

LIDARS

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Optimisation of frequency-modulated characteristics of output radiation in a lidar with Raman amplification

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Abstract. **The reported study is aimed at increasing the power in the transmission path of a lidar with Raman amplification for long-path sensing of methane by optimising the frequency-modulated characteristics of the output radiation. The pump current of the used distributed-feedback master laser was modulated by a linear-frequency signal with simultaneous application of a non-synchronous high-frequency signal. For such a modulation regime, the Raman amplifier provided the mean output power of 2.5 W at a wavelength of 1650 nm. The spectral broadening did not significantly decrease the lidar sensitivity at long paths.**

Keywords: *lidar, Raman amplifier, laser, Brillouin scattering.*

To increase the Brillouin scattering threshold in optical fibre, the authors of Ref. [1] proposed to use additional frequency modulation of the laser pump current with the aim of increasing the distance of consistent reception via the fibre-optical communication line. In Ref. [2] this idea was applied to increase the Brillouin scattering threshold in the fibre of a Raman amplifier, used for methane sensing. At the output of such an amplifier the power of ~1 W was obtained. The results of methane detection at the distance ~10 m were presented.

The aim of the present paper is to study the possibility of obtaining a maximal power of radiation at the output of the Raman amplifier for increasing the range of lidar operation by using optimised frequency-modulated characteristics of the output without noticeable reduction of the lidar sensitivity for methane detection.

Below we present the results of optimising the transmitting path with a Raman amplifier by additional high-frequency modulation of the pump current of the master laser source, which provided the mean power at the amplifier output ~2.5 W and the power in the maximum of linear-frequency signal greater than 3 W without a noticeable reduction of the lidar sensitivity. At first, the spectral width of the optical signal at the output of the fibre Raman amplifier amounted to ~0.0005 nm (~60 MHz), and the amplifier was used as a component of the setup, the schematic of which is presented in Fig. 1. The target distance was ~100 m. The oscilloscope recorded the signals from the reference photodetector 1 and photodetector 2 that received the signal from the remote target. The oscillograms of the signals from the photodetectors are shown in Fig 2 for the case of a narrow-band spectrum of the optical signal. It is seen that the signal received by photodetector 2 is strongly distorted due to the interaction of the scattered Brillouin signal with the useful signal in the fibre of the Raman amplifier. From period to period of the linear-frequency modulating (LFM) signal the chaotic fluctuations do not repeat each other, i.e., the observed noise is nonstationary and irremovable.

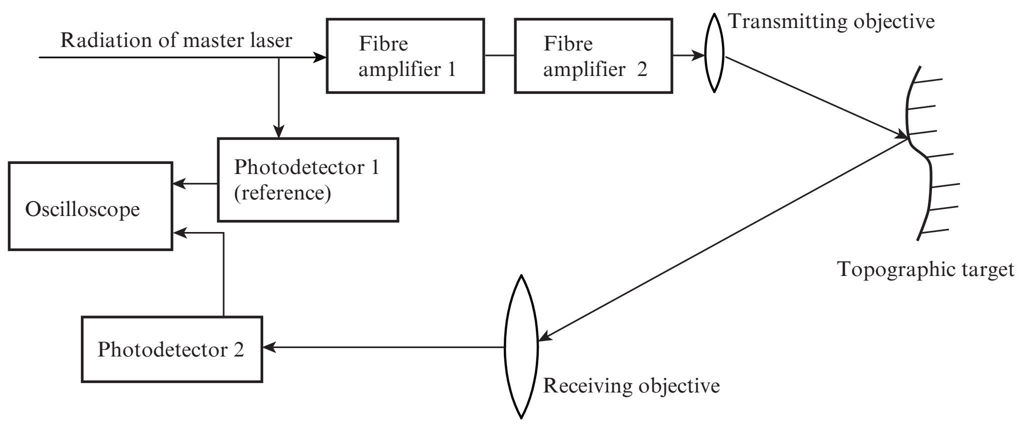

Figure 1. Block diagram of the setup for methane detection.

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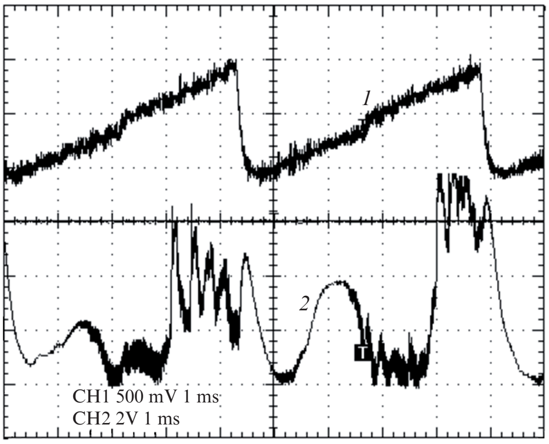

Figure 2. Signals from photodetectors 1 (*1*) and 2 (*2*). Signal (*2*) is produced by reflection of light from a grey brick placed at a distance of 100 m from the lidar. The output power of the lidar is 2.5 W.

To eliminate the mutual influence of two optical coherent signals (the useful and the scattered one), a non-synchronous additional signal with the frequency 36 MHz was admixed to the signal modulating the laser pump current. Hence, alongside with the LFM component with the frequency ~200 Hz the total modulation signal incorporated the component with the frequency 36 MHz and the optimal amplitude. The frequency of the additional modulation was chosen based on the following considerations: the smaller this frequency would be, the greater amplitude would be necessary to provide the maximal nondistorted output signal of the lidar. However, the increase in the amplitude of the additional modulating signal lead to the broadening of the output radiation spectrum, which reduced the methane detection sensitivity of the lidar. On the other hand, the amplitude of the additional signal did not noticeably affect the time dependence of the output radiation intensity at frequencies beyond 36 MHz, so that it could be chosen minimal for this frequency. Under the optimal additional modulation, the optical spectrum width increased up to 0.03 nm at the 3 dB level. In this case the signal received from the trace became stable (Fig. 3) with slight white noise easily amenable to averaging.

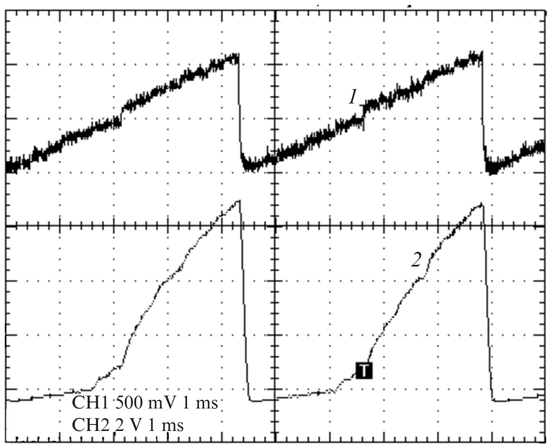

Figure 3. Same as in Fig. 2, but with additional nonsynchronous modulation of the laser pump current with the frequency 36 MHz.

As shown in Ref. [2], the Brillouin scattering threshold increases proportionally to the ratio of the widths of the broadened spectrum and the initial spectrum of the signal source, i.e., in our case by 0.03/0.0005 = 60 times. In the absence of additional high-frequency modulation, the threshold of the Brillouin scattering amounts to 20 mW [2], and in the presence of this modulation, it equals 1200 mW. As a result, the Brillouin scattering does not produce undesired noise in the signal received from the trace.

Let us estimate the loss of the lidar sensitivity due to the additional broadening of the radiation line. Figure 4 presents the dependence of the relative sensitivity of the lidar detecting methane (the absorption line width is assumed to equal 0.1 nm) on the line width of the lidar radiation $\Delta\lambda$. It is seen that the sensitivity decreases insignificantly with increasing line width. Thus, for $\Delta\lambda = 0.03$ nm the decrease in sensitivity is only ~6%. The output power of the lidar increases by six or seven times, so that the loss of sensitivity does not affect the accuracy of measurements, and the lidar range increases by two or three times. The calculations were performed using the Mathcad programme.

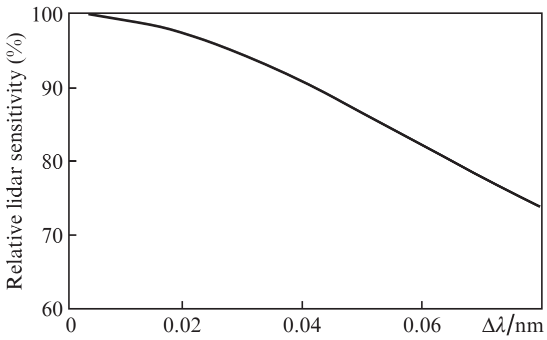

Figure 4. Relative sensitivity of the methane detecting lidar as a function of the line width of the lidar radiation $\Delta\lambda$.

For example, Fig. 5 presents the results of measuring the concentration of methane in the calibrated cuvette, located at the measurement path, the light being reflected from a grey silicate brick. The first measurements were performed without the methane cuvette at the measurement path, and then the cuvette was installed in front of the collimator of the transmitting laser. The transmission and reception optical systems were separated by ~10 cm, so that the parasitic reflection from the cuvette did not appear in the receiving path and did not perturb the results of recording weak input optical signals. The total length of the trace (forth and back)

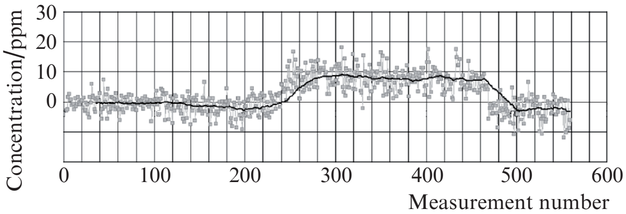

Figure 5. Measured methane concentrations in the calibrated cuvette (points) and their approximation (solid curve). The distance to the target is 1.2 km.

amounted to 2.4 km. Each point in Fig. 5 corresponds to a single measurement during ~50 ms. The optical density of methane in the cuvette was equal to that of a methane layer 15 mm thick at the atmospheric pressure, which corresponded to the mean concentration of methane ~6 ppm at the given path. By approximating the measured concentrations with a linear filter (solid curve in Fig. 5) one can reliably determine the variation of the background signal, equivalent to the methane concentration of 2–3 ppm at the path.

Thus, the studies carried out allowed an increase in the lidar output power by 6–7 times without a noticeable reduction of its sensitivity in methane detection. For the used Raman amplifier the optimal amplitude and frequency of additional modulation of the pump current of the laser source were found that reduce practically to zero the undesired coherent Brillouin scattering in the output fibre of lidars.

References

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2. Mitchell D., Duffin K., Johnstone W. *Proc. SPIE Int. Soc. Opt. Eng*., **7503**, 750350 (2009). Doi: 10.1117/12.835810.