SOFTWARE PRODUCT FOR ENGINEERING CALCULATIONS OF THE LASER RADAR SYSTEMS

I.A. Razenkov, Yu.M. Andreev, and N.A. Shefer

Institute of Atmospheric Optics
Siberian Branch of the Russian Academy of Sciences, Tomsk
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We describe here GF1 computer program for making engineering calculations of the laser radar systems. The program allows one to calculate a geometric function of a lidar with any geometry of the transceiver and to estimate the lidar potentialities. The results of testing Italian IR DIAL (Barbini R. et al) are presented by way of example.

At the development of laser radars (lidars) intended for determination of different atmospheric parameters,[1] the requirement arises on quick and high-quality calculations of potential variants of the developed system. It is desirable for a designer of a lidar to have a good instrument for work. In the given case it is a computer program to make engineering calculations. Authors of this paper sometimes faced such problems while working, but believing that the time spent on the development of such a program will later pay off, we started to develop software for calculation of lidars by stages.

Any lidar must be developed for a solution of some particular problem and it must come up to specific requirements, therefore in the first place it is necessary to be able to calculate the geometric diagram of a transceiver of the lidar and to estimate its potentialities.[2] On our point of view, the complete engineering calculation of lidar must consist of two basic stages. At the first stage, as though the structure (configuration) of the lidar is developed (optical arrangement, external appearance, dimensions, and its basic performance characteristics). At the second stage, individual units of the system must be designed, basic characteristics of which were determined at the first stage.

The program, which we called "GF1," is intended only for making the first–stage engineering calculations. It is executed on a TURBO PASCAL high–level language (Borland firm) for IBM compatible computers. At the early stage of its development, GF1 was designed only for calculation of a geometric function of a laser radar.[2] Later an idea arose of addition and expansion of GF1 for calculation of potential characteristics of infrared (IR) lidar of differential absorption and scattering (DIAL) and other types of lidars (of aerosol lidar for visible spectrum range; lidars, which operate on the principle of Raman scattering (RS), and other).

The block diagram of GF1 program is presented in Fig. 1. We note that Fig. 1 presents only basic features of the program. The program has a convenient user's interface. Specification of any parameters is conducted by a user. Lidar parameters are divided into two groups: geometric and energy, and a type of lidar is specified in advance. The first group of parameters includes optical arrangement of transceiving part of the lidar (coaxial and biaxial); a type of laser beam (uniform or Gaussian); its diameter and divergence; diameter and focus of the receiving telescope; the size of aperture diaphragm; position of the diaphragm relative to focus; spacing between optical axes of transmitter and receiver; radius of shading body for mirror receiving telescopes. Lidar energy parameters include laser pulse energy, pulse duration, sensitivity, time-constant, the noise level and quantum efficiency of a photodetector; bandwidth and transmission of receiving system.

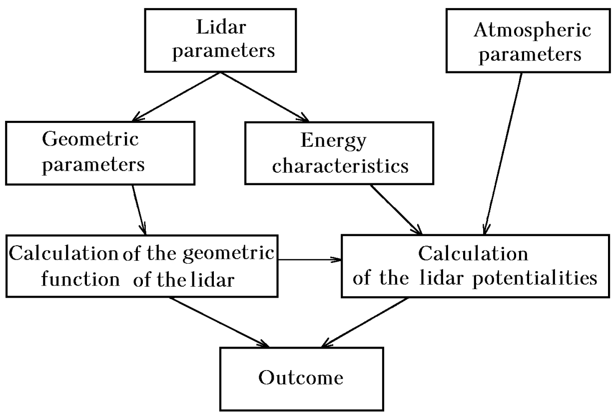

FIG. 1. Block diagram of GF1 program for calculation of laser radar systems.

The atmospheric parameters call for specification of the aerosol extinction coefficient; the aerosol backscattering coefficient; absorption coefficient at the laser wavelength; differential absorption coefficient of the gas under study (DIAL lidar), scattering cross section; uncertainty of the backscattering coefficient; the sky background noise.

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Calculation of geometric function has been conducted in accordance with an algorithm, presented in Ref. 2. Calculation of potential characteristics has been made mainly according to Ref. 3. As the parameter, by which lidar systems can be compared, so-called modification parameter[3] was selected, which takes into account the area of the receiving telescope, sensitivity of the photodetector and other basic lidar parameters. Calculation of potential lidar characteristics includes the modified parameter of the system; power of the lidar return; maximum detection range; sensitivity of the system on the whole; power of the background illumination; noise power; minimum detection power; necessary accuracy of the recording system.

Required accuracy of recording system is set by a word length m of an analog-to-digital converter (ADC), which is defined as a logarithm to the base 2 of the ratio of the lidar return maximum power, $P_{\max}$, to the noise power, P_{noise}, by the formula $m = \log_2(P_{\max}/P_{\text{noise}}) + 1$. Addition of unity takes into account the ADC noise, which ordinarily does not exceed the noise of the least digit. As an example of the use of GF1 program, let us show results of calculations for lidar, described in Refs. 5 and 6. It is the Italian IR DIAL lidar[5] on the basis of two pulsed CO_2 lasers, intended for determination of density of any atmospheric gas. Presented in Ref. 6 are the results of sounding of water vapor with this lidar.

Characteristics of the lidar[5] are shown in Table I, and Fig. 2 shows real returns, taken from Ref. 6. Signals correspond to CO_2 laser lines $10R20$(ON) and $10R18$(OFF). The relative rate of a decrease of signal levels with the range allows one to judge on the concentration of the gas under study. Incidentally, differential coefficient of absorption by water vapor was $7.7\cdot10^{-4}$ cm^{-1}atm^{-1}. The temperature of the air was 18°C and its relative humidity was 72%, that corresponds to the number density of water molecules of 13200 ppm.

TABLE I. Parameters of IR DIAL.[5]

Transmitter	
Wavelength	9÷11 μm
Pulse energy	1÷4 J
The beam shape	Gaussian
The total divergence	1 mrad
Recording system	
Word size of the ADC	12 bit
Frequency of the ADC operation	10 l Hz

Receiver Newtonian telescope	
Diameter of telescope	39 cm
Focal length	100 cm
The total field of view	1 mrad
Detector (HgCdTe)	
Area size	1×1 mm^2
Detection capability	$2\cdot10^{10}$ cm·Hz$^{1/2}$/W

Figures 3 and 4 show the results of calculation, conducted with the GF1 program. Figures 3 and 4 presents two copies of a computer display screen formed by GF1 program. Figure 3 shows geometrical lidar parameters and geometric function of the lidar corresponding to them. Figure 4 presents energy parameters of the lidar[5] and lidar returns ON($10R20$) at the radiation frequency, which coincides with the absorption line of water vapor, and signal OFF($10R18$) at the frequency off the absorption lines of water vapor. We note that a comparison of signals, presented in Fig. 2 and Fig. 4, shows that they are similar. We note that the difference between ON and OFF signals in Fig. 4 is larger than that in Fig. 2. It may be explained by the fact that shown in Fig. 2 are signal oscillograms, and, probably, at arbitrary coefficients of amplification just in order to compare the falling parts of ON and OFF signals.

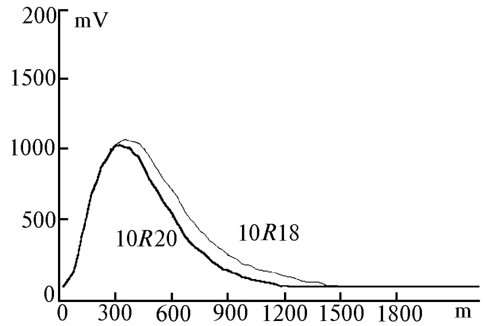

FIG. 2. Lidar returns for CO_2 laser lines 10R20(ON) and 10R18(OFF) obtained along horizontal path on October 20, 1989, 10:00 LT at air temperature of 18°C *and relative humidity of* 72%. *The data are taken from Ref. 5.*

Calculations of potentials have been conducted for spatial resolution of 50 m by analogy with the result obtained in Ref. 6. Incidentally, it was obtained that minimum density of water vapor, which can be recorded with the lidar at a distance of 1 km, is 640 ppm. Minimum distance, at which the density equal to 13200 ppm can be determined with the given lidar, was 200 m. Estimation error of this density for distance of 1 km and 20 pulses of averaging was 13%. The testing of the lidar[5] conducted with GF1 program had shown that possibilities of the given lidar are realized almost completely. The value of the modified parameter of the system[5] was $1.6\cdot10^{21}$ cm^2/J.

In Ref. 4 it was proposed to use three generalized parameters, which are the potentials of the lidar in the operation under noisy conditions, and "frequency of information restoration" was introduced as a characteristic of process. In our opinion, an approach, described in Ref. 4, deserves special attention and we intend to include the calculation of these generalized parameters into the following versions of GF1 program.

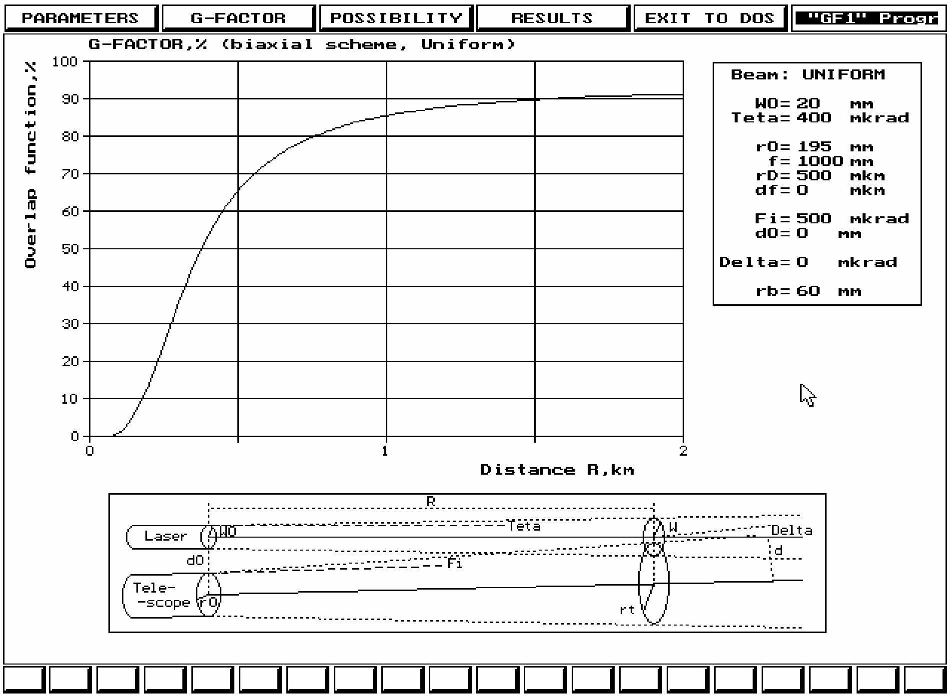

FIG. 3. Results of calculation by GF1 program: geometric parameters and geometric function of the lidar.

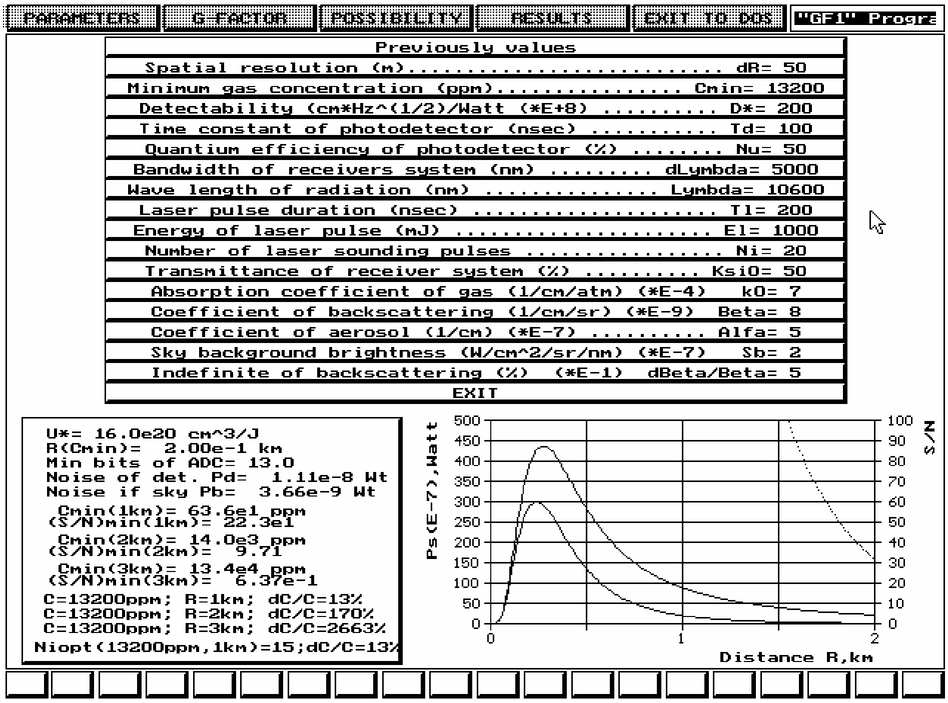

FIG. 4. Energy parameters and returns of IR DIAL.[5]

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