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Photodetector interference field

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ABSTRACT

Traditionally, special optical systems are used for observation of interference fields. The name of that system is interferometer. Beam of light source is divided on two. The names of light beams are object and reference. The way in which, the light beams integrate and transfer in area of an image dependent from type interferometer.

The Fizeau and Michelson interferometers are used so often. In all these interferometers the course of reference and object light beams going in one direction is interrupted on photodetectors. Energy of light beams is absorbed a photosensitive material of the photodetector, being transformed in a photoelectric signal. The photodetectors of different types: photodiodes, photoelectric multiplying tubes pyroelectric, solid-state detectector arrays are use for registration of interferogram. The known photodetectors considerably distort a course of light beams. They are large absorption, distort the form of a wavefront.

This article provides presentation photodetector having sensitivity to distribution of an interference field of light waves in space and time. The photodetector has little distortion of a wavefront. It does not destruction an interference field. Thus, the process of a measurement influence on an interference field is a little.

The photodetector can be used for registration of distribution of an interference field in space and its time history. Usage of photodetector is for a measurement of light streams extending as in one, and opposite directions. The application of the photodetector allows simplifying the optical schemes. Beam splitters and reference mirrors are not necessary. Some example applications photodetector represented. A simple interferometer for a measuring transitions and holographic images is described.

Keywords: photodetector, interference field**,** interferometer, holographic images, counter beams, photoelectric probe surface, standing light waves, thin films, photodetector array

1. INTRODUCTION

They are two classical type interferometers. The courses of reference and object light beams are equal direction in area of an image for the first interferometers. The courses of reference and object light beams are contrary directions in area of an image for the second interferometers. The major variety of photodetectors is present for registration of interference fields of the first type of interferometers. The photographic materials are applied to measurement of interference fields of counter driving of light beams. The interferometer on colliding beams is the elementary example of observation of standing optical waves experimentally realized by the Wiener /1/ in 1890.

At the same time, the interferometers on contrary beams, in most cases have more simple optical schemes, contain less optical components. For example, the interferometer with which experimented the Wiener consists all of two units of a photographic plate and metal mirror located under a small corner to each other. The experiment of the Wiener, was repeated Ives and Fry /2/ which have used as the sensor of an interference field a photoelectric probe surface. In the recent studies, which we have been making, this idea has found the further development. The purpose of studies is the creation of

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[1]Also known as maximum likelihood.

a photodetector for direct registration spatially - temporary allocation of an interferential field from opposite moving of light beams.

2.INTERFERENCE RESPONSE OF PHOTODETECTOR.

The standing light waves are outcome of interaction of the direct and reflected light waves in space. The period of a field of an interference is equal λ/2. The width *d* of a photoelectric probe surface should obey to a condition *d* < λ/2. The transparency of a photoelectric stratum is the second necessary condition. The response of a photodetector is outcome absorption of energy of standing light waves in volume of a photoelectric material. Attenuation intensity light obey the law Buger-Lambert

$$I = I_0 e^{-4\pi nkd/\lambda},$$

where I_0 – intensity incident light; I – intensity light emerge from photodetector; k - coefficient absorption photosensitive stratum; n – index of refraction; λ – wavelength.

Generally, it is coefficient absorption k photosensitive stratum sufficiently large value. The width is little value d < λ/2. Approximately intensities $I \approx I_0$ to exist, when k d little value. Interference contrast and transparency are achieved due to the fact that value of a photoelectric stratum is a little. The considerations of dependencies optical width and interference response are to exist low and distribution deviation optical width too.

Photodetector is (figure 1) thin photoelectric stratum and transparency undercoat. Field of interference found in everywhere over the region at the intersection of monochromatic light beams S1 and S2. The flat wave front is parallel surface of a photoelectric stratum.

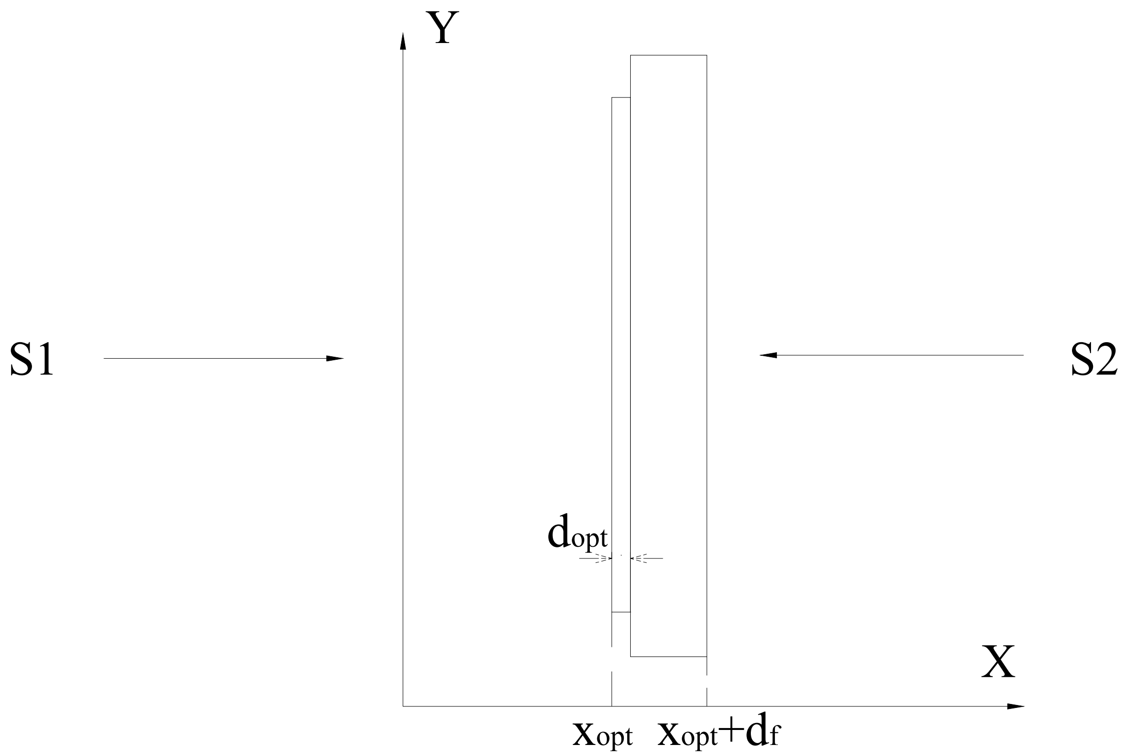

Fig.1. Arrangement photodetector and optical axis position data.

Optical axis position data of a photoelectric stratum is equal

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

x_g – geometric distance;

n(x) – index of refraction;

The next initial conditions was accepted for simplification. Amplitudes and wavelengthes of S1 and S2 is equal. At the beginning optical axis position data, phases of S1 and S2 is equal nought. Photosensitive of a photoelectric stratum is homogeneous in all volume. Absorption is not take into account. Optical distance on square is constant for all components of photodetector.

Wave equation of monochromatic light beams S1 and S2 are

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

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

E_m – amplitude electrical vector;

c – velocity of light;

t- time;

τ - time break flat wave front S2 relatively S1.

The resulting wave can be represented by expression:

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

Intensity of a resulting wave is:

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

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

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

$$\cong \frac{1}{2}\sin\left(\frac{2\pi}{\lambda}d_{opt}\right)\cos\left(\frac{4\pi}{\lambda}x_{opt} + \frac{2\pi c}{\lambda}\tau + \frac{2\pi}{\lambda}d_{opt}\right) + \frac{\pi}{\lambda}d_{opt}.$$

The response of a photodetector to an interferential signal is

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

Q_{max}, Q_{min} – are values of response of a photodetector, when coordinate x_{opt} or τ change in limits of interference period.

The dependence of normalized value ΔQ from d_{op} can be represented by expression:

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

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

The response of a photodetector is proportional to interference and average components intensity of itensity. The parameter describing interferential component of response of photodetector is contrast

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

The dependence of normalized value V from d_{op} can be represented by expression:

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

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

The parameter describing efficiency interference sensitivity of a photodetector is multiplying ΔQV .

The dependence of normalized value ΔQV from d_{op} can be represented by expression:

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

The dependences describing above parameters from a normalized optical width of a photoelectric stratum d_{opt}/λ represented on fig. 2. The photodetector hasnot interference sensitivity at optical width of a photoelectric stratum about $\lambda/2$. The interval of an optical width of a photo-electric stratum up to $d_{opt}<\lambda/2$ is apart selected, where interference sensitivity photodetector is wide spectral band and has high sensitivity of response on interferential 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 is determined by minimum width of a photoelectric stratum. The photodetector has dead zones on working lengths of waves λ_0, about doubled width of a photoelectric stratum. Thus, photodetector is selective.

2.1 Dependence of response of a photodetector on 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 insident 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:

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

For intensity resulting:

$$I_{pe3}(S) \cong \cos^2\left(\frac{2\pi}{\lambda}(x_{opt} - \frac{\Delta d_f(S)}{2}) - \frac{\pi c}{\lambda}\tau\right).$$

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

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

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

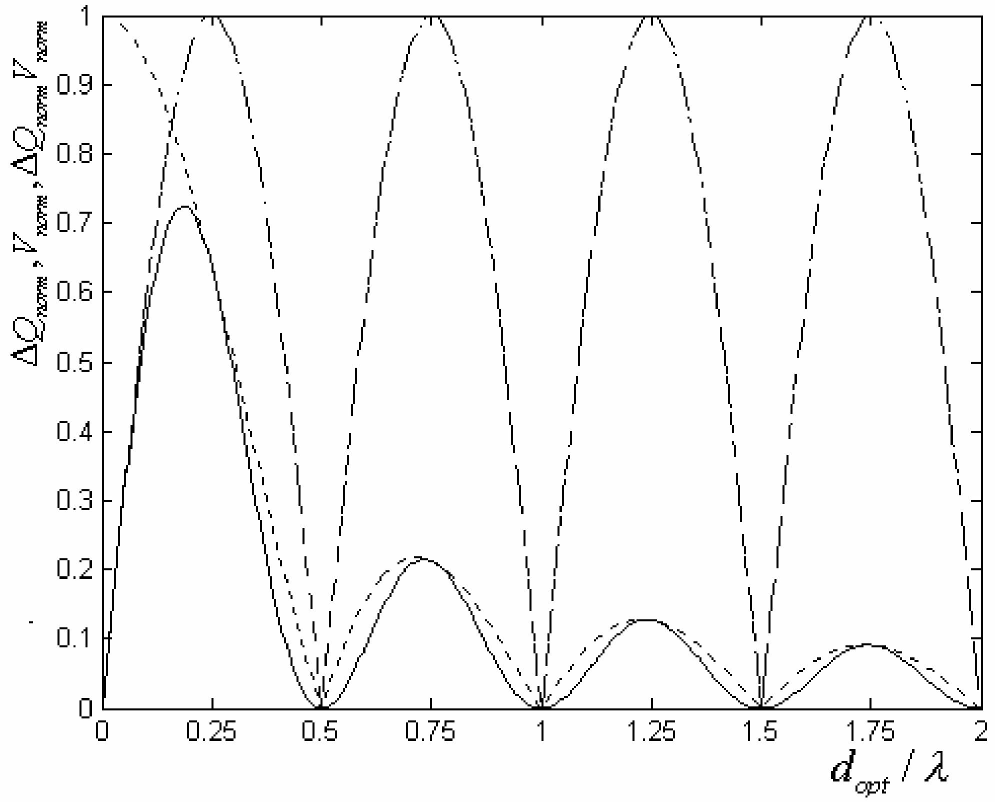

Fig.2. Interference signal of a photodetector ΔQ_{norm} (dash-dotted line), contrast $\varsigma_{vo\rho\mu}$ (dashed line), $\Delta Q_{norm}V_{norm}$ (continuous line). On an abscissa axis the normalized optical distance of a photoelectric stratum is postponed.

The total response of a photodetector is proportional:

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

S_f – working square of a photodetector.

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

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

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

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

According to this dependence, introduced on fig. 3 for uniform and normal distribution of deviation of an optical distance, at increase of absolute mean deviation of width of a photodetector up to l/4 and more, interferential sensitivity of a photodetector impinges sharply.

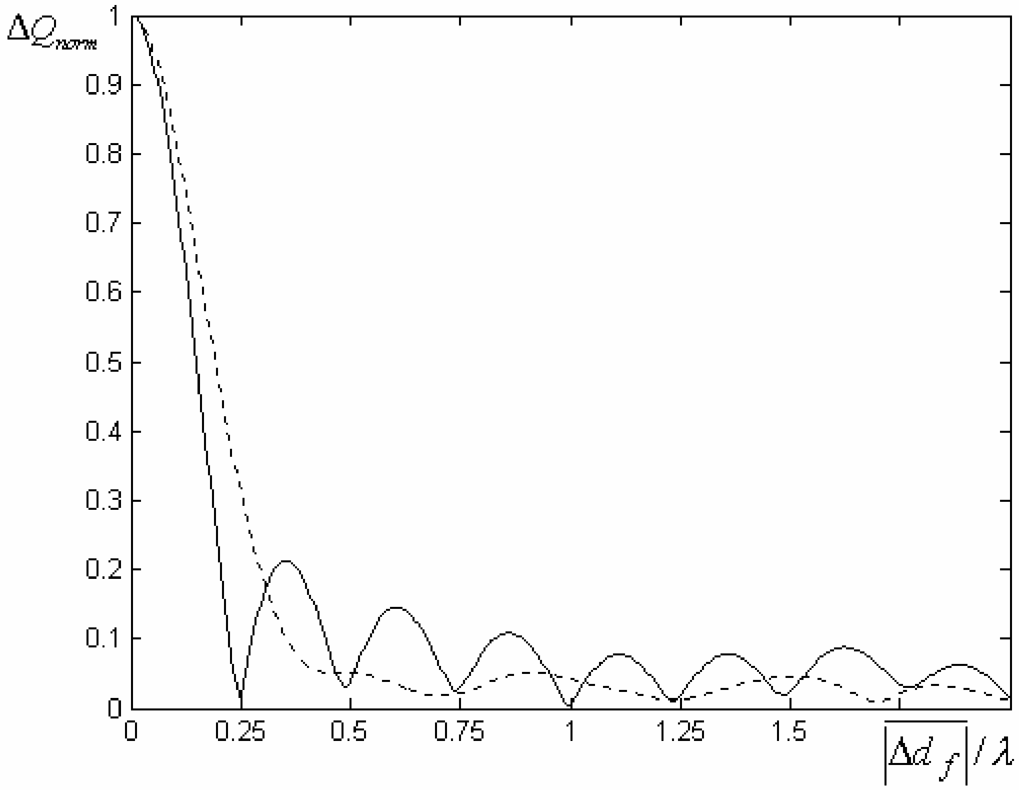

Fig.3. Dependences of an interferential component of response of a photodetector on absolute mean deviation of an optical distance, normalized to a wavelength. The deviation of an optical distance on square of a photodetector is distributed under the uniform law (continuous line) and normal (dashed line) laws.

2.2 Example of execution of a photodetector

The scheme of a photodetector represented on fig.4.

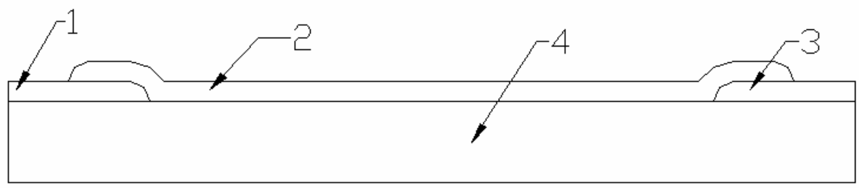

Fig.4. The scheme of an interference responsive photodetector.

The photodetector manufactured by a method of thermal evaporation. The photoelectric stratum 1 from PbS (d=100 angstroms) was plotted on a glass parallel plate substrate 2, on which nickeliferous electrodes 3,4 beforehand were marked. As a substrate the plane glass plate by width about 2 mm was manufactured. The deviation of flatness of surfaces 0,15 microns on 30 mm, was inspected on an interferometer IT-100. After activation of the obtained stratum in oxygen, the photodetector was tested in a field of light radiation of the helium-neon laser.

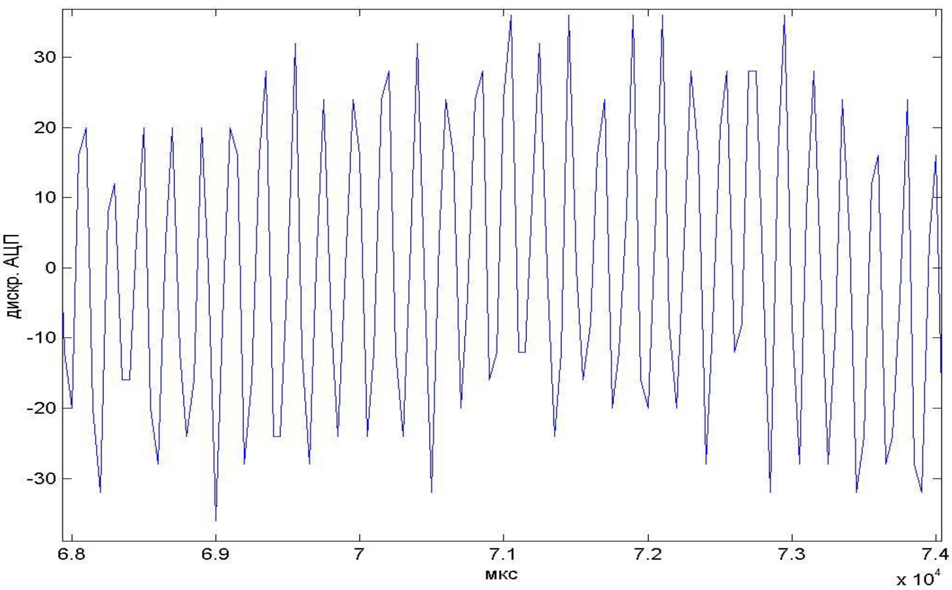

Fig. 5. Response of a photodetector at its uniform driving in an interferential field of counter luminous fluxes He-Ne of the laser.

The application of a photodetector placed on paths of light rays spreading as in one, and opposite directions allows to measure a spatial distribution of amplitudes and phases of interferential light fields with inappreciable distortions and absorption. The influence of process of measurement and photodetector on a gauged interferential field are a little. The optical schemes become simpler, as the necessity in beam splitter passes, the dimensions of optical instruments diminish.

2.3 examples of application of a photodetector of an interferential field

Writer of the holographic images of real time. For the first time, the scheme of record of the holographic map on colliding beams was offered by Denisuk /3/. Fig. 6 shows the schematic of a device for record of the holographic images in real time. The light going from a source of coherent radiation 1, on beam expander 2. The luminous flux, transiting through 2 or 3 measuring photodetector array 3.The light beams illuminates object 4 and, partially dissipating on it, is mirrored back to a photodetector array. This wave interreacts with a wave going immediately from a source and a being reference wave, creating an interference pattern. The photo-electric units of a matrix work out electrical signals proportional intensities of an interferential field in a point of finding of a unit. The analog signals from all units of a photodetector array act on an inlet of an analog-to-digital converter 5, are conversed to a numerical code, which is remembered in the electronic storage device.

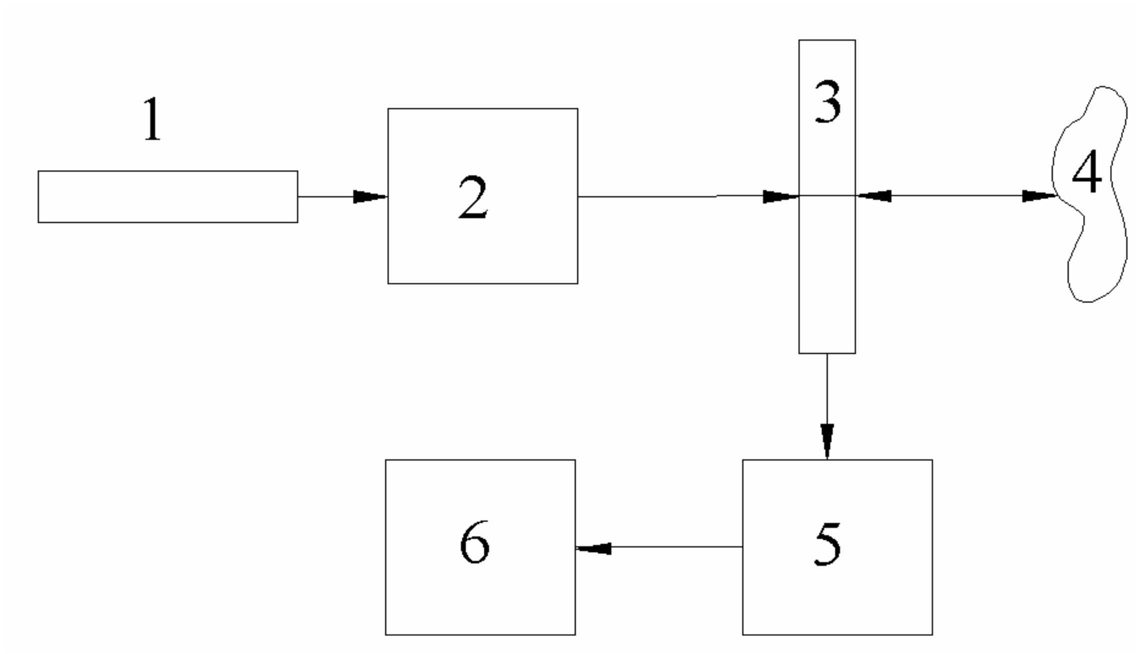

Fig. 6. A writer of the holographic images of real time.

2.4 interferometer

On fig. 7 scheme of an interferometer is represented. The luminous flux S1 with a plane wavefront set transits through a interference photodetector 1, is mirrored in the opposite direction by mirror 2. The luminous flux S2 intersects a quadrature photodetector 1 in the opposite direction. The counter luminous fluxes will derivate in space an interferential field, which allocation measures a quadrature photodetector consisting of two photo-electric stratums, carried on optical distance is equal $k\lambda/4+\lambda//8$, where k - whole non-negative number. Fulfilled separately, quadrature photodetector and mirror allow to fulfil electronic measurements of a spatial distribution of amplitudes and phases of light waves in a wide range of propagation differences, quadrature components of an interferential signal registered by a photodetector, allow is reverse to measure shift of fringe an interferential field.

The difference from the traditional schemes used in interferometry is consisted, that all optical components, bound with the reference channel of an interferometer (beam splitters, mirrors), are eliminated from an interferometer. A reference and measuring waves of space an interferential field directly are measured by a photodetector.

At the expense of it the simplification of the optical schemes of interferometers is achieved, the dimensions diminish, the reliability rises.

The offered technical solution, allows to reduce number of units even as contrasted to by most simple interferometer, for example, Fizeau interferometer consisting from two mirrors, beam splitter and photodetector.

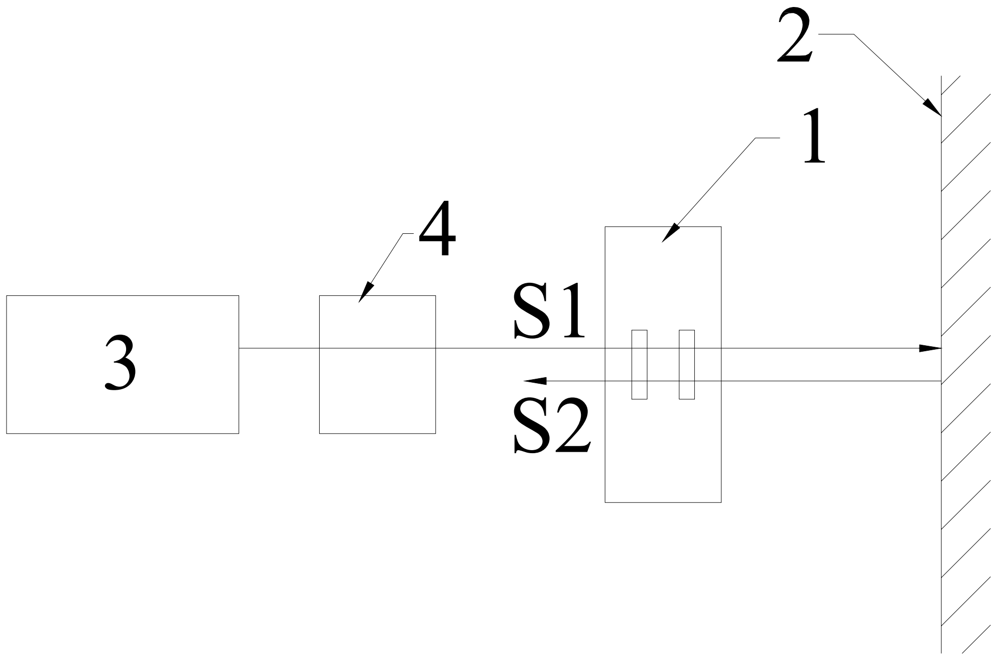

Fig. 7. The scheme of an interferometer . 1 - quadrature photodetector responsive to allocation of an interferential field; 2 - reflector; 3 - He-Ne the laser; 4 - collimator.

3. CONCLUSION.

The photodetector of an interferential field can be utilised for the wide class of the tasks of optical engineering, especially, in a holography and interferometries.

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