INVESTIGATIONS OF LFM-LIDAR WITH THE FREQUENCY CONVERSION

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The capabilities of the LFM-lidar with the frequency conversion for different approaches to environmental monitoring are estimated. The principles of the CW-lidars designed and the ways of improving their metrological characteristics are discussed.

1. INTRODUCTION

LFM-lidars are finding wider use to investigation of structure and dynamics of the atmosphere as well as to control the presence and distribution of different artificial pollutants in the atmosphere. This is due to the following well known factors: the principle of energy equivalence of pulsed and CW lidars, the possibilities of improving the range resolution and the cost of making LFM-lidar. In recent years, some papers devoted to development of the principles of LFM-lidars which are used in different atmospheric sounding techniques (differential absorption, differential absorption and scattering, laser-induced fluorescence) and operated in the modes of direct or heterodyne detection of backscattered signals. The characteristic feature of each lidar is the methods of frequency modulation: tuned with the use of piezoceramic mirrors and a wavelength switch CO_2-laser (Ref. 1), amplitude electro-optical chopper of germanium crystal and two He-Ne laser operating on close transitions (Ref. 2), electrooptical chopper made from lithium methaniobat crystal converted single-frequency coherent radiation into double-frequency one (Ref. 3).

The advantages of our electrooptical frequency converter (see Ref. 4), block diagram of the LFM-lidar, and estimation of its performance parameter of its possible version are presented in Ref. 3.

In this paper, we present some results of further investigations of the LFM-lidar with the frequency conversion.

2. THE CAPABILITIES OF LIDARS WITH THE FREQUENCY CONVERSION

High reproducibility of the laser wavelengths and their differential frequency, as well as, the stability and equivalence of radiation power at both frequency components are necessary for high-accurate lidar measurements. Besides, for fine and hyperfine structures of absorption spectra to be investigated one should provide a means for smooth frequency tuning of radiation in accordance with a given law and at a given rate. The above mentioned requirements can be satisfied with the use of electrooptical devices with extended bandwidth which converts a single-frequency coherent radiation into a double-frequency one as a sources of double-frequency laser radiation (see Refs. 3, 4) and a set of single-frequency CW lasers. The device described in Ref. 3 is in fact a converter with the tuning range up to $0.04\ cm^{-1}$ and operating wavelength range from 0.4 to 4.5 μm. With the method of frequency conversion using electrooptical modulator ML-8 it is possible to obtain laser radiation at $\lambda \sim 10.6$ μm tuned in the range of $0.02\ cm^{-1}$. Germanium crystal providing intense heat transfer in the modulator can provide widening of the tuning range up to $0.1-0.2\ cm^{-1}$.

Since half-width of the absorption lines of gases in the near-surface atmospheric layer is on the order of $0.01-0.1\ cm^{-1}$ while resolution required for true line shape recording is no less than $0.001-0.01\ cm^{-1}$, the frequency converter can be widely used for development of differential adsorption lidars or in measurements of absorption on a long path. Besides, considerable gain can be achieved in the course of integral measurements.

Recall that power parameters of a possible lidar version operating in the modes of direct and heterodyne detection and performance parameters of the LFM realization presented in Ref. 3 are as follows: frequency deviation $F_d = 15$ MHz at maximal sounding range $R = 2$ km, pass band $\Delta f = 2$ MHz.

The pass band for the heterodyne detection mode well agrees with the data presented in Ref. 5. Frequency stability of IR lasers provides bandwidth of the beat signal of transmitter frequency and the heterodyne to be lower than 1 MHz even for a long path. Broadening due to scattering on the atmospheric turbulence is generally no more than 1 MHz, as well. If the scattering medium consists of atmospheric aerosol, strong wind can cause the frequency shift of several MHz, which was taken into account in our estimations of the lidar selectivity with respect to the velocity of the sounding objects. For direct detection mode pass band of the device is simply related to the deviation frequency value.

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2.1. Direct Detection Mode

Integral measurements. The LFM regime is realized with the preliminary separation of the frequency components by several MHz which defines the central frequency of the selective intermediate amplifier. Hence, the measurements are carried out with the transfer of the backscattered signal spectrum into the range of minimal level of the photodetector noise. Range control is made by measuring the difference in the frequency of LFM-signal modulation and the frequency of signal at the output of the intermediate amplifier of the recording system, while the control of the atmospheric parameter is performed by the power of the detected signal at the frequency of measurements.

Omitting discussions of the physical nature of phenomena we can say that in the direct detection mode the internal noise of a photodetector exceeds the background one and determines the threshold power of the signal to be detected. The gain in the signal-to-noise ratio can be calculated from the following expression:

$$G = \int\limits_0^{\Delta f} S(f)\,\mathrm{d}f \Big/ \int\limits_{f_0-\Delta f}^{f_0+\Delta f} S(f)\,\mathrm{d}f , \qquad (1)$$

where $S(f)$ is the spectral density of the photodetector noise. Despite the increase in the required pass band, the gain is mainly determined by different nature of the noises and their levels in different spectral regions. In the range $\{0, \Delta f\}$ these are the current noise with the distribution of $1/f$ kind and other powerful low-frequency noises, in the range $\{f_0 - \Delta f, f_0 + \Delta f\}$ this is a low-intense shot noise.

For a short path requiring the recording system pass band of 0.1–1 MHz the gain can reach 1 to 2 orders of magnitude.

Differential absorption measurements. In this case the preliminary separation is defined by tuning on the absorption line to be selected. The first frequency component falls within the absorption line shape of a gas to be investigated, while the second one is outside it. Considering the maximal frequency tuning range to be equal to 0.04 cm^{-1}, one can conclude that the half-width of the absorption line and the sounding path length may not exceed 0.005–0.01 cm^{-1} and 1–2 km, respectively. In the LFM-regime the adjustment of the frequency components of the sounding radiation on the absorption line is retained, while the measurement error includes a component ideally determined by Lorentz absorption line shape.

In the near-IR range the components of a double-frequency radiation obtained with the frequency converter under study can not be separated in space or in time. Therefore, differential absorption lidar operated in the direct detection mode may contain a scanning Fabry-Perot interferometer placed in front of the photodetector for temporal-frequency separation of the backscattered signal. In the range of 10.6 μm this separation is feasible by using a grating and classical scheme of differential LFM-lidar.

Doppler measurements. The symmetry of the sounding signal spectrum results in equal in magnitude and sign Doppler shifts of both spectral components. In the integral measurement mode the presence of the Doppler shift is not observed and the lidar operates at a fixed intermediate frequency f_0. For differential absorption measurements one should take into account that the Doppler shift and the LFM-shift are identical or opposite in sign for the first or second frequency components. This enables us to detect the Doppler shift practically in the direct detection mode by the method of first or second derivative.

2.2. Heterodyne Detection Mode

As was shown in Ref. 3, the advantage of the heterodyne detection mode over direct detection one is the 3–4 orders lower threshold power. Therefore, in this paper we have mostly concentrated on the question of the coherent homodyne or heterodyne detection of the Doppler shifts resulted from intense turbulent or wind motion.

Homodyne detection. One possible variant of the lidar is to use a single laser with the optical separation of radiation into the channel of single-frequency heterodyne and the channel of double-frequency sounding formation. In the absence of Doppler shift the backscattered signal at two frequencies W_n and W_v which are defined by the LFM law and symmetric about W_n and W_v heterodyne signal at frequency W_0 enter the photomixer at the instant t. As shown in Fig. 1, Doppler shift breaks this symmetry since the frequency components W_n and W_v are shifted by the Doppler frequency W_d and take the values W_n' and W_v', respectively. In this case we obtain at the output of the photomixer two signals at the frequencies $W_n - W_d$ and $W_v + W_d$. Then, by entering these signals to the electron square-law detector one can obtain at its output a signal with doubled Doppler frequency. The signal containing information on the atmospheric transmission at a given distance can be separated before the square-law detector using a spectrum analyzer tuned at the instant t to the doubled modulation frequency $W_m = 2\,W_n = 2W_v$.

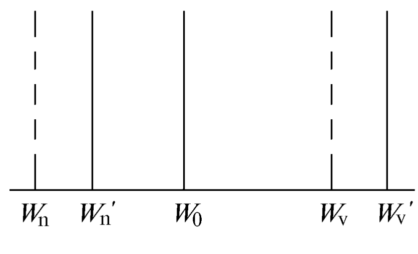

FIG. 1. On detecting of the Doppler frequency.

Heterodyne detection. For the Doppler measurement of intense wind motion to be performed the pass band of the lidar should be increased by several hundreds of kHz or several MHz. But in this case the signal-to-noise ratio of the receiving apparatus significantly decreases. One way to increase this ratio is in the use of one more laser with higher output power. The heterodyne power required can be determined from the following expression (see Ref. 5):

$$P > A/[\hbar F_0(D^*)^2] , \quad (2)$$

where A is the photomixer cross-section area, $\hbar$ is the Plank constant, F_0 is the laser frequency, D^* is the detecting capacity.

However, the use of two lasers leads to the problem with beat of the emitter and heterodyne frequencies. The beat amplitude in the vicinity of 1 MHz introduces large errors into the Doppler frequency measurements. Since the beat and Doppler shift in the processed signal are identical in their evidence we suggest for the beat compensation to integrate into a lidar optical scheme additional channel for photomixing of the external heterodyne radiation with that of double-frequency transmitter. Next, the beat signal separated out in the same manner as the Doppler one is considered when processing measurement results. Application of that channel in coherent system without frequency conversion is limited due to high level of the photomixer noise and other low-frequency noises.

3. EXPERIMENTAL MODEL OF THE LIDAR WITH FREQUENCY CONVERSION

The LFM-lidar model presented in Fig. 2 provides detection of the atmospheric inhomogeneities at a distance up to 100 m at a signal-to-noise ratio no less than 10. Two CW He-Ne lasers of the LGN-207 type with output power of 2 mW were used as a sounding radiation source and as an external heterodyne. Radiation frequency conversion was performed in the device developed on the basis of electrooptical converter ML-5. The receiving optics was constructed based on MTO = 1000 A objective with the focal length of 1 m and 100 mm diameter. The photomultiplier FEU-84 was used as a photodetector in the measurement and beat compensating channels from the outputs of which the signals enter two processing channels comprising the spectral analyzer and the detector. Then the signal detected was converted into a digit form by means of 1113PV1 ADC and transmitted for processing into an IBM PC AT386 computer.

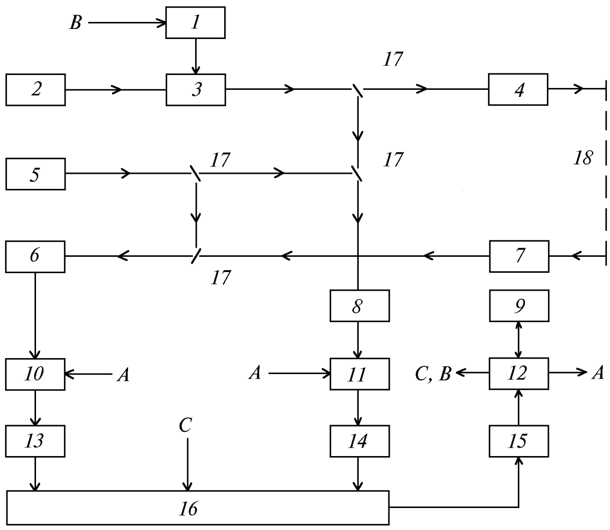

FIG. 2. Experimental model of LFM-lidar. 1 – LFM-generator, 2 – laser, 3 – double-frequency converter, 4 – collimator, 5 – heterodyne, 6 – photomultiplier of the measurement channel, 7 – telescope, 8 – photomultiplier of the compensation channel, 9 – computer, 10, 11 – spectral analyzers, 12 – interface, 13, 14 – detectors, 15 – analog-to-digital converter, 16 – multiplexer, 17 – combination of beam splitters, 18 – the object sounded.

4. CONCLUSION

Thus, we have shown a possibility of creating LFM-lidar with frequency conversion based on electrooptical frequency doubler which may be used for implementing different methods of sounding of the atmosphere. The estimations and the experimental results obtained confirm the possibility of creating lidar of a given class and describe the ways to improve its metrological parameters.

REFERENCES

1. E.P. Gordov and G.S. Hmel'nitskii, in: *Proceedings of the First Interrepublic Symposium on Atmospheric and Oceanic Optics* (Tomsk Affiliate of the SB RAN, Tomsk, 1994), Part 2, pp. 44–45.

2. R.R. Agishev, L.R. Aibatov, and Yu.E. Pol'sky, Atmos. Oceanic Opt. **7**, No.11–12, 882–885 (1994).

3. G.I.Il'in, O.G. Morozov, and Yu.E. Pol'sky, *ibid.* **8**, No. 12, 1055–1057 (1995).

4. G.I. Il'in, O.G. Morozov, and Yu.E. Pol'sky, in: *Proceedings of the 9th All-Union Symposium on Laser and Acoustic Sounding of the Atmosphere* (Tomsk Affiliate of the SB RAN, Tomsk, 1986), Part 2, pp. 314–317.

5. E.D. Hinkly, ed., *Laser Monitoring of the Atmosphere* (Springer Verlag, New York, 1976).