CONSTRUCTION PECULIARITIES OF ELECTROOPTICAL AMPLITUDE-PHASE GENERATORS OF BI-FREQUENCY LASER RADIATION FOR DIFFERENTIAL LFM-LIDARS

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The characteristics of different generators of bi-frequency laser radiation used in differential LFM-lidars are comparatively analyzed, and the analysis results are presented. The development of amplitude-phase electrooptical devices of this class is shown to have considerable promise. Different schemes are considered. Results of experimental study of output spectral purity as a function of transformation parameters are presented. This function is considered as a main function determining the metrological characteristics of the LFM-lidar as a whole.

1. INTRODUCTION

Works on development the principles of construction and technical realization of multi-purpose LFM-lidars intended for differential study of structure and dynamics of the natural atmosphere noticeably liven up in recent years. The distinctive feature of every lidar scheme is the method of generation of bi-frequency laser radiation and its modulation: Cn_2 laser tuned with piesoceramic mirrors and a wave length switch,[1] Germanium crystal amplitude electrooptical modulator and two He–Ne lasers at close transitions,[2] Zeeman splitter on resonance photoelastic modulator,[3] and electrooptical transformer of single-frequency coherent radiation into bi-frequency one.[4]

In addition to these devices, known are mechanical and acousto-optical modulators widely used to obtain the bi-frequency radiation.[5] All the above references evaluate the possibilities of a particular scheme of LFM-lidar from the viewpoint of the classical theoretical approach, and no one justifies the choice of generator of bi-frequency laser radiation, whereas just the generator metrological characteristics to a great degree determine the metrological characteristics of lidar as a whole.

This paper is mainly aimed to determination of the most rational methods for generation of bi-frequency laser radiation. Then these methods will be used as the basis for development of devices ensuring high purity and stability of output spectral characteristics, as well as the possibility of smooth tuning of difference frequency by a given law and with a given rate that is necessary for creation of multi- purpose lidars.

2. COMPARATIVE ANALYSIS OF CHARACTERISTICS OF THE EXISTING GENERATORS OF BI-FREQUENCY LASER RADIATION

At the first stage of our study, we have conducted the comparative analysis of the existing generators of bi-frequency laser radiation (GBLRs) in the following characteristics: capability to reproduce wavelengths and their difference frequency, difference frequency range, stability and equality of amplitudes of both frequency components, possibility of radiation frequency tuning by a given law with a given rate, linearity of the modulation characteristic, peculiarities of use as a lidar part, and cost of technical realization.

Some initial data borrowed from Refs. 1–5 for comparative analysis are presented in the Table I. The signs "−B and "+B are respectively for summary negative and positive evaluations of characteristics presented in the corresponding columns of the table. These evaluations result from principal possibility to realize the corresponding characteristics for a given GBLR and the comparative evaluation of complexity and cost of realization for different GBLRs. The sign "−/+B means the presence of contradictory opinions in the literature.

Based on the analysis results, we can state that most promising for use in differential LFM-lidars are Zeeman lasers, acoustooptical and electrooptical transformers. However, first, the complexity of smooth frequency tuning explained by the nonlinear *S*-shaped dependence between the difference frequency and the applied field and, second, inconvenient construction of optical schemes associated with the presence of

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angle between the initial radiation and that shifted in frequency put in the forefront the use of electrooptical devices provided that purity and stability of spectral composition of output radiation are improved in the case of deviation of the transformation parameters from the optimal values.

The stated requirements are met in the amplitude-phase electrooptical GBLR with the principle of operation and technical characteristics described in detail in Ref. 4.

TABLE I.

Generators of bi-frequency laser radiation and their characteristics	Range of difference frequencies, MHz	Instability of the difference frequency	Degree of spectral purity of an output signal	Possibility of smooth tuning of the difference frequency	Possibility to create the reference channel for synchronous processing of information
Rotating diffraction grating	0...500	10^{-3}	–	–	–
Two-wave laser	100	10^{-8}	+	–	–
Zeeman Laser	100^{-3}...100	10^{-9}	+	–/+	–/+
Acoustooptical modulator	10^{-2}...100	10^{-6}	+	+	+
Electrooptical modulator:					
polarization	0...20	10^{-6}	–	–	+
phase	0...5	10^{-6}	–	+	+
amplitude-phase	0...200	10^{-6}	+	+	+

3. DIFFERENT SCHEMES OF AMPLITUDE-PHASE ELECTROOPTICAL GBLR

Operation of the amplitude-phase electrooptical GBLR is based on the method of transformation of single-frequency coherent radiation into bi-frequency one. This method consists in amplitude modulation of the initial radiation by the control field with frequency equal to the difference frequency and in switching of the phase of obtained amplitude-modulated vibration when its envelope passes the minimum.[6] In this case, the output radiation spectrum at optimal transformation parameters consists of two components symmetrical against the frequency of suppressed initial radiation and having the same amplitude.

Based on this method, we developed three versions of electrooptical devices by the single-modulator, two-modulator, and single-crystal schemes.

The single-modulator scheme,[7] being the base one, is made on the base of Lithium metaniobate crystal of the electrooptical modulator ML–5. The transformator working point is chosen at the bend of its modulation characteristic, that allow frequency transformation with the help of only one control voltage. The structure scheme of the single-modulator version is shown in Fig. 1.

Two-modulator transformer[8] is also constructed on the base of electrooptical modulators ML–5 and intended for use in precision LFM-lidars. High purity of the spectrum of output radiation in this case is reached at the expense of selection of working points of amplitude and phase modulators at the linear sections of their modulation characteristics. The structure scheme of the two-modulator version is shown in Fig. 2.

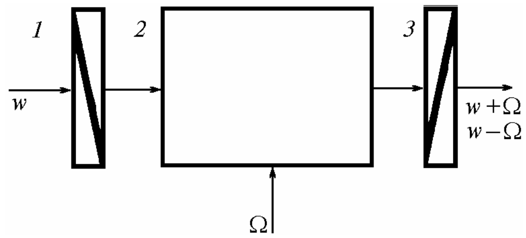

FIG. 1. Structure scheme of the single-modulator electrooptical device for transformation of single-frequency radiation into bi-frequency one: polarizators (1 and 3) and electrooptical modulator (2).

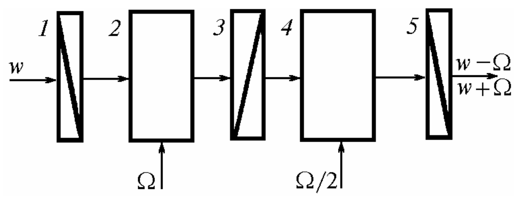

FIG. 2. Structure scheme of the two-modulator electrooptical device for transformation of single-frequency coherent radiation into bi-frequency one: polarizators (1, 3, and 5); electrooptical modulators (2 and 4).

The single-crystal transformer[9] includes two pairs of control plates for realization of amplitude modulation and phase switching at a single crystal. The transformer was developed for studies at different wavelengths of laser radiation. The known electrooptical GBLRs, including single-modulator and two-modulator transformers, include narrow-band $\lambda/4$

and $\lambda/2$ polarization transformers, hence they can be used at only one certain laser wavelength. When using the Lithium metaniobate crystal, the transmission window is from 0.4 to 4.5 μm. The structure scheme of the single-crystal version is shown in Fig. 3.

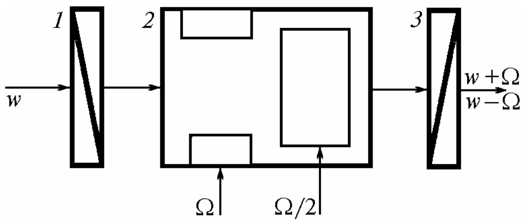

FIG. 3. Structure scheme of the single-crystal electrooptical device for transformation of single-frequency coherent radiation into bi-frequency one: polarizators (1 and 3); electrooptical crystal with two pairs of control electrodes (2).

When using the Germanium crystals basic for electrooptical modulators ML–7 and ML–8, similar schemes can be constructed for the range 10.6 μm.

4. STUDY OF THE PURITY OF OUTPUT RADIATION SPECTRUM IN AMPLITUDE-PHASE ELECTROOPTICAL GBLRs

Main characteristics of GBLRs determining the metrological characteristics of LFM-laser as a whole are the output radiation spectrum purity and its stability when transformation parameters deviate from the optimal ones.

The study of influence of transformation parameters deviation from the optimal ones on the spectral composition of output radiation for different schemes of amplitude-phase electrooptical GBLR was performed at the experimental setup constructed on the base of scanning interferometer SAI–8.

For two-modulator and single-crystal schemes, 30% deviation of the phase switching parameter from the optimal value on retention of optimal voltage of amplitude modulation results in 10% and 50% decrease of the amplitude of useful and parasitic components, respectively. The coefficient of nonlinear distortions in this case does not exceed 4%. The 30% decrease of optimal voltage of amplitude modulation on retention of optimal value of the parameter of phase switching results in 5% increase in amplitude of parasitic components and insignificant decrease in amplitude of useful components. The coefficient of nonlinear distortions in this case does not exceed 10%. With optimal transformation parameters, the coefficient of nonlinear distortions is 1%.

The output radiation spectrum for single-modulator scheme when operating at the optimal working point Γ_{opt} is determined by the following expression:

$$e_{out}(t) = -jE_{in}\, e^{jwt}[2\sum J_{2k+1}(Z)\sin(2k+1)\,\Omega t], \quad (1)$$

where w is the frequency of initial single-frequency radiation; Ω is difference frequency; $J_{2k+1}(Z)$ is the Bessel function of the $(2k+1)$th order; Z is the transformation parameter determined by the amplitude of modulating voltage; j indicates that polarization of the output bi-frequency radiation is orthogonal to the initial single-frequency radiation.

When the position of the working point deviates from the optimal value, the spectral pattern changes markedly, and it is determined by the following expression:

$$e_{out}(t) = -j(\sqrt{2}/2)\,E_{in}\,e^{jwt}[J_0(Z) +$$
$$+ 2\sum J_{2k}(Z)\cos 2k\,\Omega t +$$
$$+ 2\sum J_{2k+1}(Z)\sin(2k+1)\,\Omega t]. \quad (2)$$

Thus, change in the position of the working point has significant influence on the spectral composition of output radiation. The results of experimental studies of relative amplitude of spectral components of output radiation n as a function of the position of the working point Γ are shown in Fig. 4. Zero point corresponds to the position Γ_{opt}.

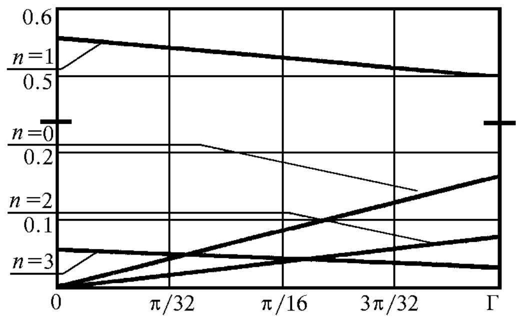

FIG. 4. Relative amplitude of spectral components of output bi-frequency radiation vs. the position of the working point.

It should be noted that, at any changes in spectral composition, the equality of amplitudes of useful components remains undistorted by virtue of spectrum symmetry. At optimal transformation parameters, the coefficient of nonlinear distortions is 1%. Temperature changes and inaccurate adjustment result in shift of the transformer working point by 0.02 V/°C and 2 V/min of arc, respectively, and cause insignificant spectral changes of additive character.

5. CONCLUSION

Elaboration of amplitude-phase electrooptical generators of bi-frequency laser radiation is the promising direction of development of differential LFM-lidars. Capabilities of devices of this class can be used in both visible and near infrared wavelength ranges, as well as in the range of 10.6 μm. In this case, ensured are:

– low coefficient of nonlinear distortions;

– high stability of frequency and energy characteristics of transformers;

– possibility of smooth tuning of the difference frequency by a given law with a given rate.

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