ECHO SIGNAL DETECTION WITH A HE–HE LASER GENERATING ON LINKED TRANSITION

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Operation of a coherent lidar with intracavity detection of echo signals with a laser generating on linked transitions is discussed. The sensitivity of a two–frequency He–He laser can exceed the sensitivity of the single–frequency one by a factor of nine.

1. Laser detection of optical echo signal is successfully employed in coherent lidar systems used to investigate the atmospheric parameters.[1–4] A high–sensitivity lidar scheme with a two–frequency laser detector (LD) generating on linked transitions was proposed and substantiated in Refs. 5 and 6. The principal advantage of this lidar along with the apparent increasing of its functional capabilities consists in a significant increase in sensitivity in comparison with the case of a single–frequency intracavity detection. Two models of a lidar with a two–frequency LD were investigated in Ref. 6: *A* — the sensing and recording are performed on a single wavelength; *B* — the sensing is conducted on one wavelength, while the recording is realized on laser radiation generated on an adjacent transition. The conditions were found under which the sensitivity of a two-frequency LD is significantly increased in comparison with the case of a single–frequency one.

The aim of our experiments is to study variations In the sensitivity of recording of the weak echo signal with a He–Ne laser at $\lambda = 0.63$ μm when generation is excited on linked transition at 3.39 μm.

2. A relative variation of the intensity of generation (the degree of modulation) of a two–frequency laser, detecting the signals reflected from an external mirror has the form[6]

$$\frac{\delta I}{I} = (1-\eta_{12})^{-1}\frac{\delta A_1}{A_1} - \eta_{21}(1-\eta_{21})^{-1}\frac{\delta A_2}{A_2} \qquad (1)$$

in the presence of losses in the external laser resonator. Here $\delta I = I(A + \delta A) - I(A)$, $A_{1,2} = \kappa_{1,2} - \varkappa_{1,2}$ characterizes the gain excess $\kappa_{1,2}$ over losses $\varkappa_{1,2}$ and η_{12} and η_{21} are the coefficients of nonlinear coupling of waves being generated by the laser. In this case $\delta A_2 = \delta\kappa_2$ and $\delta A_1 = \delta\kappa_1 - \delta\varkappa_1$. The indices 1 and 2 in Eq. (1) correspond to: 1 — $\lambda = 0.63$ μm, 2 — $\lambda = 3.39$ μm. The variation δA_1 is caused by losses $\delta\varkappa_1$ induced in external resonator (R_0, R_1) (Fig. 1) at $\lambda = 0.63$ μm, and the variation $\delta\kappa_2$ is caused by the optogalvanic effect.[7]

We now reduce Eq. (1) to a form suitable for comparing with the sensitivity of a single–frequency LD $\delta I/I = \delta A/A$ (Ref. 6)

$$\frac{\delta I_1}{I_1} = \frac{1-\eta_{21}\left[1-\tilde{\Delta}(1-\eta_{12})\right]}{(1-\eta_{12})(1-\eta_{21})}\frac{\delta A_1}{A_1},$$

where $\tilde{\Delta} = \dfrac{\delta A_2}{A_2}\Big/\dfrac{\delta A_1}{A_1}$. Apparently, the value of the factor of $\delta A_1/A_1$ determines an increase (decrease) in sensitivity of a two–frequency LD in comparison with a single–frequency one. It follows from Eq. (2) that for

$$\tilde{\Delta} \lessgtr \frac{\eta_{12}(1-\eta_{21})}{\eta_{21}(1-\eta_{12})} \qquad (3)$$

the sensitivity increases (upper sign) *or* decreases (lower sign).

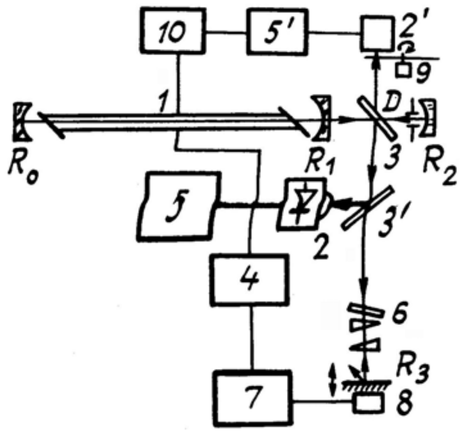

FIG. 1.

Let us assume that $I_1 > I_2$, i.e., $\eta_{21} \to 1$, $\eta_{12} \to 0$.[6] In this case inequality (3) is simplified to

$$\tilde{\Delta} \lessgtr 0.$$

It is easy to see that the sign of $\tilde{\Delta}$ depends on that of δA_1, since we consider a two–frequency regime of generation for which $A_{1,2} > 0$ and $\delta\kappa_2 > 0$ (an increasing part of the dependence of κ_2 on the discharge current strength i_d). For low values of i_d and small oscillations of the external mirror we have $\delta\kappa_2 > \delta\kappa_1$ and consequently $\tilde{\Delta} > 0$. According to Eq. (4) it means a decrease in the sensitivity. However,

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with increase of the discharge current strength the effect of the variation of the field in the resonator upon i_d is weakened, and δA_1 becomes negative. This effect will result in increase in sensitivity.

Let us consider the second regime in which the detection is realized on the wavelength of the weak field, i.e., $I_1 < I_2$. Then $\eta_{21} \to 0$ and $\eta_{12} \to 1$.[6] The right side of inequality (3) will vanish zero with increase of I_2 when it approaches I_2^{max}. Hence, the lower sign will be correct in inequality (3) meaning an increase in the sensitivity of the two-frequency LD in comparison with a single–frequency one.

3. The experimental arrangement is shown in Fig. 1. An LG–126 slightly modified three–frequency He–Ne laser was employed with a gas–discharge tube *1* 90 cm long and 3 mm in diameter. To obtain two–wavelength generation on transitions linked via their common upper level, a three–mirror resonator was used. The visible light was generated between the mirrors R_0 and R_1 in the maxima of reflection at $\lambda = 0.63$ μm and the radii of curvature of 2 m. The resonator for IR radiation was formed by the mirrors R_0 and R_1 and an aluminum mirror R_2. A thin gallium arsenide plate *3* was inserted between the mirrors R_1 and R_2 to prevent the effect of the mirror R_2 on generation of the visible light. In addition this plate was intended to extract both the visible and IR beams from the resonator. The visible beam having passed through the calibrated attenuators *6*, was reflected from a flat vibrating mirror R_3 and directed back into the laser being investigated. The reflecting mirror 8 was clamped on a piesocorrector with electrodes being fed by a preliminary amplified sine voltage from the SK4–56 heterodyne–spectrum analyzer *4*. The amplitude of the mirror oscillations did not exceed the radiation wavelength and could be continuously regulated using an amplifier *7*. The part of the visible light beam was directed on the photodiode *2* by a glass plate *3'*. The variable component of photocurrent strength was fed to the input of the spectrum analyzer. The constant component of the signal from the photodiode was measured by a voltmeter *5*. Having passed through the chopper *9*, the IR laser beam was recorded by a pyroelectric detector *2*. The output signal of this pyroelectric detector was measured with a selective amplifier tuned to the chopping frequency. Photosignals of both the visible and the IR radiation were visually monitored on a screen of a double–beam oscillograph *10*.

The variation in the degree of modulation of the intensity of laser generation was studied at $\lambda = 0.63$ μm with laser generating on the transition at the 3.39 μm as functions of the discharge current strength for a fixed effective reflectance of the vibrating mirror R_3 (Fig. 2) and of the effective reflectance of that mirror for a fixed discharge current strength and a given intensity of laser generation of the IR radiation (Fig. 3). The sensitivity of a two–frequency LD may both increase and decrease in comparison with that of a single–frequency detection (Fig. 2). Under optimal conditions, a nine–fold excess in sensitivity of a two–frequency LD was recorded in comparison with the single–frequency detection within a wide range of reflectance of the external mirror (Fig. 3). The obtained experimental results agree qualitatively with theoretical conclusions of Ref. 6 and item 2 of the present paper. The problem of the limiting value of.the increase in sensitivity of a two–frequency LD, in comparison with that of a single–frequency sensitivity will be treated statistically elsewhere.

Thus it has been demonstrated both theoretically and experimentally that the sensitivity of a lidar with two–frequency LD may be several times higher in comparison with a single–frequency detector.

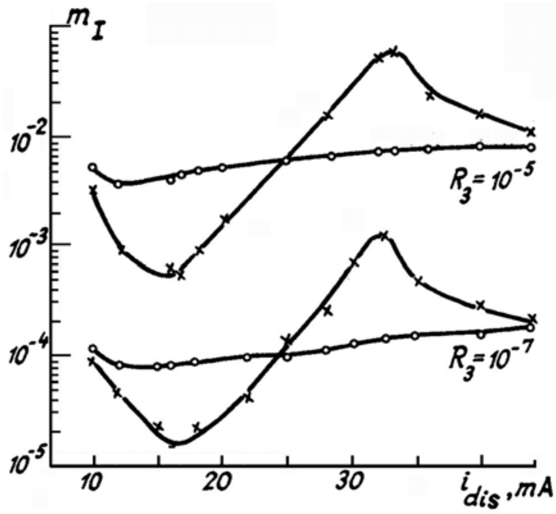

FIG. 2. The degree of modulation of the intensity of laser generation at $\lambda = 0.63$ μm *vs the discharge current strength for two values of reflectance of the external mirror* R_3. *Empty circles — single–frequency generation; crosses — two–frequency generation.*

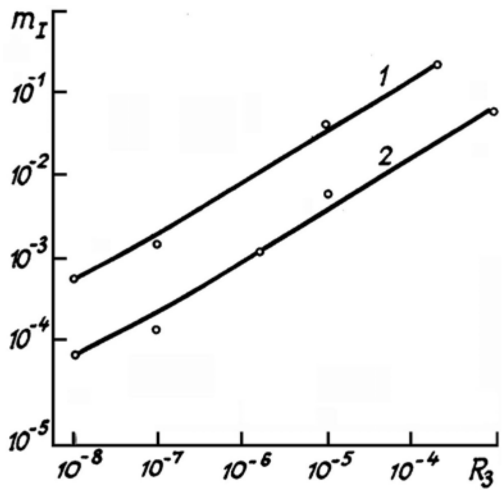

FIG. 3. The degree of modulation of the intensity of generation of a He–Ne laser at $\lambda = 0.63$ μm *vs reflectance of the external mirror. 1 — laser generation on linked transitions; 2 — single–frequency laser generation of a He–He laser.*

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