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Compensation of time phase fluctuations in atmospheric optical homodyne data transmission system*

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The efficiencies of various methods of the optical signal repection have been compared experimentally at a 500 meter long atmospheric path at the wavelength of 10.6 μm. The methods considered are the following ones: direct detection, homodyne detection with and without compensation of a time phase fluctuations. The measurements have been performed both for the reception by a single aperture and for the space-diversity reception by two apertures. It is shown that the use of the compensation makes it possible to reduce considerably the error probability. The new method of compensating of an angular misalignment of local oscillator and signal beams is also mentioned.

It is well known that there are two reasons for which a heterodyne receiving of a weak optical signal is particularly promising in infrared (IR) systems of laser Doppler anemometry, atmosphere sounding and data transmission. Firstly, it is easier to maintain the rigid requirements of alignment of signal and local oscillator (*LO*) fields on long waves [1]. Secondly, the absence of the photoreceivers with high internal amplification (like the photomultipliers) in IR region may be compensated by the basic advantage of the heterodyne receiver, i.e., its high sensitivity.

The strict requirements of alignment may be mitigated by focussing the signal on the photodetector [2], or by the method proposed in [3]. Its essence may be understood from Fig. 1, representing the signal (E_s), *LO* (E_0) field

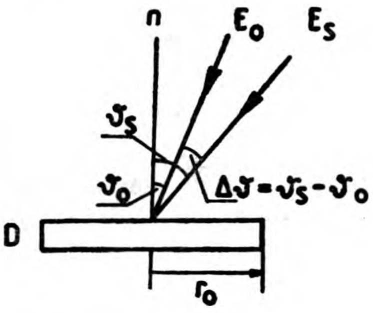

Fig. 1

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vectors and the normal (n) to the circular detector (D) of radius r_0, as well as from the expression for beat frequency current

$$i_{\mathrm{IF}} = \mathrm{const} \times \cos \omega_{\mathrm{IF}} t \int_0^{r_0} \eta(r) U_s(r) U_0(r) J_0[(k_s \sin \vartheta_s - k_0 \sin \vartheta_0) r] r dr$$

where $\eta(r)$ is quantum efficiency of photocathode, $U_s(r)$ and $U_0(r)$ are connected with field vectors by the expressions $|E_s(r, t)| = U_s(r) \cos \omega_s t$ and $|E_0(r, t)| = U_0(r) \cos \omega_0 t$, $\omega_{\mathrm{IF}} = \omega_s - \omega_0$, k_s and k_0 – wave vectors, $J_0[\ldots]$ – Bessel function, ω_s, ω_0 – optical angular frequencies.

Other conditions for the optimal effectiveness of photomixing for an arbitrary r will take place, if

$$J_0[(k_s \sin \vartheta_s - k_0 \sin \vartheta_0) r] = 1,$$

that is, $k_s \sin \vartheta_s - k_0 \sin \vartheta_0 = 0$, or in case of small angles

$$\Delta\vartheta \approx \frac{\omega_{\mathrm{IF}}}{\omega_0} \vartheta_s. \tag{1}$$

From (1) it follows that angular misalignment $\Delta\vartheta$ may be compensated by simultaneous changes of ϑ_s and ϑ_0 or ω_s and ω_0. The first way is more attractive, as the fine alignment of $\Delta\vartheta$ is replaced by $\omega_0/\omega_{\mathrm{IF}}$ times less precise change of $\vartheta_s(\vartheta_0)$.

Additional difficulties arise in the case of beam propagating through the randomly inhomogeneous medium, such as atmosphere, because of deterioration of beam coherence and fluctuations of its level, angle and time (phase) of arrival.

Fadings (multiplicative noise) can be succesfully overcome by applying diversity [4–6] reception; the fluctuations of wave front tilts may by corrected in the real time scale by several means (adaptive receivers). The situation is worse when we are concerned with fluctuations of optical path length of the signal, as it deteriorates the time correlation between signal and *LO* beams.

It is shown in [7] that for sufficiently long (tens of seconds) integration time, heterodyne receiving has an advantage over direct detection, if compared with S/N ratio. However, if we measure error probability (P_e), in other words, if we operate with short pulses (pulse duration is shorter than that of the phase fluctuation caused by propagation medium) the advantages of homodyne detection are not revealed because of possible loss of a series of pulses [4, 9]. A simple and direct way of overcoming this difficulty [4, 8] is the forced phase modulation of the *LO* beam with a frequency at least several times higher than reciprocal of pulse duration. This results in some reduction of S/N ratio but prevents the loss of a series of elementary signals. The photodetector output current (in the case of homodyning) may be written as

$$i_d(t) \sim \mathrm{const} A_s A_0 \cos[\delta_0(t) + \delta_a(t)] \tag{2}$$

where A_s and A_0 are the respective amplitudes of the time fluctuating signal and *LO* fields, $\delta_a(t)$ is time fluctuating phase shift of signal beam caused by atmosphere, $\delta_0(t)$ phase shift between signal and *LO* beams caused by forced modulation in receiver, when necessary.

It follows from (2) that sometimes i_d will become zero because of the random nature of $\delta_a(t)$.

After phase modulation of signal and *LO* beams the cos term of (2) can be rewritten in the following form:

$$\cos[\delta_a(t)+\delta_s\sin\Omega_s t-\delta_0\sin\Omega_0 t] \tag{3}$$

where δ_s and δ_0 are phase deviations, Ω_s and Ω_0 – phase modulation frequencies. After using obvious trigonometric transformations and Bessel series expansion, the necessary operations which solve our main problem can be easily seen. The signal should be filtered through a band pass filter with central frequency Ω_s. Then linear detection and averaging in low pass filter with cut-off frequency Ω_c, such that $\Omega_a \ll \Omega_0 < \Omega_c < 2\Omega_0 < \Omega_s$ yield the term

$$2J_1(\delta_s)[2J_1(\delta_0)\cos\delta_a(t)\sin\Omega_0 t - J_0(\delta_0)\sin\delta_a(t)] \tag{4}$$

where Ω_a is the highest frequency in atmospheric phase fluctuations spectrum, J_0, J_1 are the Bessel functions.

From (4) it may be seen that signal envelope (on Ω_s) oscillates with Ω_0. If $\Omega_0 \gg \Omega_a$, then averaging of envelope for several periods of Ω_0 will exclude the possibility of its dropping to zero.

The results of experimental check of this possibility are presented below. Laser beam from the output of transmitter, located 10 m above a flat sandstony soil, was directed to the flat 20 cm-mirror, positioned 0.5 m above the ground at 250 m distance from the transmitter. After reflection the beam came back to the receiver, placed beside the transmitter. The strength of atmosphere turbulence was estimated by continuous measurement of average structural characteristic of atmospheric refractive index.

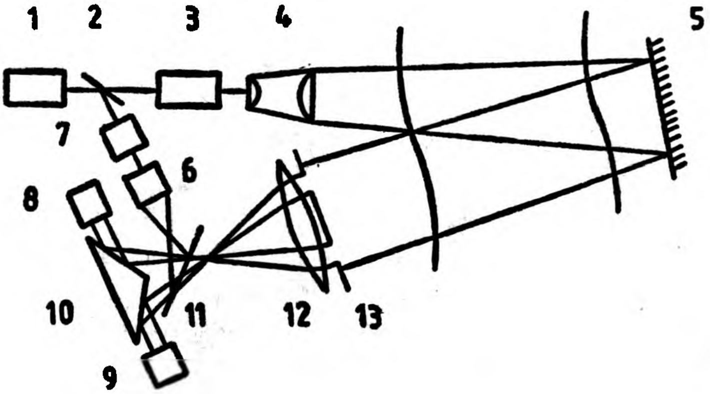

Fig. 2

Experimental setup is shown in Figure 2. Co$_2$-laser beam 1 was modulated by electrooptical modulator 3, having passed collimator 4 it was directed to the mirror 5 (beam output diameter was 1–2 cm, divergence $\geqslant 5'$). Unmodulated optical carrier corresponds to zero, while the 50 μm-duration pulse with 500 kHz modulating (filling) frequency – to unity.

Semitransparent mirrors 2, 11 and matching optics 6 were necessary for homodyne receiving. Diversity paths were formed by means of diaphragm 13, located before a big receiving telescope mirror (for the sake of simplicity, receiving telescope in Fig. 2 is shown as a lens 12). The radiation from each aperture was directed through mirror prism 10 to the corresponding photodetectors 8, 9 (nitrogen – cooled photoresistor). 7 is the *LO* beam modulator. The outputs of receiver were connected to the computer of the number of errors. Diversity receiving apertures diameters were equal to 80 mm, distance between them – 115 mm. The receivers with a single, as well as two apertures (with linear composing of outputs, being the best one [5]) were compared for direct and homodyne detections, the latter with and without phase modulation (30 kHz) of *LO* beam.

For a single receiving aperture the ratio of S/N ratios for homodyne and direct detector outputs vs. the direct detector output $(S/N)_d$ at equal input conditions is shown in Fig. 3.

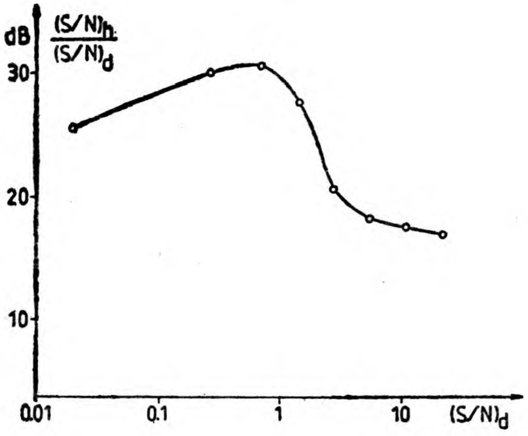

Fig. 3

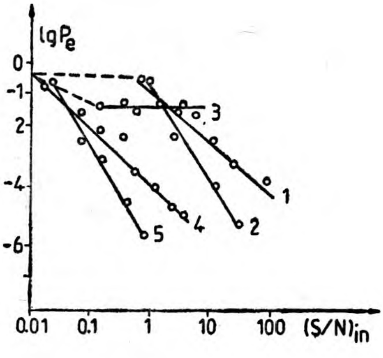

Fig. 4

As one can see, in the case of weak signals the gain of homodyne detector is considerable ($\sim$30 dB).

Figure 4 represents the dependence of P_e on the value of S/N reduced to the input. It has been assumed that the proportionality between direct detector input and output is linear. In this figure the following notations are used: curve 1 denotes a single aperture direct detection, curve 2 stands for linear composing of both aperture signals for direct detection, curve 3 represents a single-aperture homodyne detection without compensation of fluctuations of optical path length, curve 4 corresponds to a single-aperture homodyne detection with compensation of fluctuations of optical path length, and curve 5 is linear composing of both aperture outputs for homodyne detection with compensation.

The behaviour of curves shows evidently the advantage of the last way. When $S/N > 1$, homodyne detector without forced phase modulation is worse than direct detection. If, however, S/N is not very large (<100), then single-aperture homodyne detector with compensation is better than two aperture direct detection. We have no possibility, moreover, to trace the behaviour of curves in the case of very large S/N; it can be assumed that the curves 1 and 4 will tend to draw together with the increasing S/N.

Thus, in the case of a weak signal, homodyne detector with forced phase modulation gives a gain of 3-orders of magnitude over that of the direct detection. All the curves correspond to a moderate turbulence ($C_n^2 \approx 10^{-15}$ cm$^{-2/3}$). The wask dependence of P_e on the state of turbulence was observed experimentally: P_e was changed 3–5 times, when C_n^2 was changed by 3-orders of magnitude.

The performed investigations give reason to expect that not very complex reliable IR atmospheric data-transmission homodyne system will be designed.

References

[1] Andrade O. A., Rye B. J., J. Phys. D., Appl. Phys. **7** (1974), 280–291.

[2] Ross M., *Laser receivers,* John Wiley, New York 1966.

[3] Abramyan A. S., Kazaryan R. A., Radiotechn. and Electron. (USSR) **25** (1980), 2238.

[4] Gasparyan S. S., Kazaryan R. A., Quant. Electron (USSR) **4** (1977), 2403.

[5] Abramyan A. S., Kazaryan R. A., Milyutin E. R., Yaremenko Yu. I., Quant. Electron. (USSR) **7** (1980), 1763.

[6] Churniside J. H., McIntyre M. C., Appl. Opt. **19** (1980), 582.

[7] Gasparyan S. S., Kazaryan R. A., Quant. Electron. (USSR) **3** (1976), 1985.

[8] Abramyan A. S., *Preprint of the Physical Research Institute of Armenian Academy of Sciences,* No. 78–70 (1978).

[9] Abramyan A. S., Kazaryan R. A., Quant. Electron. (USSR) **9** (1982), 601.

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