SOFTWARE FOR TUNING AND TESTING AN IR DAS LIDAR

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A procedure for tuning of optical channels and testing of laser radar systems has been described based on comparison betweeen real echo signals and signals calculated from the special computer code CF1 intended for engineering calculations of special-purpose lidars. Results of tuning of optical channels and testing of an infrared (IR) differential absorption and scattering (DAS) laser radar produced by the Institute of Atmospheric Optics of SB RAS (Tomsk) to order of the Korean Institute of High Technology, are presented.

Any laser radar is a complex electron-optical device[1] whose tuning depends on a number of factors. The tuning of optical channel is of the largest difficulty, and in practice, lidar tuning usually begins with a lidar echo signal reception and the operator strives for signal optimization for its shape in the correspondence with the problem solved.

Our approach to developing and tuning of a lidar is the following. First, of all the stage of engineering design must precede the lidar development. Then after lidar prototype production, detailed investigation of real dependences of the amplitude and duration (shape) of recorded signals on relative position and tuning of units of the lidar optical channel has been conducted. Optimal tuning of the lidar optics, and then electronics, has been conducted, and, finally, obtained experimental data are simultaneously compared with theoretical estimations, conducted on codes, developed on the stage of engineering design, but with due account for real current parameters of lidar optical channel and atmospheric conditions.

The lidar backscattering signal may be used as the initial experimental information to carry out a comparison, and the signal shape is governed by the geometric function of a lidar receiver-transmitter[1] and the atmospheric parameters sought, or the atmospheric parameter determined independently. To isolate the influence of methodical errors in determining the atmospheric parameter sought from lidar signal based on lidar equation and a mathematical method, we gave preference to use of lidar signals.

The given approach was evaluated in developing and tuning a mobile infrared (IR) differential absorption and scattering (DAS) lidar that uses two pulsed TEA CO_2-lasers. Lidar is intended for the control of gaseous composition of the atmosphere in situ and it is a prototype of a commercial field gas analyzer. The lidar operates in the switching mode as a long path meter with the use of topographical targets as reflectors (TT-mode) and in the mode of remote measurements with the use of atmospheric aerosol as a spatially distributed reflector (DAS-mode). Lidar specifications are given in Table I.

TABLE I. IR DAS lidar specifications.

Transmitter (Cassegrainian telescope)		*Receiver Newtonian telescope*	
Diameter	260 mm	Diameter	500 mm
Wavelength	11 μm	Focal length	1490 mm
Pulse energy	1–4 J	Full field-of-view	670 μrad
Beam profile	Gaussian		
Total beam divergence	1 mrad		
Recording system		*Detector (photodiode)*	
The number of bits of the ADC	10	Type	HgCdTe
ADC sampling rate	10 MHz	Aperture size	2 ×2 mm^2
		Detectability level	10^{10} cm $Hz^{1/2}$/W

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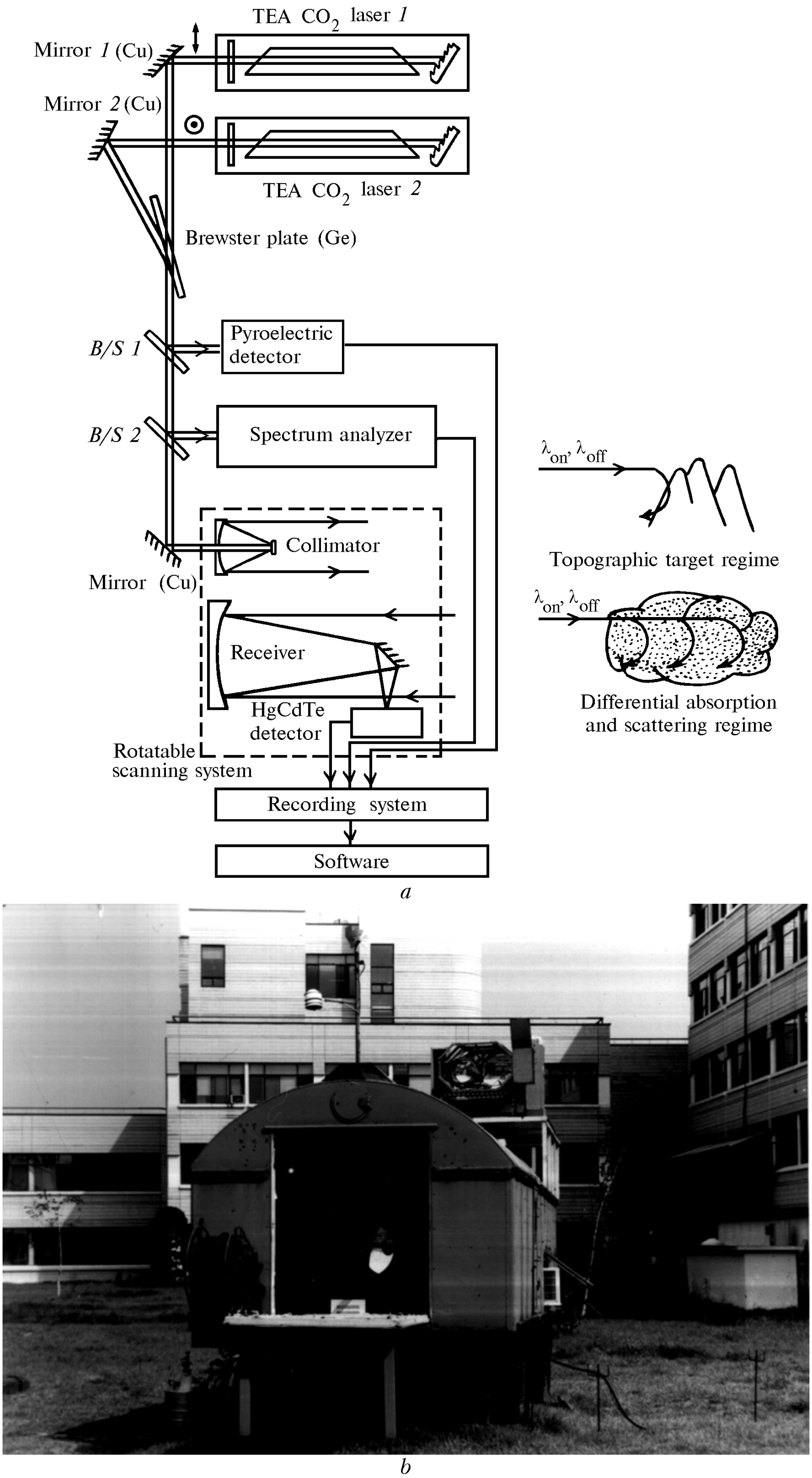

FIG. 1. Optical arrangement (a) and external appearance (b) of the IR DAS lidar.

Lasers with the cavity of 1.5 m length operated in a multimode regime with the output beam dimensions of 27×17 mm^2, and the beam was diaphragmed inside the cavity, when necessary, to make a beam of ∅ 15 mm. Energy distribution across the beam determined by a burn method was rather a uniform.

Figure 1*a* shows the optical diagram of the lidar and Fig. 1*b* – its external appearance. We note that in the van shown in Fig. 1*b* a path atmospheric gas analyzer is additionally installed, seen inside the van. A rotating receiving-transmitting system of the lidar is on the van top.

Basic feature of the lidar optical arrangement is the possibility to control all basic parameters: the spacing between axes of receiving and transmitting telescopes, the angle of convergence between the axes, the size of field diaphragms and/or sensitive element of a photodetector, etc. Sounding radiation in the collimator output is focused at a distance of 3 km or it is defocused to total beam divergence ≤1 mrad.

Engineering design and subsequent computer comparison of obtained and desired signals were made with the use of the code GF1 described in Ref. 2. The code GF1 makes it possible to calculate the geometric functions of lidar at variations of all the basic parameters of optical-mechanical channel of the lidar of any design, a shape of lidar signals with due account for meteorological atmospheric conditions, its gas and aerosol composition, parameters of laser sources of radiation, photodetectors, electronic recording system and processing of signals.

The shape of lidar signals was recorded with a recording system on the basis of 12-digit AD872 ADC, AD*$$ head amplifier, and AD600 amplifier of Analog Devices (USA) with the amplification coefficient controlled by a voltage. Depending on the state and composition of the atmosphere, the total amplification coefficient was selected within the limits of 100–1000. Recording was also performed with a digital storage Tehtronics TDS644A oscillograph with a band of 0.5 Hz and with a memory on a magnetic disk. In all cases all parameters of reference signals were also recorded. A C964 HgCdTe photodiode of EG&G Judson firm, USA, was used as a photodetector, with a receiving area of 2×2 mm^2, or home-produced HgCdTe photoresistor. In the reference channel, after proper beam attenuation, only half cooled HgCdTe photoresistor with the aperture size of 1×1 mm^2, was used. Parameters of all photodetectors were investigated in detail by comparison between their response and response from Ge:Au photodetector using media with a time constant about 2 ns. A level of input signals of photodetectors and amplifiers, their conditions of operation eliminated the shape distortions of recording signals. Time constants of all HgCdTe photodetectors were between 8 and 10 ns.

Thus, the possibility of exactly determining the family of lidar signal parameter dependences on the relative position and turning of lidar optical-mechanical units in real time was maintained, and, consequently, possibility to evaluate the effect of adjustments on the lidar signal and to establish the tendency to tuning of the lidar as a whole, to compare the results of the tuning with the potential results for this lidar and in the end to carry out optimal tuning. It appears that parameters of the lidar tuned optimally may be compared with potential parameters of other known lidars and, thus, it is possible to evaluate a level of production as a whole.

We will present for illustration intermediate results for tuning and adjustment of the above-mentioned lidar.

Figure 2 shows the results of lidar testing when laser beam divergence varied by the detuning the collimator (Cassegrainian telescope), removed at a distance of 5.6 m from lasers by way of changing the distance between its mirrors. A counter-reflector was 80 mm in size.

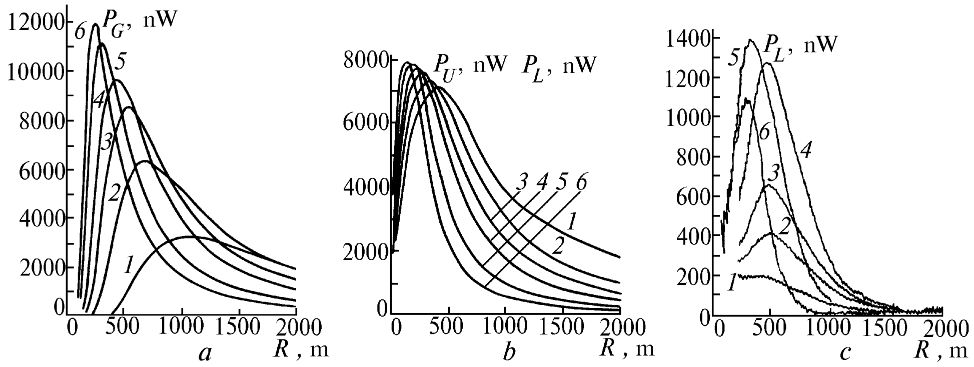

FIG. 2. The dependence of a lidar echo-signal shape on laser beam divergence. Theoretical curves for Gaussian distribution (a) and uniform distribution (b); the experimental curves (c) are for laser beam divergence: 1) 400, *2)* 600, *3)* 800, *4)* 1000, *5)* 1400, *and 6)* 1800 μrad.

Figure 2*a* shows the family of calculated signals for different angles of laser beam divergence, when the laser beam profile was Gaussian (single-mode regime of laser operation). Figure 2*b* shows the family of curves for the uniform distribution of energy over the laser beam cross section (an approximation to multimode regime of laser operation). Figure 2*c* shows the corresponding family of experimental curves, recorded without the use of diaphragming laser beam and a constant angle of output beam divergence, which was equal to 15 mrad.

Comparison of all three parts of Fig. 2 shows that the behavior of signals vs the collimator detuning does not correspond to behavior of the beams with neither purely Gaussian nor uniform distribution of the energy. Nevertheless, the real distribution is closer to a Gaussian one.

Analyzing the operation of the receiving–transmitting system as a whole, we must draw attention to two facts: the low total efficiency and the sharp fall off of the signal from distances of the order of 1 km. Further analysis had revealed that a sharp fall off of the signal is due to higher, about 20 mrad, actual laser divergence, determined not exactly by the burn method because of the low-intensity part of radiation beam. The use of field diaphragms, cutting off this part of the beam, had led to the correspondence between calculated and experimental dependences. The efficiency of receiving – transmitting system has been increased by a decreasing the reflector diameter and a central hole of basic collimator mirror through the elimination of auxiliary (adjustable) optical elements in the measurement time, the integration of functions of optical elements used, through an installation of dust protective devices etc.

When this stage of the tuning and use of the amplifier was complete, the backscattering signals were recorded from a distance to 3 km with a signal-to-noise ratio equal to 1000 in one couple of shots. The efficiency of system was increased by almost 3 times.

The dependence of the echo-signal shape on the angle of convergence between the optical axes of the transmitter and the receiver in the first stage of tuning was investigated by way of rotation of a plane elliptic mirror of the Newtonian telescope with a microscrew. Figure 3 shows corresponding dependence of the lidar signal shape for theoretical beams with the Gaussian intensity distribution (*a*) and uniform intensity distribution (*b*) over the beam cross section. Corresponding experimental curves are shown in Fig. 3*c*. As before, the behavior of the signal shape vs the detuning of the selected parameter points to the Gaussian beam profile. The value of the order of 250 rad may be selected as optimal for the angle of convergence between the axes, with the intersection point of the optical axes of the transmitter and the receiver being at a distance of 1500 m from the lidar.

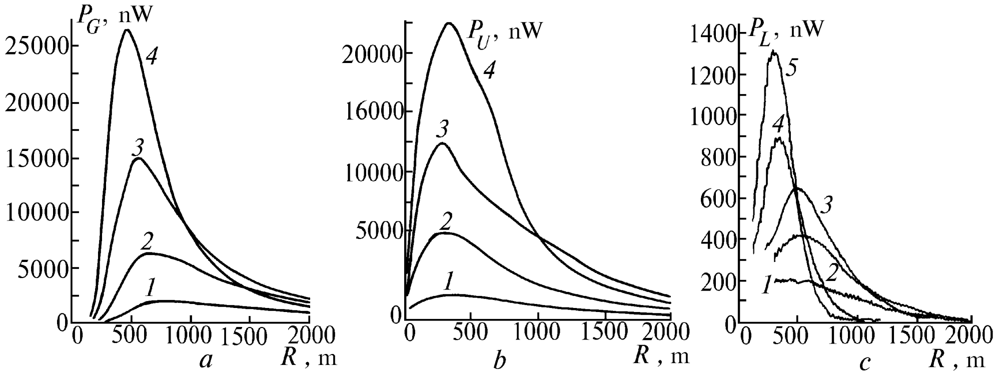

FIG. 3. The dependence of the lidar echo-signal shape on the angle of convergence between the optical axes of the transmitter and the receiver. Theoretical curves are for the Gaussian distribution (a): 1) –250, *2)* 0, *3)* +250, *and 4)* +500 μrad *and uniform distribution (b): 1)* –500, *2)* 0, *3)* +500, *and 4)* +1000 μrad. *Experimental curves (c): 1)* –250, *2)* 0, *3)* +250, *4)* +1000, *and 5)* +1500 μrad.

Selection of the position of the photodetector sensing element relative to the focus of the receiving telescope is important too. The point is that the radiation scattered near the lidar is focused by the receiving telescope behind the focal plane. Small error in the detector arrangement can cause the noticeable decrease of a signal. The arrangement of the detector before the focus of the telescope results in the decrease of a signal as a whole. The arrangement of the detector behind the focal plane may result in the increase of a signal coming from the near zone of the lidar and its sharp decrease in the far zone. The displacement by 1–2 mm behind the focal plane should be considered as optimal for the detector of the given lidar design.

Summing up, we can draw the following conclusions:

1. Our method for lidar tuning makes it possible for experimentators not to work blindly but to orient themselves to model signals calculated for the parameters of laser system under development.
2. This method reveals the discrepancy between the real and rated parameters of lidar units at the stage of lidar development.

3. Testing of the operating laser radar has shows in practice the efficiency of the procedure and has made it possible to achieve the results close to the expected ones for the given lidar design.

In conclusion, we note that the analysis of all theoretical and experimental curves points to the complex dependence of the signal shape on lidar tuning and quality of design and production of its units. In addition, computer testing makes it possible to predict and to guide main efforts to obtain satisfactory results in real time.

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2. I.A. Razenkov, Yu.M. Andreev, and N.A. Shefer, Atmos. Oceanic Opt. 9, No. 10, 905–908 (1996).