MEASURING THE PARAMETERS OF THE ATMOSPHERE USING LASER HETERODYNE RECEPTION

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The results of analysis of heterodyne laser reception are presented that demonstrate the feasibility of measurements of the structural constant of the refractive index as well as of monitoring of the dynamics of fast processes in real time.

One way to improve the quality and to extend the information content of instruments used for optical measurements of the atmospheric parameters is to increase the sensitivity of photodetector channel. State–of–the–art of linear photodetectors is so technologically advanced, that it makes possible to approach their theoretical threshold sensitivity, which does not exceed 10^{-15} W/Hz$^{1/2}$ for the best moment.[1]

The authors of Ref. 2 demonstrated that much higher performance characteristics may be attained by employing the heterodyne reception technique in the optical range. One of the factors limiting the practical application of that technique is the effect of atmospheric turbulence on the parameters of optical radiation. The operation of heterodyne receivers was analyzed in Refs. 3–5 with allowance for the turbulence in the real atmosphere. The results of analysis indicated that such receivers should be designed and developed taking into account the effects of the real turbulent atmosphere on their parameters, among them on the diameter of the receiving aperture.

According to Frid,[5] there always exists an optimal diameter $D_0 = \lambda^{6/5}/C_n^2\, L^{3/5}$, which yields the maximum output signal–to–noise ratio of the receiver. In Ref. 5 it was also demonstrated that by measuring that ratio at the exits from both the heterodyne and linear detector, one may calculate the radius of coherence, with its subsequent recalculation into other parameters, e. g., the structural characteristics of fluctuations of the refractive index C_n^2 and the temperature C_T^2. As for practical implementation of optical train, no principal limitations are imposed on it, since the maximum value of the coherence radius in the turbulent medium does not exceed 50 cm even for a wavelenght of 10.6 μm and drops to 10 cm in case of reception of scattered radiation[6].

Following the above reasoning, we consider several examples of possible means for measuring the parameters of the atmosphere using heterodyne reception of laser radiation. Fig. 1 shows the diagram of one version of such measurements.[7]

The radiation from the source *1* is formed by the optical system *2* and transmitted to the receiving objective *3* through the atmosphere. The light–splitting plate *4* deviates a portion of the incident beam to the calibrated linear detector *5*, which measures the power of the received signal. The remaining part of the beam enters the light–splitting plate *6*, where it is mixed with the beam from the heterodyne *7* and directed toward the detector *8*. The signal–to–noise ratio

$$W(a_t) = \frac{\eta}{q}\left(\frac{A_s^2}{a_d}\right)^2 \left(\frac{a}{a_{eff}}\right)^2 \frac{\pi}{8}\,\frac{4\,\rho_c^2\, a_d^2}{a_d^2 + \rho_c^2}, \qquad (1)$$

is measured at the exit from this detector, where

$$\rho_c^2 = \frac{L}{k}\left(1 + \frac{4\,L}{3\rho_c^2\, k\, a_{eff}^2}\right)^{-1},$$

q is the wave parameter, A_s is the amplitude of the signal field, a_d is the diffractional radius of the beam; a is the radius of the transmitting aperture; a_{eff} is the effective radius of the beam in the turbulent atmosphere, and ρ_c is the coherence radius of the plane wave field in the turbulent medium.

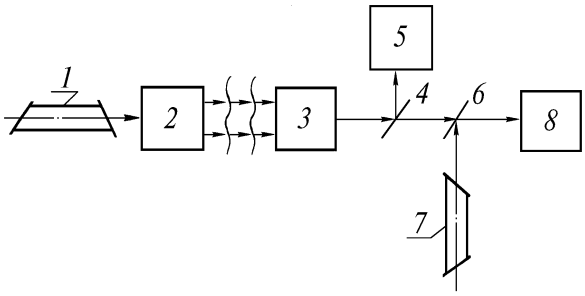

FIG. 1.

The signal power at the exit from the linear detector is

$$S = \eta\, A_s^2 \left(\frac{a}{a_{eff}}\right)^2 2\,\pi\, a_d^2. \qquad (2)$$

Taking into account that the expression $\rho = 0.09\, C_n^2 kL$ holds for the coherence radius of a plane wave, we derive from Eqs. (1) and (2)

$$C_n^2 = 7.8\, L\, [k^2\, a_{eff}^2 (4\, q\, \Omega\, W - 1)]^{-1}, \qquad (3)$$

where k is the wave number and Ω is the Fresnel number of the transmitting aperture.

As compared to the technique proposed in Ref. 8, the above approach to measuring the structural characteristic features higher accuracy, since the parameters of the atmosphere, affecting the final result, remain practically unchanged during measurements.

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Because of the need to calibrate two receiving channels according to this scheme, a possibility naturally arises not only to simplify the scheme, but actually to improve the measurement accuracy when the detectors are combined in one unit.

If we assume that at the exit from the modulator the signal varies by the law $A_s = A'_s(1 - m \sin\omega_0 t) \sin\omega_s t$, where m is the degree of modulation and ω_s and ω_0 are the frequencies of the signal and heterodyne beams, respectively, the output photodetector current will be proportional to $\eta(A_0 + A_s)^2$, where $A_0 = A'_0 \sin\omega_0 t$. Assuming that time constant of the photodetector is much shorter than $1/\omega_0$, after averaging we derive for the output current

$$I_{out} \sim \eta A_s A_0 \cos(\omega_s - \omega_0) + \eta\, 2 A_s^2\, m \sin\omega_m t \qquad (4)$$

The second term of the above relation describes the value of the output signal of linear detector. In what follows that application of selective amplifiers tuned to the frequencies ω_s, ω_0, and ω_m makes possible a measurement device built around a single detector.

Let the radiation frequency be tuned by the law $\omega = \omega'_0 + \nu_\omega t$, where $v_\omega = d\omega/dt$ is the rate of frequency tuning of the source and ω'_0 is the starting frequency.

After a time required for the beam to pass through the "emitter – reflecting object – heterodyne detector" path, the radiation frequency changes and becomes $\omega_t = \omega'_0\, \nu_\omega\, t_1$, where t_1 is propagation time of the beam.

Only the frequencies of the signal reflected from the sounded volume at the distance

$$L = 0.5\, t_1\, c = \frac{(\omega - c)}{2\, \nu_\omega} \qquad (5)$$

are transmitted through the channel of the amplifier. The radiation source frequency changes in a time required for the beam to propagate to the reflecting volume and back; however, the frequency difference $\omega - \omega_0$ remains always such that it falls within the pass band of the intermediate frequency amplifier. In this case the profile of measurable parameter can be calculated along the beam path, due to the variation of the intermediate frequency of the heterodyne detector and turing of the frequency of the source by the linear law with variable rate. The detector will record only the scattered radiation for which the difference between its frequency and the running frequency of heterodyne falls within the pass band of the intermediate frequency amplifier. The incoming radiation carries information on a scattering volume at a distance corresponding to the delay of the signal with the frequency of scattered radiation from the heterodyne signal. Let the cross section of directional pattern of the receiving antenna at the distance L from the receiver be d and exceed the cross section of the sensing beam (see Fig. 2). Then the time required for the directivity pattern to pass through a given volume V is

$$\Delta t = d/\nu. \qquad (6)$$

where $v = \omega t$ is the linear scanning velocity at the distance L from the receiver and ω is the angular velocity of scanning.

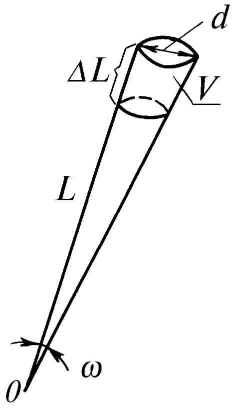

FIG. 2. Method of spatially resolved sensing of the atmosphere.

In a time required to scan the cross section d the radiation will pass the distance $\Delta L = \frac{1}{2} c\Delta t$; which on account (6) will be

$$\Delta L = \frac{c\, d}{2\, \omega\, L}. \qquad (7)$$

It is apparent from the derived expression that the value ΔL, characterizing the spatial resolution along the direction of sensing, is determined by the angular scanning velocity ω and the ratio of the cross section of the antenna directivity pattern (sensing beam) d to the distance L to the sounded volume. Using X–Y scanners, one may obtain a raster image and measure the spatial distribution of optical characteristics of the atmosphere in real time. Such measurements make it possible to monitor the fast processes, e.g., to estimate the wind velocity associated with the motion of atmospheric inhomogeneities.

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