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Influence of Microrelief of the Modulator on Characteristics of the optical holographic Correlator of acoustic Signals

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Introduction

One of ways of speeding up of processing of acoustic signals may be using of optical processing methods [1,2]. The light reflected by the traveling wave membrane modulator is filtered by holographic matched filter which contains information about base acoustic wave. By matching of coming acoustic signal with base signal the optical signal appears in the output of the filter. This signal announces that searched signal coincides with base signal and that identification occurs.

Theory

Suppose we have acoustic signal I(t) which is by transformer e.g. electromagnetic converted into transverse wave traveling along the tape stretched between two matched supports:

$$\Delta_z = k_* I(t - x/v), \qquad (1)$$

where z is shift direction, k is changing coefficient of transforming, x is coordinate along the stretched tape, $v=\sqrt{T/m_1}$ is velocity of transversal wave, T is tension

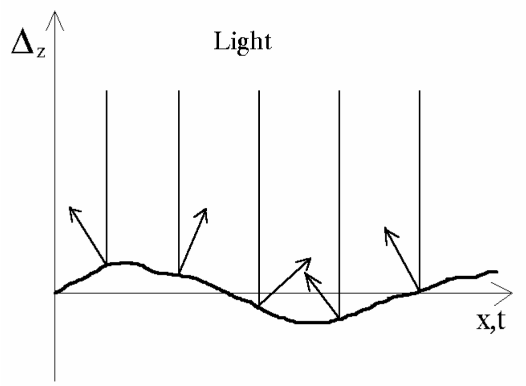


Fig.1. Diagram of reflection of light from tape of modulator

of tape, m_1 is mass of unit of length of tape. Because the tape is fasted between matched supports there is no reflection from them. Only the traveling waves exist along the tape. The tape is illuminated by parallel coherent light beam perpendicularly to the direction of the wave's spreading (fig. 1). The reflected light is modulated in accordance with the changes of installed signal and therefore the complex amplitude of the optical wave is

$$f(x,t) = A_{o*} exp(-4\pi i \Delta_z/\lambda), \qquad (2)$$

where λ is optical wavelength. The phase of $f(x,t)$ is found by evaluating of parameters of optical waves reflected from deformed tape in plane of undeformed tape. We assumed that local inclination of the tape do not exceed an angle $\pi/6$ and therefore there are no double reflections from the tape.

The optical holographic matched filtration realizes correlation of two complex amplitudes $f_1(x)$ and $f_2(x)$ of optical waves modulated by acoustic signals [3]:

$$\varphi(\xi) \sim \int_{-\infty}^{\infty} f_1(x)_* f_2^*(x-\xi)dx, \qquad (3)$$

where ξ is spatial shift, * means the complex conjugate.

In case of membrane modulator with traveling transverse wave a changes of reflected from each point of tape optical wave are related mainly with the changes of a phase of complex amplitudes. Besides that the shift of each point of tape is bound up with the time by velocity of transverse wave. Therefore in our specific case for the central point (ξ,ζ=0) of output plane (ξ,ζ) of optical diagram we can write:

$$\varphi(0,t-t_0) \sim \int_{-\infty}^{\infty} exp\{4\pi i[\Delta_z(x,t_0) - \Delta_z(x,t)]/\lambda\}dx, \qquad (4)$$

where $\Delta_z(x,t_0)$ is base signal; $\Delta_z(x,t)$ is filtered signal.

For the first approximation we used in the mathematical modeling as a base signal the unity amplitude and unity frequency harmonic signal

$$\Delta_z(t_0 - x/v) = sin(2\pi_* x). \qquad (5)$$

The signals with changing amplitude and frequency

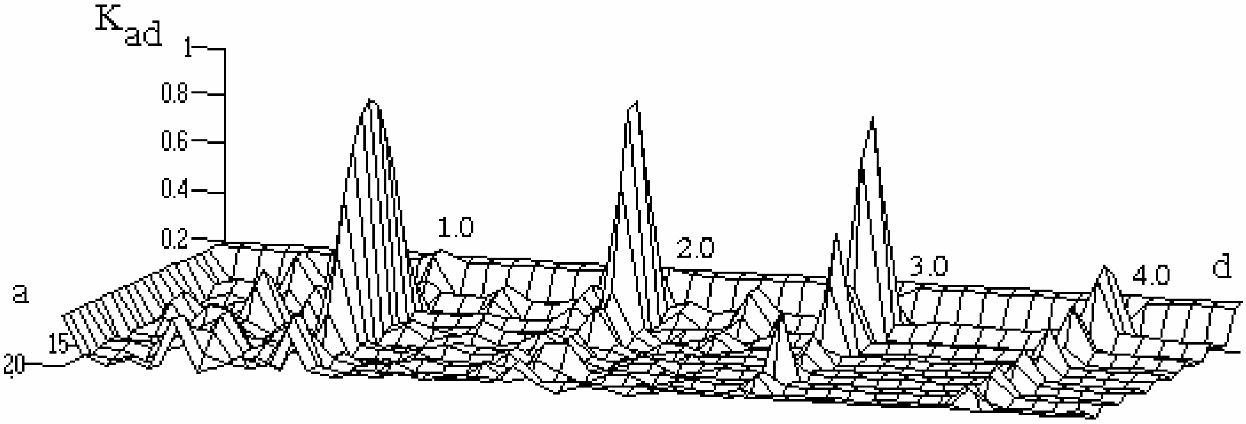
$$\Delta_z(t-x/v)=a*\sin(2\pi*d*x), \qquad (6)$$

were chosen as a filtered signals where a is relative amplitude and d is relative frequency.

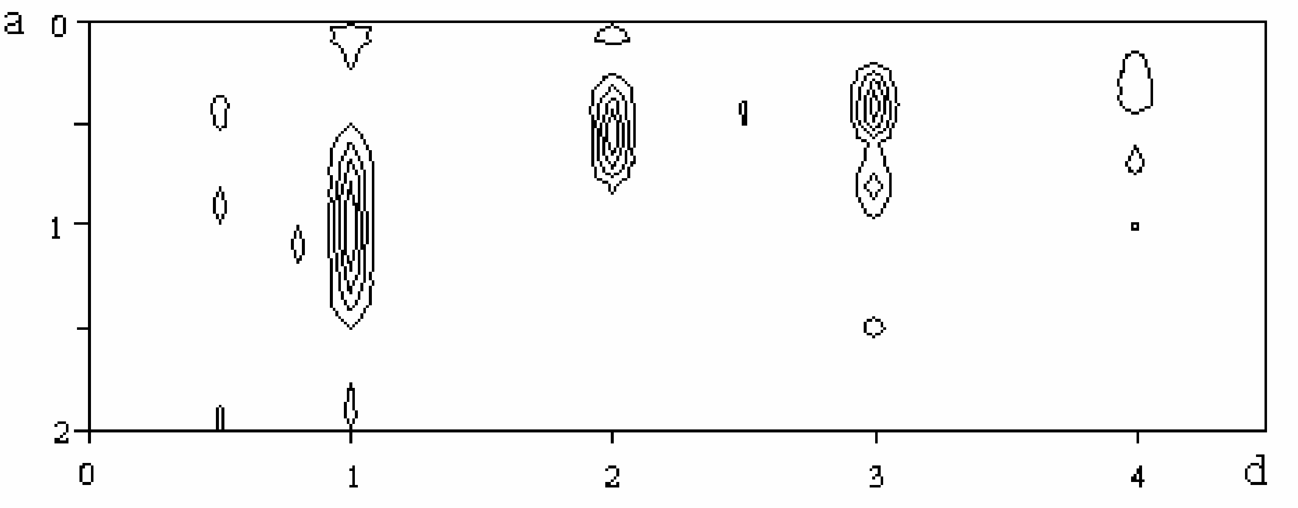
If we take the real part of the integral (4) only the matrix of correlation is:

$$K_{ad}=1/(2m+1)\int_{-m}^{m} \cos\{2\pi*b[\sin(2\pi*x) - (a*\sin(2\pi*d*x))]\}\, dx, \qquad (7)$$

where b is relative amplitude of transverse shift of modulator's surface points in comparison with optical wavelength λ. One typical graph calculated by use of equation (7) is shown in fig.2.



a)



b)

Fig.2. Amplitude - frequency filtering characteristics: a) - surface graph, b) - contour graph

The range of amplitudes was selected a=0...2, the range of frequencies was selected d=0...4.5. Four crests are in this region with peak values equal to one. This means that the signals passed the filter appear when the filtered signal is of base frequency (d=1), and also of double (d=2), of triple (d=3), of fourfold (d=4), obviously of other multiple frequencies. Therefore there are additional misleading signals. The steepness of crests in the direction of amplitude's axis is smaller as in the direction of frequency's axis, however there are no misleading crests in regions of double or other multiple amplitudes.

The influence of misleading crests may be avoided by using additional modulation of optical wave.

The surface of the tape of modulator practically always has a microrelief. It is not mirror, but it is formed in the simplest case from one unequal to another small uniform areas the characteristic diameter and height of which are bigger than optical wavelength λ. If the amplitudes of transverse shift of the tape are big in comparison with λ (b>1), then inclination of tape influences reflections from microrelief.

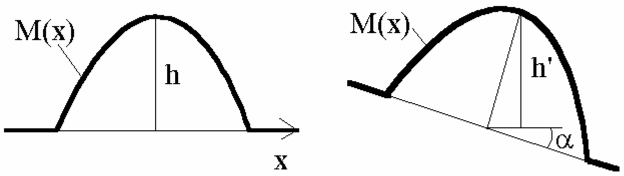


Fig.3. Diagram of evaluation of effective height of microrelief

Let we evaluate influence of such microrelief to results of filtering. Suppose the illuminated area of tape has rippled surface which is described by function *M(x)* (fig.3). If the wave Δ_z travels along the tape then each peak of roughness leans over and its effective height *h'* becomes smaller. If the initial height is *h*, then

$$h' = h_* \sin[(\pi/2)-\alpha] = h_* \cos\alpha, \qquad (8)$$

where the angle of lurch

$$\alpha = arctg(d\Delta_z/dx). \qquad (9)$$

The phase of reflected from tape modulator optical wave contains two components:

$$\psi_M(x,t) = 4\pi_*\{\Delta_z + M(x)_* \cos[\, arctg(\, d\Delta_z/dx)]\}/\lambda. \qquad (10)$$

Calculations

Therefore the calculations with evaluating of microrelief were carried out by using equation received by placing (10) into (7) with earlier used model functions:

$$K_{Mad} = [1/(2m+1)] \int_{-m}^{m} \cos\{2\pi_* b[(\sin(2\pi_* x) - a_* \sin(2\,\pi_* d_* x)) + M(x)_*(\cos(arctg(\cos(2\pi_* x)) - \cos(arctg(a_* {}_* d_* \cos(2\pi_* d_* x)))]\}dx. \qquad (11)$$

Here K_{Mad} is the correlation matrix when microrelief is evaluated; parameters *a*, *d* and *b* have the same significance as in equation (7). We supposed that:

$$M(x) = \sin(2\pi_* r_* x), \qquad (12)$$

where *r*>1 is relative spatial frequency of microrelief. These calculated amplitude - frequency filtering characteristics by such law of microrelief. They are optimum when $M(x)=\sin(2\pi_* 4x)$ (fig.4), because in this case we obtain only one distinct maximum of filtering, and misleading crests (fig.2) are either very small or disappeared. Thus by including of even simple model of microrelief we have returned considerably better results of filtering.

Experiments

The experimental investigation was carried out by modeling setup which diagram is in fig.5.

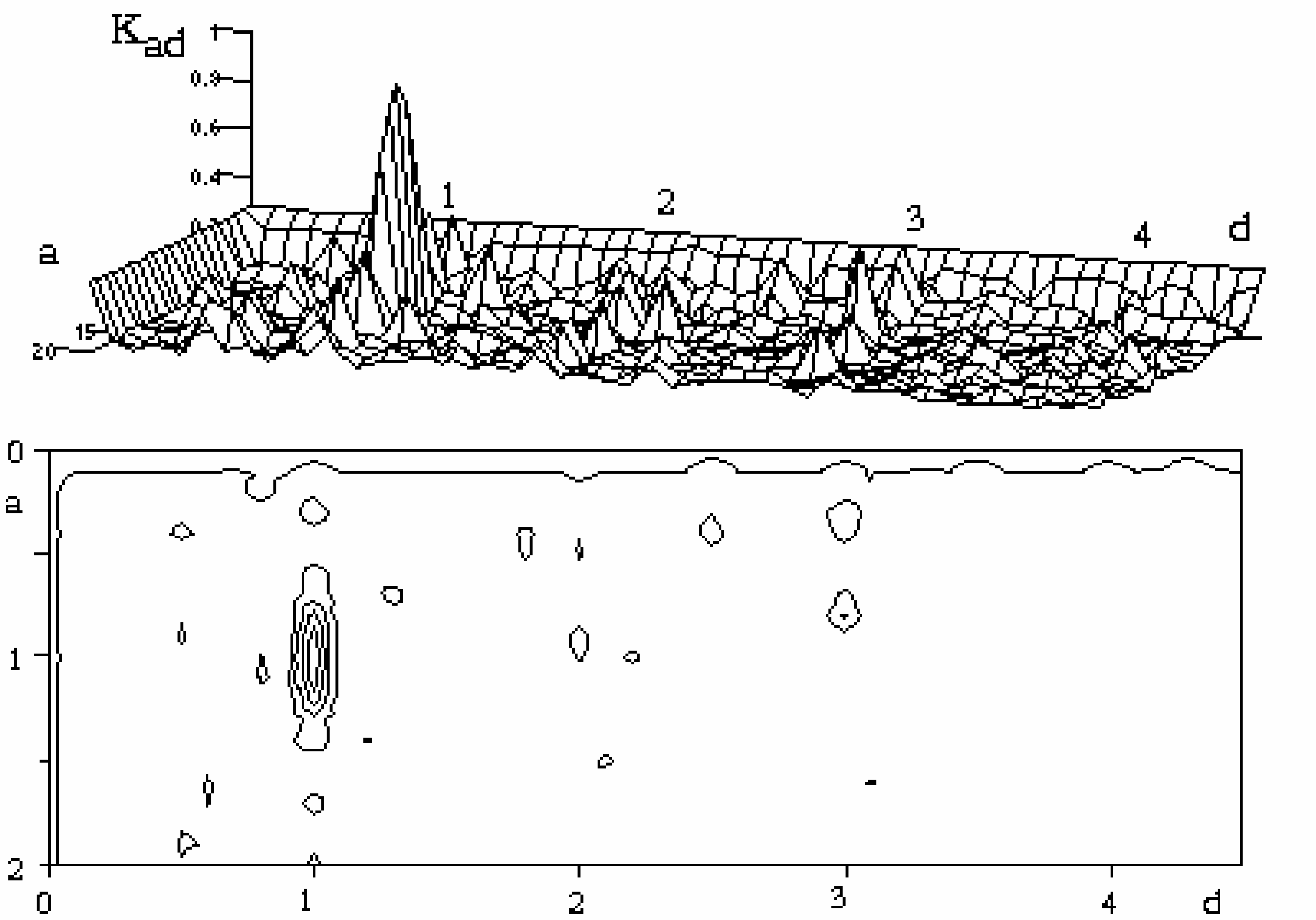


Fig.4. Amplitude - frequency filtering characteristics when microrelief $M(x)=sin(2\pi.4.x\ )$ is evaluated

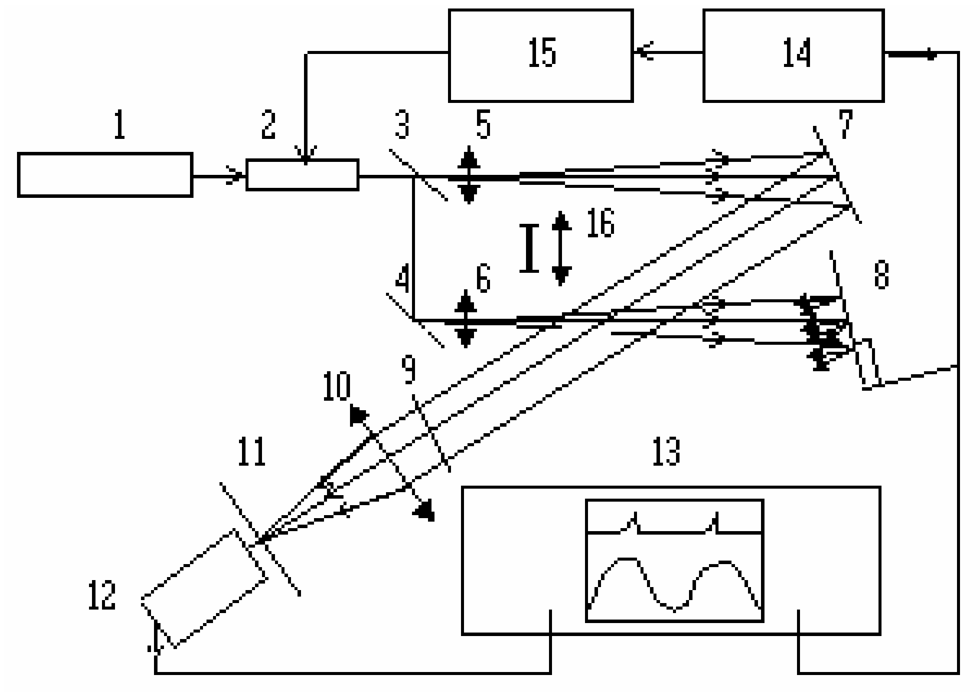
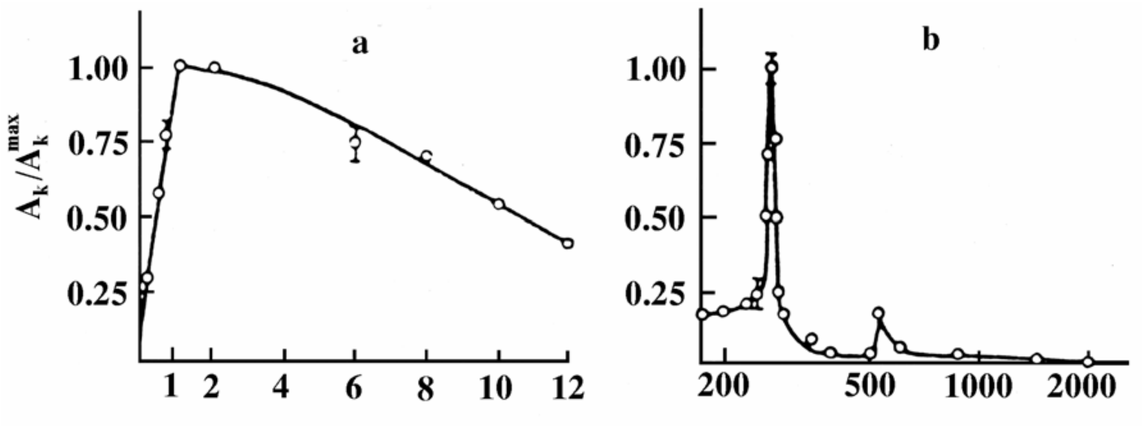


Fig 5. The experimental equipment diagram: 1-laser, 2-shutter, 3,4,7-mirrors, 5,6,10-lenses, 8-modulator,

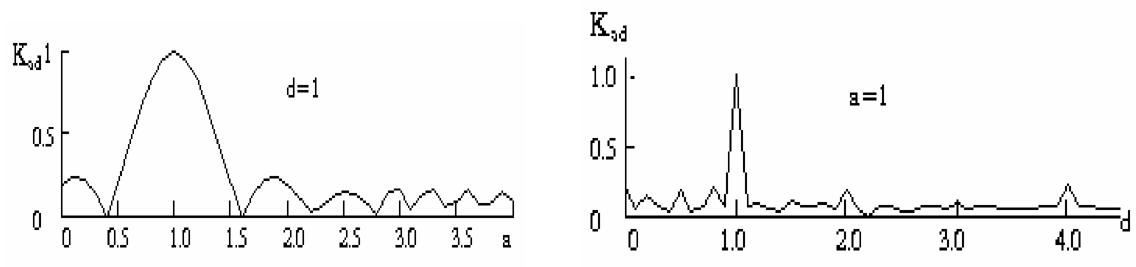
9-hologram, 11-pinhole, 12-photomultiplier, 13-oscillograph, 14-oscillator, 15-pulse oscillator, 16-reference beam shutter



U/U$_M$

f,Hz

a) b)



c) d)

Fig.6. Comparison of results of experimental and mathematical modeling: a),b) - experimental curves; c),d) - calculated curves

As modulator the metallic tape was used which was stretched between two supports with absorbers of vibrations. The Fresnel holograms were recorded during the experiment. By using of such holograms the amplitude of optical wave corresponds to central part of correlation signal described by equation (4) only in the center of output plane 11 [4]. Therefore the pinhole was placed in this plane in front of photoreceiver 12. It passed only light of central part. He-Ne laser 1 was used. Synchronized pulse generator 15 and electrooptical shutter 2 were switched on during recording of stroboscopic hologram when transverse shift wave of base signal was traveling along modulator 8. During the investigation of filtering process of signals with various amplitudes and frequencies they were switched off and the reference light beam was interrupted by shutter 16. Experimental curves shown in fig.6 a),b) were measured in such way. The results of mathematical modeling when parameters of mathematical model are chosen so that they correspond to parameters of experiment are shown near in fig.6 c),d). We can see that conditions of the experiment correspond in the best way the case of mirror reflection.

Conclusions

Thus the possibility to process analyzed acoustic signals quickly and continuously by optical method is shown by experimental and mathematical modeling of optical holographic correlator of acoustic signals. The parameters of amplitude - frequency filtering characteristics depend on parameters of tape modulator. Light is additionally modulated by including additional surface relief with accordingly chosen parameters and therefore a possibility of penetration of misleading signals disappears, the filtering quality is much better.

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Moduliatoriaus mikroreljefo átaka akustiniø signalø optinio holografinio koreliatoriaus charakteristikoms

Reziumë

Apraðyti keli optinio holografinio koreliatoriaus charakteristikø matematinio modeliavimo rezultatai. Parodyta juostelës pavirðiaus mikroreljefo átaka filtravimo charakteristikoms. Palygintos eksperimento ir matematiðkai suskaièiuotos kreivës.