High Precision Registration of Optical Picosecond Impulses Responses in Case of Their Propagation in Natural and Artificial Environments

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Abstract— **In this paper, a scheme of a subpicosecond dispersion range-finder is proposed and an estimate of the precision of range-finding for large distances in open atmosphere using this device is performed. Using subpicosecond pulses allows us not only to improve range-finding precision, but also to eliminate the effect of air refractive index indeterminacy on the path of propagation quite effectively.**

I. INTRODUCTION

In recent years, subpicosecond laser technique has been developed rapidly. Record low durations of femtosecond and even shorter laser pulses are obtained. In this connection, new opportunities for measuring devices arrive, in which pico- and subpicosecond laser pulses may be used. In this paper, a scheme of a subpicosecond dispersion range-finder is proposed and an estimate of the precision of range-finding for large distances in open atmosphere using this device is performed. Using subpicosecond pulses allows us not only to improve range-finding precision, but also to eliminate the effect of air refractive index indeterminacy on the path of propagation quite effectively. Even in 1957, in [1] a way of eliminating air refractive index indeterminacy on the path by using two rays with different wavelengths, which propagate at different speeds by virtue of normal air dispersion, and basing on this fact, one can compute the average air refractive index on the propagation path. Currently, quite a lot of two-wave (dispersion) range-finders have been produced and work on geodynamical and geophysical polygons. However, the precision does not exceed the value of $3 \cdot 10^{-7}$ (3 mm per 10km) because of a number of factors, the main of which is using two lasers (or one laser with frequency doubling) or two photo-receivers with non-uniform light-sensitive elements. In a situation of random variations of laser directivity diagrams, the spots on the light-sensitive area elements of photo-receivers change their position that yields a significant error in phase measurements, and, therefore, in range-finding too [2, 5].

II. METROLOGY

In this paper, a scheme of a dispersion range-finder is proposed, in which just one laser and one photo-receiver used. In Fig. 1, a simplified block scheme of a range-finder is presented. Here 1: a laser of a wavelength of 0.4mkm emits short pulses of duration of 10^{-13} s, provided by the modulator of laser 2. The laser wavelength is chosen in order to make air dispersion as large as possible, and, hence, widening of the pulse on receiving would be bigger. The laser beam is directed onto retro reflector 8 by transmitting lens 3, and then received by receiving lens 4. Photo-receiver 5 converts the optical pulse into electric, which is directed into the pulse delay time processing block 7 and pulse duration processing block 6.

The main formula for determining the distance **D** by a dispersion range-finder is written as follows:

$$D = L_1 - f(\lambda_1)\cdot(L_1 - L_2)/[f(\lambda_1) - f(\lambda_2)] \quad (1)$$

where $\mathbf{L_1}$ and $\mathbf{L_2}$ are optical lengths measured by the device at the wavelength $\lambda_1$and λ_1, and $\mathbf{f(\lambda)}$ is a function depending only of the light wavelength. Formula (1) and Fig. 1 imply that the pulse duration processing block determines (L_1-L_2) and the pulse delay time processing block determines L_1. In the case of modulation of the laser by a short pulse of length t_0, the width of the spectral radiation width is df ~ $2/t_0$ = 2 10^{13} Hz, in this case, the magnitude $f(\lambda_1)/[f(\lambda_1)-f(\lambda_2)]$ is about 150 on the edges of this spectral width.

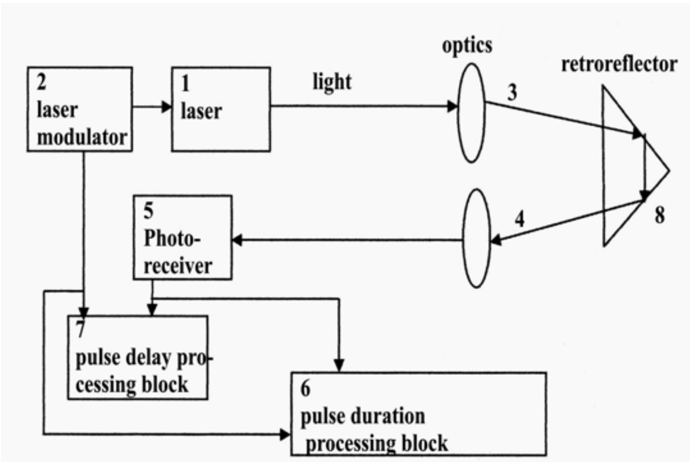

Fig. 1. Block scheme of the dispersion range-finder

This is resulted from the dependence of refractive capability of air on light frequency (fig. 2) and from the formula, connecting the refractive capability of air and the function $\mathbf{f(\lambda)}$

$$f(\lambda_1)/[f(\lambda_1) - f(\lambda_2)] = N(\lambda_1)/[N(\lambda_1) - N(\lambda_2)] \cong 150 \quad (2)$$

for the accuracy of measuring the time intervals equal δ t =$t_0/3$ = $0.33 \cdot 10^{-13}$ s from equation (1), we obtain the error of measuring D : δ D = 151$\cdot\delta$ t$\cdot$c = 1.51 mm. This range-finding accuracy is higher by a factor of 1.5 — 2 than the present accuracy of existing dispersion range-finder. In addition, the time of computing average values of measurements in the

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considered device may be reduced significantly, since the necessity of taking the average values of slow displacements of spots of the received radiation by sensitive area elements of photodiodes [2].

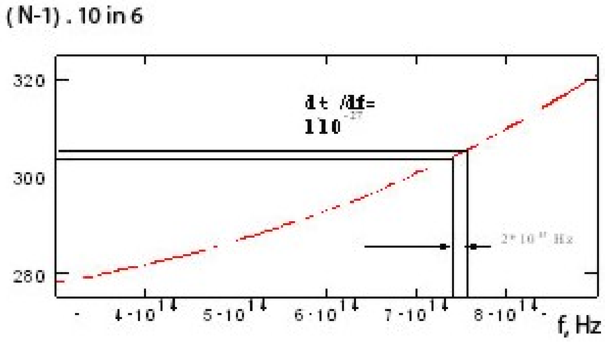

Fig. 2. The dependence of the refraction index of air on light frequency

In this case, equation (1) takes the following form:

$$D = L_1 - 150 \cdot (L_1 - L_2) \qquad (3)$$

and the error of measuring the distance becomes as follows

$$\delta D \approx \delta L1 + 150 \cdot \delta(L1 - L2) = c \cdot \delta t + 150 \cdot c \cdot \delta t = 151 \cdot c \cdot \delta t \quad (4)$$

In the scheme we consider these displacements are absolutely synchronous in the entire frequency range of the radiation, since, first, there is only one receiver and, second, there is no noticeable divergence of spectral components of the radiation because of atmosphere refraction. It is interesting to estimate the duration t_1 of the incoming pulse, in the case if the outgoing pulse has a duration of $\mathbf{10^{-13}}$ sec. Using the equation from [3] for the received pulse in the dispersing environment with time dispersion per a unit of length dt/df ,we have:

$$t1 = \{t_0{}^2 + [(2L / \pi\tau_0) \cdot (d\tau / df)]^2\}^{1/2} = 60 \text{ ps} \qquad (5)$$

In formula (5), the relation of time dispersion and the refractive capability of air is dt /df = dN /df · (L/c), where L=1 m, and c is the speed of light in vacuum. Thus, the duration of pulse during receiving is increased by a factor of 600 compared with the duration of the pulse emitted. Of course, measuring of these time intervals with a precision about 10^{-13} sec is itself a rather complicated but solvable problem.

The simplified scheme of a range finder can be executed, for example, on the basis of a known way of transformation femtosecond light impulses in terahertz impulses [4].

At our opinion, the dispersion range-finders constructed according to the scheme presented, may be used effectively not only in geophysical range-finders, but also in satellite range-finders, since a rather no long taking of average values of the results of measurements, and also by virtue of the fact that small durations of pulses may be obtained with high peak power.

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