a focusing region between the two depths induced by the surface disturbance—passage through the region changes focusing to defocusing.

This approach yields a fairly complete understanding of the effect the interface layer can have on echo-signal characteristics and qualitatively explains the aforesaid experimental results. For a more quantitative description we must simultaneously measure both the echo-signals and the surface disturbance of the UOL.

In summation, the double passage of waves through the distrubed UOL boundary must be taken into account to interpret adequately laser probing experiments. This conclusion also holds for other, analogous experimental situations.

[1]F. E. Hoge and R. N. Swift, Appl. Opt. **22**, 3778 (1983).
[2]D. V. Vlasov, Izv. Akad. Nauk SSSR., Ser. Fiz. **50**, 724 (1986) [Bull. Acad. Sci. USSR, Phys. Ser. **50**(4), 90 (1986)].

Translated by A. Zaslavsky