NEW PHOTODETECTOR - METER OF THE CORRELATION FUNCTION OF OPTICAL SIGNALS

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ABSTRACT

The principles of device for measurements of correlation function counter optical signals are presented. Matrix photodetector is a basis new correlator. Each cell of matrix is photodetector sensitivity to an interference field. The examples of experimental implementation new photodetector presented. The interferograms for response of a photoresistor PbS and multialkaly vacuum phototube on an interference field of counter luminous fluxes from a source of coherent radiation by power 1 mw, λ= 633 nm are measured. The ratio signal noise for interference responsive was achieved more than one hundred.

Keywords: correlator, interferometer, photodetector, interference field, counter optical signals, holographic images, standing waves

1. INTRODUCTION

The possibility of build-up a meter of the correlation function of counter light signals is attractive. It is implemented in such type of interferometers, in which light beams are moved in opposite directions [1] in the field of registration of an interferogram. The interferometer of the Wiener is an example of such interferometer. It consists from a photoplate press to a surface of a plane mirror. For the first time photoplate was exchanged with a photodetector H. Ives and T. Fry [2]. In this operation the photodetector consist of a thin and transparent photoelectric stratum. The experiment is fulfilled on an interferometer of the Wiener. This idea of replacement of a photoplate in on a photoelectric stratum has received development in the works [3,4,5]. However, the photodetectors were not constructed for industrial application. The problem consists of receiving response of a photodetector to loops and crests of a standing wave with a high relation a signal to noise. It was required about 20 years for creation of such photodetector. The solution is offered in work [6,7]. The model of a photodetector in composition of an one-reflecting interferometer for the first time presented on the exhibition in "7-th International Simposium on Laser Metrology applied to Science, Industry and Everyday Life " – (LM-2002) September 9 – 13, 2002, Novosibirsk, Russia. The ratio signal noise was achieved more than one hundred.

2. NEW PHOTODETECTOR - METER OF THE CORRELATION FUNCTION OF OPTICAL SIGNALS

The conventional spectrometers of Fourier transform usually contain two or more mirrors, beamsplitter, photodetector, device for changing and accurately measuring parth difference.

In them by a photodetector registers intensity of interfering luminous fluxes, which depended from relative temporary shift. Thus intensity depended from change of a difference of lengths of paths, which luminous fluxes went [8]. This dependence is a correlation function of luminous fluxes. As a rule, the change of a difference of lengths of paths (propagation difference) is implemented by moving of a mirror. In conventional interferometers two interfering waves are spread in a point of registration in one direction. We will consider another type of interferometers with contrary motion light streams in the registration field.

In a meter of the correlation function of luminous fluxes operating interferential - responsive photoelectric stratums (photosensitive stratums having electrically gauged response and them possessing sensitivity of electrical response to the position concerning nodal and bulges points of the standings wave interfering counter luminous fluxes [6]), the interference of two waves moved in opposite directions takes place. The function circumscribing an energy distribution of counter light waves in space and depending on an optical path difference of counter light beams or phase delay, it is a correlation function of counter luminous fluxes.

The photodetector - meter of the correlation function of optical signals is shown in Fig.1. Its take place in the interference field from counter light beams $S^{(1)}$ and $S^{(2)}$, which have got a plane wave front. The plane of wave front and plane photosensitive lairs are parallel. There are N photosensitive lairs 2 in the photodetector 1. We will believe that photosensitive lair is interference sensitive if it has sensitivity to nodal and bulges points of standing wave. The i-th interference sensitive lair is arranged at some optical distance from the first external flatness 3 of correlator 1. This optical distance is equal

$$l_i^{(1)} = \left(l_2^{(1)} - l_1^{(1)}\right) \cdot (i-1) + l_1^{(1)} . \quad (1)$$

The i-th interference sensitive lair is arranged at some optical distance from the second external flatness 4 of correlator 1. This optical distance is equal

$$l_i^{(2)} = \left(l_1^{(2)} - l_2^{(2)}\right) \cdot (N-i) + l_N^{(2)} . \quad (2)$$

The correlation function $B(\tau_i)$ for contrary flexes measure with interval discreteness for N counting out. The temporal interval discreteness of this flexes is equal

$$\Delta\tau = \frac{\left(l_2^{(1)} - l_1^{(1)}\right) + \left(l_1^{(2)} - l_2^{(2)}\right)}{c} , \quad (3)$$

where i - integer from 1 to N,
c – rapidity of light in vacuum,
phase shift for this flexes $\tau_i = (i-1)\cdot\Delta\tau$. Optical distance is result multiplication geometrical road light beam and average index refraction of material. Optical distance from flatness j to i photoelectric layer is equal

$$l_i^{(j)} = \int_0^{r_i^{(j)}} n_i^{(j)}(r)\cdot dr , \quad (4)$$

where
j – number external surfaces correlator ($j = 1;2$);

$r_i^{(j)}$ – geometrical distance from flatness j to photoelectric layer i.

$n_i^{(j)}(r)$ - index refraction of material on the road light flex $S^{(j)}$ at the distance r from flatness j .

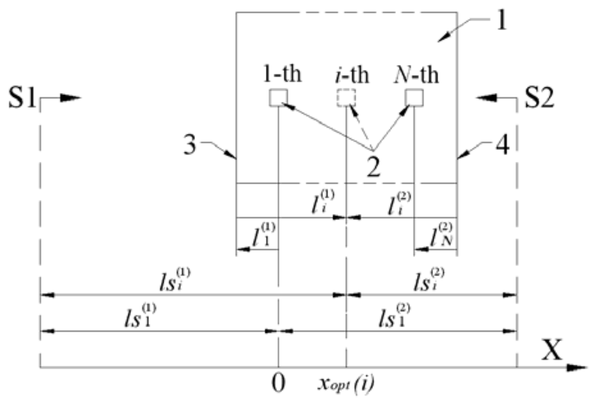

Fig.1. Schematic diagram of the meter correlation function for contrary flexes of optical signals. S1, S2 - contrary light flexes; 1 – correlator; 2 – interference sensitive photodetectors; 3,4 - external flatness of correlator 1.

Optical distance from j source of light for light stream $S^{(j)}$ to i photoelectric layer is equal

$$ls_i^{(j)} = \int_0^{rs_i^{(j)}} ns_i^{(j)}(r)\cdot dr , \qquad (6)$$

where

j – number light stream ($j = 1;2$);

$rs_i^{(j)}$ - geometrical distance from source j light stream $S^{(j)}$ to photoelectric layer i;

$ns_i^{(j)}(r)$ - index refraction of material on the road light flex $S^{(j)}$ at the distance r from source light stream j.

The first photoelectric layer is take place at the equal optical distances from sources light streams $S^{(1)}$ and $S^{(2)}$. The mutual temporal shift for signals $S^{(1)}$ and $S^{(2)}$ in this place is equal zero.

The amplitudes of their electric field, accordingly, are equal $E^{(1)}(t)$ and $E^{(2)}(t)$. Everyone i-th the photoelectric stratum registers average intensity. The time of average is equal by time constant of this stratum. The intensity is in proportion

$$I_i(t) \cong \left\langle \left[E^{(1)}(t-(i-1)\cdot\Delta\tau^{(1)}) + E^{(2)}(t+(i-1)\cdot\Delta\tau^{(2)})\right]^2 \right\rangle =$$

$$= \left\langle \left(E^{(1)}(t-(i-1)\cdot\Delta\tau^{(1)})\right)^2 \right\rangle + \left\langle \left(E^{(2)}(t-(i-1)\cdot\Delta\tau^{(2)})\right)^2 \right\rangle +$$

$$+ \left\langle 2E^{(1)}(t-(i-1)\cdot\Delta\tau^{(1)})\cdot E^{(2)}(t+(i-1)\cdot\Delta\tau^{(2)}) \right\rangle , \qquad (7)$$

where

$\Delta\tau^{(1)}$ - difference delay light stream $S^{(1)}$ from flatness 3 of correlator 1 to (i+1) and photoelectric layer i.

$\Delta\tau^{(2)}$- difference delay light stream $S^{(2)}$ from flatness 4 of correlator 1 to i and photoelectric layer (i+1).

The detentions $\Delta\tau^{(1)}$, $\Delta\tau^{(2)}$ are specified to express by a formulas:

$$\Delta\tau^{(1)} = \frac{l_2^{(1)} - l_1^{(1)}}{c} \text{ and } \Delta\tau^{(2)} = \frac{l_1^{(2)} - l_2^{(2)}}{c} . \qquad (8)$$

The time constants of photoelectric stratums are much greater of frequency period of an electric vector of light fluxes S_1 and S_2 , therefore

$$\left\langle \left(E^{(1)}(t-(i-1)\cdot\Delta\tau^{(1)})\right)^2 \right\rangle = \left\langle \left(E^{(2)}(t-(i-1)\cdot\Delta\tau^{(2)})\right)^2 \right\rangle = I_0 , \qquad (9)$$

where

I_0 - is intensity average over time.

The data reading

$$B(\tau_i) = B((i-1)\cdot\Delta\tau) =$$

$$= \left\langle E^{(1)}(t-(i-1)\cdot\Delta\tau^{(1)})\cdot E^{(2)}(t+(i-1)\cdot\Delta\tau^{(2)}) \right\rangle =$$

$$= \left\langle E^{(1)}(t)\cdot E^{(2)}(t+(i-1)\cdot\Delta\tau) \right\rangle , \qquad (10)$$

where

$\Delta\tau = \Delta\tau^{(1)} + \Delta\tau^{(2)}$ - relational temporal delay light streams $S^{(1)}$ and $S^{(2)}$ are argue for the correlation function of luminous fluxes.

If the light streams $S^{(1)}$ and $S^{(2)}$ from one source, then carry out equality

$$\tau_i = \frac{\left(ls_i^{(1)} - ls_1^{(1)}\right) + \left(ls_1^{(2)} - ls_i^{(2)}\right)}{c} = \frac{ls_i^{(1)} - ls_i^{(2)}}{c} \qquad (11)$$

and $B(\tau_i)$ is an autocorrelation function. If the light streams $S^{(1)}$ and $S^{(2)}$ from other sources, then no carry out equality and $B(\tau_i)$ is mutual correlation function. The correlator is meter an autocorrelation function then one mirror is take place closely to the first interference sensitive photodetector.

Optical correlometer can be applied as optical Fourier transformation spectrometer (FT-spectrometer is optoelectronic microchip), new device can be used for meter a duration of short optical impulses, for electronic registration holographic images, in devices of selective registration of interfering counter luminous fluxes.

3. THE RESPONSE OF INTERFERENCE SENSITIVE PHOTODETECTOR

The interference sensitive photodetector is a base of correlator. It is contain some quantity interference sensitive photodetectors. We will consider the response for one photodetector with one photosensitive layer. For the simplify we suppose, there are two monochromatic waves with flatness wave front. These waves moved in opposite directions (Fig.2.) through transparent photodetector. In particular case the two contrary waves can be obtaining at the reflection from the flatness mirror.

The interference field (standing wave) is there between mirror and light south. The period of interference is equal half of wavelength. The sensitivity of photodetector to nodes and crests has a major maximum if the thickness photoelectric layer is less then $\lambda/2$. However, there are some other maximums of sensitivity then the thickness photoelectric layer is not equal

$\lambda/2$ ($t \neq k\lambda/2n$, n - index refraction photoelectric layer k - arbitrary positive integer number).
The photoelectric layer must be such as transparent as possible in spectral band light sensitivity. The contrast of an interference field of interacting luminous fluxes is maximum at nearly equality of intensities of luminous fluxes. The weakening of intensity of a luminous flux past through a photodetector is featured by the law Buger - Lambert:

$I = I_0 exp(-4\pi n\alpha d / \lambda)$, where I_0 - intensity incident light; I - intensity light emerge through photodetector; α - absorption coefficient photoelectric layer; n - index of refraction; λ - wavelength. The approximate equality of intensities of luminous fluxes $I \approx I_0$ takes place, when product αd is a small. High contrast of an interference pattern and transparency are reached at the expense of small width of a photoelectric stratum.

4. The influence of an optical thickness of a photoelectric stratum and deviation of optical thickness

The detached photodetector (see Fig. 2) consists of a thin photoelectric stratum and transparent substrate. The interference field is result interaction counter luminous fluxes $S1$ and $S2$ of monochromatic radiation with plane wavefront sets, parallel photoelectric stratum.

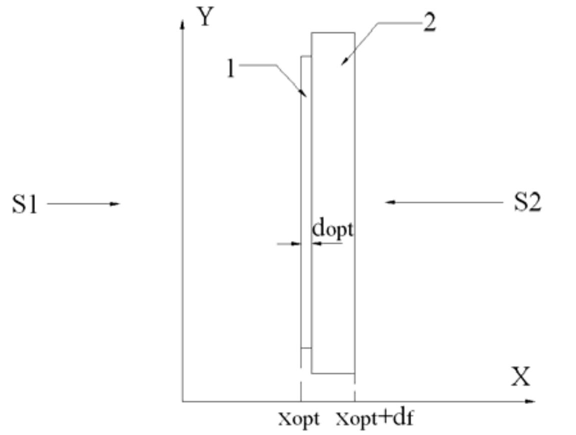

Fig. 2. A position of a photodetector concerning an axis of optical coordinates and contrary flexes. S1, S2 - contrary light flexes; 1 - photosensitive stratum; 2 - transparent substrate.

On an axis X optical distance which is taking into account an index of refraction the environments on a propagation path of luminous fluxes is counted. Optical coordinate of a photoelectric stratum is equal

$$x_{opt} = \int_0^{x_g} n(x)dx, \tag{12}$$

where

x_g - geometrical distance counted from an origin of coordinates;

$n(x)$ - index of refraction of the environment on propagation paths of luminous fluxes along a X axis.

For simplification of reviewing the following initial conditions accepted: the amplitudes and lengths of waves $S1$ and $S2$ are equal; the origin of coordinates is selected from a point of zero space phases of these signals, at zero initial phases. The photosensitivity of an electrical stratum is constant on all size; in limits of working square of a photodetector, deviation of an optical distance of all units of a photodetector and their absorption are very small.

The wave equations of allocation of luminous fluxes $S1$ and $S2$ look like:

$$E_1 = E_m \cos\left(\frac{2\pi}{\lambda}\left(c\left(t+\frac{\tau}{2}\right) - x_{opt}\right)\right), \tag{13}$$

$$E_2 = E_m \cos\left(\frac{2\pi}{\lambda}\left(c\left(t-\frac{\tau}{2}\right) + x_{opt}\right)\right), \tag{14}$$

where E_m –amplitude of an electric vector;
λ - wavelength;
c - speed of light;
t- time;
τ - initial time delay of front $S2$ concerning front $S1$.
The resulting wave can be presented by expression:

$$E_{res} = 2E_m \cos\left(\frac{2\pi}{\lambda}x_{opt} - \frac{\pi c}{\lambda}\tau\right)\cos\left(\frac{2\pi c}{\lambda}t\right). \tag{15}$$

Intensity of a resulting wave:

$$I_{res} \cong \cos^2\left(\frac{2\pi}{\lambda}x_{opt} - \frac{\pi c}{\lambda}\tau\right). \tag{16}$$

The response of a photodetector is proportional to an integral from intensity of a resulting standing wave in limits of width of a photoelectric stratum

$$Q(x_{opt}, \tau, d_{opt}) \cong \int_{x_{opt}}^{x_{opt}+d_{opt}} \cos^2\left(\frac{2\pi}{\lambda}x + \frac{\pi c}{\lambda}\tau\right)dx \cong$$
$$\cong \frac{1}{2}\sin\left(\frac{2\pi}{\lambda}d_{opt}\right)\cos\left(\frac{4\pi}{\lambda}x_{opt} + \frac{2\pi c}{\lambda}\tau + \frac{2\pi}{\lambda}d_{opt}\right) + \frac{\pi}{\lambda}d_{opt}. \tag{17}$$

The parameter describing sensitivity of a phase-sensitive photodetector is the response of a photodetector to an interference signal

$$\Delta Q = Q_{\max} - Q_{\min}, \tag{18}$$

where $Q_{\max}$, $Q_{\min}$ - maximal and minimum values of response of a photodetector at change of coordinate x_{opt} or delay τ in limits of interference period. The dependence of normalized value ΔQ from d_{opt} is featured by expression

$$\Delta Q_{norm}(d_{opt}) = \frac{\Delta Q(d_{opt})}{\Delta Q_{\max}} = \left|\sin\left(\frac{2\pi}{\lambda}d_{opt}\right)\right|, \tag{19}$$

where $\Delta Q_{\max}$ - maximal value of the function $\Delta Q(d_{opt})$.

The response of a photodetector is proportional not only interference component intensity of luminous fluxes. It has a component, proportional average, for period of an interference, intensity of luminous fluxes, that reduces a volume range of interference sensitivity of a photodetector. The parameter describing an interference component of response of an interference - responsive photodetector, is the visibility

$$V = \frac{Q_{\max} - Q_{\min}}{Q_{\max} + Q_{\min}}. \tag{20}$$

The dependence of normalized value V from d_{opt} looks like

$$V_{norm}(d_{opt}) = \frac{V(d_{opt})}{V_{\max}} = \frac{\lambda\left|\sin\left(\frac{2\pi}{\lambda}d_{opt}\right)\right|}{2\pi d_{opt}}, \tag{21}$$

where $V_{\max}$ - maximal value of the function $V(d_{opt})$.

The complex parameter describing efficiency of a phase-sensitive photodetector is the product ΔQV.

The dependence of normalized value ΔQV from d_{opt} looks like

$$\Delta Q_{norm} V_{norm}(d_{opt}) = \frac{\lambda \sin^2\left(\frac{2\pi}{\lambda} d_{opt}\right)}{2\pi d_{opt}} . \qquad (22)$$

The dependencies of the circumscribed above parameters on a normalized optical width of a photoelectric stratum d_{opt}/λ presented on Fig. 3. The photodetector has not interference sensitivity at an optical width of a photoelectric stratum aliquot $\lambda/2$. The interval of an optical width of a photoelectric stratum up to $\lambda/2$ is apart selected where the phase-sensitive receiver is wide-band and has a sharp response of response on an interference signal.

The long wavelength boundary of a working spectral range of a photodetector is determined only by boundary of sensitivity of a photoelectric stratum, and short-wave boundary by minimum width of a photoelectric stratum. The photodetector has dead zones on working lengths of waves λ_0, aliquot doubled width of a photoelectric stratum, that is selective.

5. The influence discontinuity of an optical width of a photodetector

Let's consider response of a photodetector at deviation of its optical width Δd_f. The wave equation of a luminous flux $S2$ for sites of a photodetector by square S, in which limits the deviation of an optical distance is equal $\Delta d_f(S)$, looks like:

$$E_2(S) = E_m \cos\left(\frac{2\pi}{\lambda}\left(c\left(t - \frac{\tau}{2}\right) + x_{opt} - \Delta d_f(S)\right)\right). \qquad (23)$$

For allocation of intensity resulting:

$$I_{res}(S) \cong \cos^2\left(\frac{2\pi}{\lambda}(x_{opt} - \frac{\Delta d_f(S)}{2}) - \frac{\pi c}{\lambda}\tau\right). \qquad (24)$$

Response of sites of a photoelectric stratum by square S, in which limits the photodetector has deviation of an optical distance $\Delta d_f(S)$ is proportional:

$$Q(S) \cong \frac{1}{2}\sin\left(\frac{2\pi}{\lambda} d_{opt}\right)\cos\left(\frac{4\pi}{\lambda}(x_{opt} - \frac{\Delta d_f(S)}{2}) + \varphi\right) + \frac{\pi}{\lambda} d_{opt} , \qquad (25)$$

where $\varphi = \frac{2\pi c}{\lambda}\tau + \frac{2\pi}{\lambda} d_{opt}$.

The aggregate response of a photodetector is proportional:

$$Q \cong \frac{1}{S_f}\int_0^{S_f} Q(S)dS , \qquad (26)$$

where S_f - working square of a photodetector.

The dependence of normalized value ΔQ from $\overline{|\Delta d_f|}$ is featured by expression

$$\Delta Q_{norm}(\overline{|\Delta d_f|}) = \frac{\Delta Q(\overline{|\Delta d_f|})}{\Delta Q_{\max}} , \qquad (27)$$

where

$\Delta Q_{\max}$ - maximal value of the function $\Delta Q(\overline{|\Delta d_f|})$;

$\overline{|\Delta d_f|}$ - average absolute deviation of an optical distance of a photodetector.

According to this dependence, introduced on Fig. 4 for uniform and normal distribution of deviation of an optical distance, at increase of average absolute deviation of width of a photodetector up to λ/4 and more, interference sensitivity of a photodetector diminish, sharply. However, the cuneiform form of a photodetector is admitted (wedge does not reduce in disappearance of a signal on a separate photodetector). i.e., if the deviation of width of a photodetector is linearly distributed on working length and on working square of a photodetector, the photodetector saves interference sensitivity. It reduces only in appearance of a corner concerning a normal to a photodetector, under which is allowed to allocate one of sources of luminous fluxes.

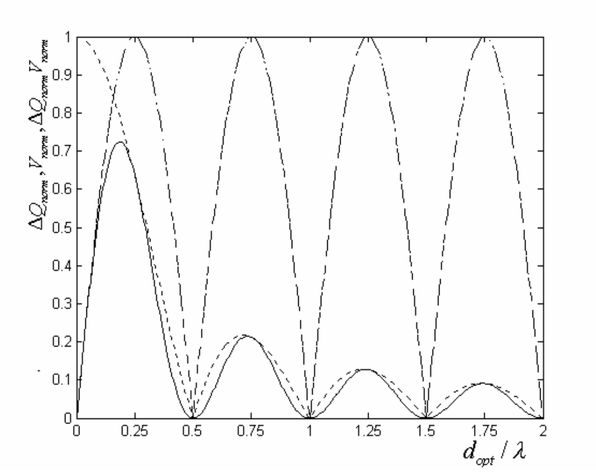

Fig. 3. An interference signal of a photodetector ΔQ_{norm} (dash-dotted line), visibility V_{norm} (dashed line), $\Delta Q_{norm} V_{norm}$ (continuous line). On an abscissa axis the normalized optical width of a photoelectric stratum is represented.

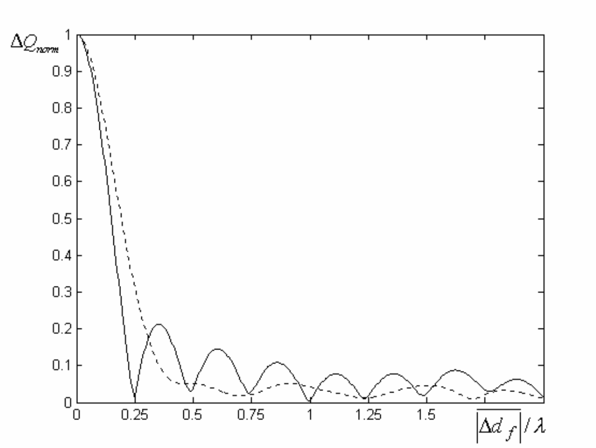

Fig. 4. Dependences of an interference component of response of a photodetector on absolute mean deviation of an optical distance, normalized to a wavelength. The deviation of an optical distance on square of a photodetector is distributed under the uniform law (continuous line) and normal (dashed line) laws.

6. EXAMPLES OF EXECUTION OF A PHOTODETECTOR

The scheme of a resistive photodetector represented on Fig.5. The photodetector manufactured by a method of thermal evaporation.

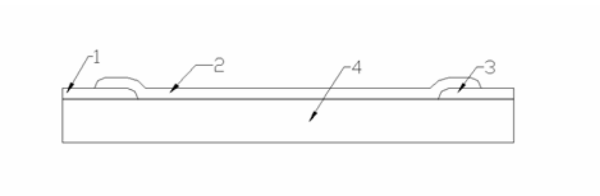

Fig. 5. The scheme of a resistive interference - responsive photodetector. 1,3 - nickel electrodes; 2 - photoelectric stratum PbS; 4 - glass substrate.

The photoelectric stratum PbS by width (d=100A) 2,, was deposited by evaporation on a glass parallel plate substrate 4, on which nickel electrodes 1,3 beforehand were marked. As a substrate the plane glass plate by width about 4 mm manufactured. The deviation of flatness of surfaces 0,15 microns on 30 mm, was inspected on an interferometer IT-100.

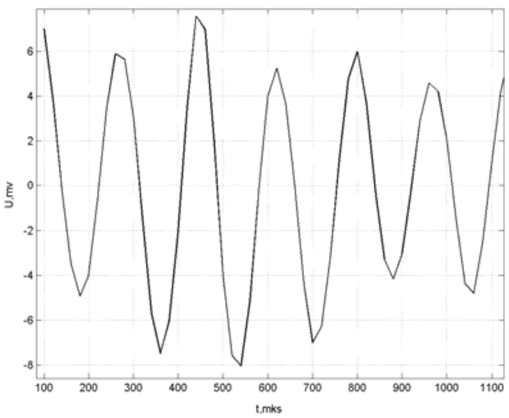

Fig. 6. Response of a photodetector at its uniform driving in an interference field of counter luminous fluxes He-Ne of the laser.

After activation of the obtained stratum in oxygen, the photodetector was tested in an interference field derived by counter driving of light rays (by a direct and reflected mirror in the opposite direction). The scheme of an interferometer represented on Fig.6. The appearance of arrangement is shown on Fig.7.

Amplitude and phase sensitivity of a photodetector was tested at lighting by its colliding beams of the helium-neon laser, perpendicularly to photo landing. At trial of the photoresistor stratum was included through bringing electrodes to a converter circuit of a resistance in power, and then the signals were introduced with the help of an analog-digital converter in a computer. On Fig. 6 the converted signal of a photodetector is reduced at its uniform driving in an interference field of counter luminous fluxes He-Ne of the laser. On an abscissa axis the time in microseconds, on an axis of ordinates response of a photoelectric stratum in relative units - quantization steps an analog-digital converter is presented.

The scheme of a vacuum photodetector represented on Fig.8 (see [9]). The response of this photodetector presented on Fig. 9 (see [10]).

The application of a photodetector installed on paths of light rays spreading as in one, and opposite directions allows measuring a spatial distribution of amplitudes and phases of interference light fields with minor distortions and absorption. The process of measurement and photodetector influences a gauged interference field a little. The optical schemes become simpler, as the necessity in beamsplitter passes, the overall dimensions of optical instruments diminish.

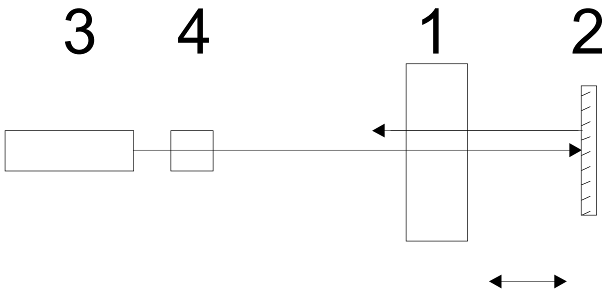

Fig.6. The scheme of an one-reflecting interferometer. Here: 1 - photodetector responsive to an interference field; 2 – mirror; 3 - light source; 4 - collimator.

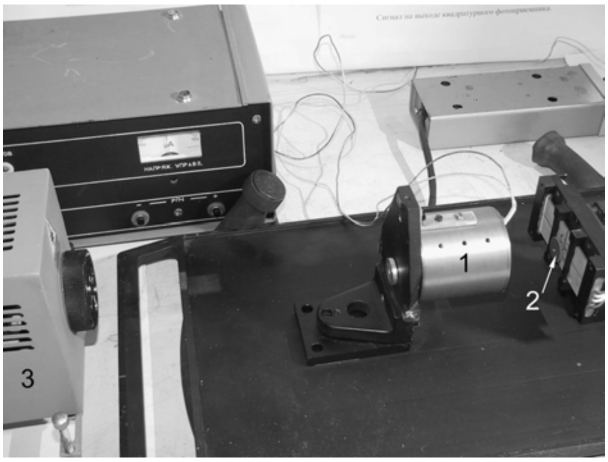

Fig.7. The appearance of arrangement of an one-reflecting interferometer. Here: 1 - photodetector responsive to an interference field; 2 - mirror installed on a piezoceramic unit, 3 - the helium-neon laser LGN-302, stabilized on frequency.

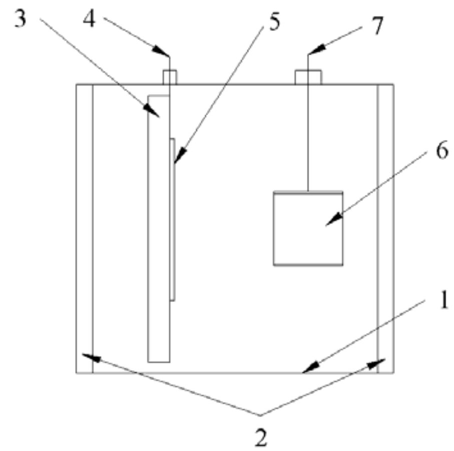

Fig. 8. The arrangement of a vacuum interference - responsive photodetector. 1- vacuum tube, 2 - optical windows, 3 - transparent substrate, 4 - electrode of a photocathode, 5 - transparent photocathode, 6 - anode as a ring, 7 - electrode of the anode.

The example by correlometer with four photodetectors responsive to an interference field is presented on Fig. 9.

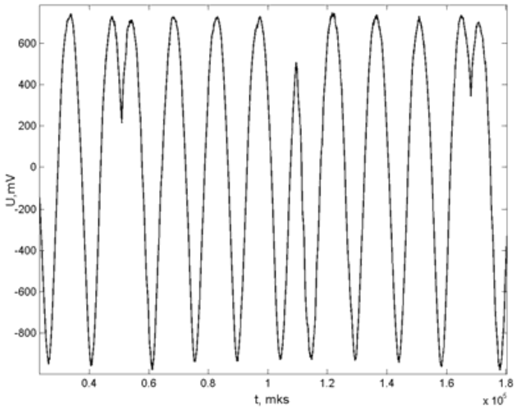

Fig. 9. Response of a vacuum photodetector at saw tooth change of a path difference of counter luminous fluxes He-Ne of the laser by power 1 mW, λ =633 nm. The interferogram is obtained on one-reflecting interferometer.

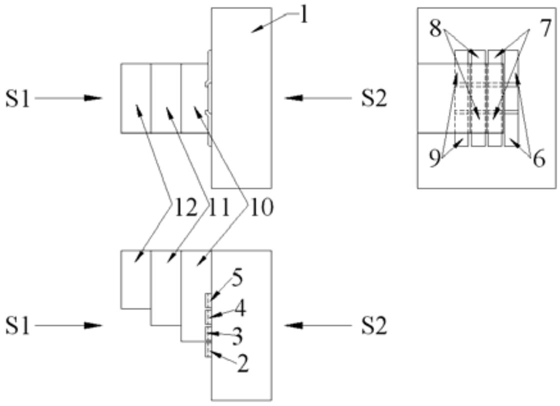

Fig. 10. Example of optical correlometer with four interference sensitive lairs. 1 - transparent substrate, 2-5 - photoelectric stratums, 6-8 - dielectric transparent stratums, 9-12 - electrodes.

7. SUMMARY

Optical interferometers are very old and precise instruments. They have a broad spectrum of important applications. The all this time development of interferometers went in a direction of such type of interferometers for which in the field of registration luminous fluxes move in one direction, [1]. The development of interferometers, for which in the field of registration light rays move in opposite directions [1], was limited. The reason is consist in that we had not photodetectors for electronic registration interference fields. Now, when the first photodetectors with the high ratio a signal to noise [6,7] are created. The interferometers with counter moving of light rays will discover the new development. Those interferometers are differing by simplicity of optical layout and small dimensions.

The new photodetector has small absorption, plane and homogeneous surfaces. It is the sensor of an interference field comes in counter light beams. For example, such sensor can be located in one or two channels of the majority of known interferometers and thus it becomes possible to inspect a propagation difference and stability of each branch of an interferometer separately. The new photodetector will allow simplifying solution of many technical problems of interferometry.

Introduced in the present work optical correlometer, counter luminous fluxes is in the essence the optical microchip, which as against conventional spectrometers does not comprise whatever moving parts. It is intended for measurement of the correlation function of counter luminous fluxes, which comprises the complete information on a transmitted spectrum. Spectrum of radiation can be reduced by a way of a converse of the Fourier transformation.

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