PANORAMIC HETERODYNE ACOUSTOOPTIC RECEIVER

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The peculiarities of acoustooptic interaction in photoelastic media are analyzed in a context of their application for a panoramic scanning of breath frequency range

1. General information

At an excitation of an acoustic wave in a photoelastic medium occur the dynamic modifications of the refraction index (density of a medium). These modifications lead to the formation of a moving diffraction grating (DG), whose step is equal to the elastic wavelength, and the amplitude is proportional both to the amplitude of an elastic wave (EW), and to the photoelastic constant of the medium. At passage through such medium, a number of parameters of an optical wave are varied (are modulated). This phenomenon is called the effect of acoustooptic interaction or photoelastic effect. Acoustooptic modulator (AOM) is the device for realization of this effect. AOM consists of a photoelastic medium (PEM), to one edge of which an electro-acoustic transducer (EAT) is attached [1]. EAT transforms an input electrical signal into an acoustic wave spreading in the photoelastic medium with a velocity, approximately, in 10^5 times less than the velocity of propagation of an electromagnetic wave.

Peculiarities of acoustooptic interaction can be used for a panoramic scanning of a wide frequencies range.

The purpose of the present work is an application of the peculiarities of acoustooptic interaction in photoelastic media for a panoramic scanning of breath frequency range.

For facilitation of perception of the accepted decisions, at first we shall consider some properties of photoelastic effect.

Owing to acoustooptic interaction an incident optical wave diffracts on dynamic modifications of the density of photoelastic media. Thus, the intensity, propagation direction and frequency of optical wave in diffraction order is defined by parameters of an electrical signal brought to terminals of the EAT. Moreover, the response of the photodetector, disposed on a path of the diffraction order, lags from action on an electrical input on the time

$$\tau = x/\vartheta \quad , \tag{1}$$

where x is a distance from the EAT up to a point of the acoustooptic interaction; ϑ is a velocity of propagation of elastic waves in the photoelastic medium [Fig.1].

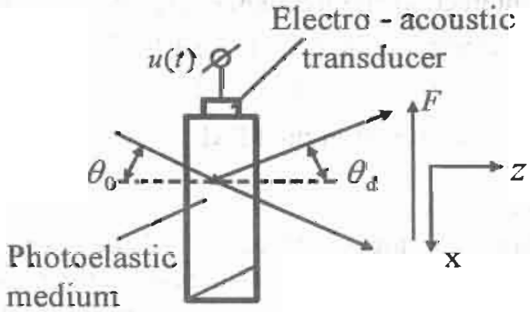

Fig.1

Depending on a geometry and character of acousto-optic interaction, diffractions of Raman-Nath and Bragg are distinguished. The basic external difference of Bragg diffraction from Raman-Nath diffraction consists of a nonsymmetrical emerging of diffraction orders, with modification of the incidence angle θ_O of a light beam in the aperture of the AOM.

Thus, the maximum of the light intensity in the diffraction order takes place if the light falls on the aperture of the AOM at the Bragg angle, i.e. when $\theta_O = \pm\theta_B$. The Bragg angle is defined from the relation

$$\sin\theta_B = \lambda/(2\Lambda) \quad , \tag{2}$$

where λ is the wave length of the incident light; Λ is the elastic wavelength in the PEM of the AOM.

Acoustooptic devices, using the Raman-Nath diffraction, have been extensively applied in systems of signal processing on frequencies up to 100 MHz. The Bragg diffraction is widely applied in acoustooptics systems of signal processing working in the frequency region from a few tens of MHz up to units of GHz.

Application of AOM, where the Bragg diffraction is used, allows raising some technical characteristics of acoustooptic devices, for example: the central frequency of a pass band; light intensity in a diffractional order etc.

At $\theta_O = \pm\theta_B$, with increase of the frequency of an acoustic wave, diffractional effects of higher orders disappear and only light beams of zero and first orders are predominating. The diffractional order spread under the angle θ_d, defined from the relation

$$\sin\theta_d + \sin\theta_0 = \lambda/\Lambda \quad . \tag{3}$$

Assuming, that the incidence angle θ_O of the light beam on a surface of the PEM is constant, i.e. $\theta_O = \theta_{B0} = const$, where θ_{B0} is the Bragg angle on the central frequency F_0 of the input action, from the joint analysis (2) and (3) it is possible to receive the following expression for the diffraction angle θ_d at the Bragg condition:

$$\sin\theta_d = 0{,}5\lambda/\Lambda = 0{,}5\lambda\cdot F/\vartheta \quad , \tag{4}$$

where F is the frequency of EW in PEM.

The equation (4) indicates that the angle of deflection θ_d is variable versus the frequency F of elastic waves in a photoelastic medium, and therefore also versus the frequency of the input electrical signal. From (4) for small modifications of the diffraction angle $\Delta\theta_d$ (where $\sin\Delta\theta_d \approx \Delta\theta_d$), it is possible to receive the following expression:

$$\Delta\theta_d = 0{,}5\lambda\cdot\Delta F/\vartheta \tag{5}$$

where $\Delta F = F - F_0$.

According to (5), in the conditions of Bragg a modification of a diffraction angle is in rectilinear dependence on frequency modification of an input action.

After acoustooptic interaction the frequency ω_d of the light beam in a diffractional order is shifted due to Dopler effect, on the magnitude $\Omega = 2\pi F$ and is defined as:

$$\omega_d = \omega \pm \Omega \tag{6}$$

where ω is the angular frequency of light in the PEM.

2. Theoretical consideration

According to relation (5), the modification of the frequency of input action is accompanied by a linear modification of a diffraction angle in space. As a result each direction of a light diffraction (in the plane xz) corresponds to definite frequency of input action (Fig.1).

Caused by Dopler effect, the shift of frequency of a light wave in a diffractional order can be used for restoring of the radiofrequency signal operating on the input of AOM, by optical heterodyning of the diffracted light beam by a part of the incident or undiffracted light (appearing in a role of the local heterodyne). In this case, if an amplitude-modulated signal

$$u_1(t) = U_0[1 + M \cdot s(t)] \cdot \cos\Omega t \quad (7)$$

is brought to terminals of EAT, we have on the output of the photodetector:

$$u_2(t) = cU_0[1 + M \cdot s(t-\tau)] \cdot \cos\Omega(t-\tau) \quad . \quad (8)$$

In a Fig. 2 is represented the structural-electrical scheme of the panoramic heterodyne acoustooptic receiver, where multichannelity and the shaping of heterodyne fields are ensured with one DG 2, located under an angle α to an axes x. Ray of the laser 1 is perpendicularly directed on DG 2. Received after DG2 symmetric diffraction orders are directed under angles determined by the relation:

$$\sin\theta_{Ln} = \pm n \cdot \lambda / l \quad , \quad (9)$$

where l is a step of DG2; n is number of the diffractional order.

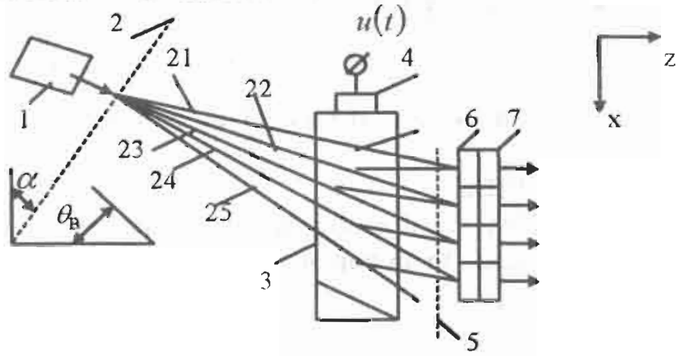

Fig. 2.

The laser 1 and DG 2 are located in such a manner that the undiffractional on DG2 part of a light bundle - the ray 23 falls on the surface of PEM 3 under an angle $\theta_B = \alpha$, determined from the relation

$$\sin\theta_B = 0{,}5 \cdot \lambda / \Lambda = 0{,}5\lambda F / \vartheta \quad , \quad (10)$$

where $F = \vartheta / \Lambda$ is an average frequency of a range of working frequencies of the panoramic receiver. In these conditions the rays 22 and 24 fall on the surface PEM 3 under angles $\theta_B \pm \Delta\theta$, where $\pm\Delta\theta \approx 0{,}5\lambda \cdot (\pm\Delta F)/\vartheta$, and rays 21 и 25 - under angles $\theta_B \pm 2\Delta\theta$, where $\pm 2\Delta\theta \approx 0{,}5\lambda \cdot (\pm 2\Delta F)/\vartheta$. In other words, the Bragg condition for incident on the surface of PEM 3 light bundles is fulfilled on various frequencies. Thus the range of working frequencies represented in the Fig. 2 panoramic receiver is determined as $F \pm 2\Delta F$ and ensures separation of 4-th radiosignals (on one less from number of incident on a surface PEM light bundles). Available in a range of working frequencies the radiosignals move on terminals of EAT 4, which rises in PEM 3 EW of equal frequency.

Spreading through PEM 3 light bundles, being dispersed on EW, are created by signal bundles hitting through appropriate slots of a diaphragm 5 on photosensitive surfaces of the photoreceivers 6. Not scattered on EW part of light bundles are used as heterodyne light bundles, which also hit on the photoreceivers 6 through appropriate slots of a diaphragm 5. Thus the unscattered part of a bundle 21 is a heterodyne field for a signal bundle obtained in an outcome of a diffraction of the bundle 22 on EW in PEM 3. The heterodyne and signal bundles, with realization of defined conditions, interfere on a photosensitive surface of photodetector.

We shall consider the process of selection of a radiosignal of number m from a mixture of radiosignals and handicap, available in observation item. Let's assume, that the radiosignal of number m is noted by the relation:

$$u_m(t) = U_{0.m}[1 + M \cdot s(t)] \cdot \cos\Omega_{0m} t \quad , \quad (11)$$

where $U_{o.m}$ and Ω_{0m} are amplitude and frequency of carrying oscillation of a m-th radiosignal; M is index of amplitude modulation; m is number of the channel intended for selection of the radiosignal with frequency Ω_{0m} and amplitude $U_{o.m}$; $s(t)$ is the modulating process. Submitted to terminals EAT 4 a radiosignals (11) raises in PEM 3 EW with appropriate parameters. An optical wave intersecting the aperture PEM 3 under an angle $\theta_{Bm} \approx 0{,}5\lambda F_{0m}/\vartheta$, where $F_{0m} = \Omega_{0m}/(2\pi)$, is dispersed on EW and will derivate a signal field, the distribution of light in which is described by the relation:

$$\dot{E}_s(t,x) = \exp\left[j(\omega + \Omega_{0m})t - K_m x_{om}\right] \quad . \tag{12}$$

The relation describes the appropriate heterodyne field:

$$\dot{E}_{Lm}(t,x) = \exp\left\{j[\omega t - K_m(x_{om} + x)\cdot \sin\theta_{Lm}]\right\}, \tag{13}$$

where $K_m = 2\pi/\Lambda_m$ is factor of a phase of an EW packet exited by a m-th radiosignal with frequency F_{0m}; $x_{o\,m}$ is the distance from EAT up to of a m-th bundle intersecting the aperture AOM under an angle θ_{Bm}.

The Signal and heterodyne light beams hit on a photosensitive surface of the m-th photoreceiver and are heterodyning. In an outcome optical heterodyning, on an exit of the m-th photoreceiver 6 is formed the signal:

$$u'_{2.m}(t) = c\int_{x_{0m}-0,5d}^{x_{0m}+0,5d} \left|E_L(x,t) + E_s(x,t)\right|^2 dx = c\int_{x_{0m}-0,5d}^{x_{0m}+0,5d}\left[\left|\dot{E}_L(x,t)\right|^2 + \left|\dot{E}_S(x,t)\right|^2\right]dx +$$

$$+ c\int_{x_{0m}-0,5d}^{x_{0m}+0,5d}\left[\dot{E}_s(x,t)\cdot \dot{E}_L^*(x,t) + \dot{E}_s^*(x,t)\cdot \dot{E}_L(x,t)\right]dx \tag{14}$$

where **d** is the diameter of square of a photosensitive surface of photoreceiver, in which limits happens optical heterodyning; C is constant factor. Disposed on an exit of photoreceiver, the m -th bandpass filter (BF) 7 selects high-frequency component of a signal (14):

$$u_{2.m}(t) = c_1\int_{x_{om}-0,5d}^{x_{om}+0,5d}\left[1 + M\cdot s(t - x_{0m}/\vartheta)\right]\cdot \exp\left[j\Omega_{0m}(t - x_{0m}/\vartheta)\right]dx \ . \tag{15}$$

Assume, that in a time interval d/ϑ the modifications happening in a treated signal are insignificant, and also that in limits of a breadth d of an incident light bundle it the transversal sizes and damping EW do not vary, the formula (15) can be copied in the other aspect:

$$u_{2.m}(t) = c_2\left[1 + M\cdot s\left(t - x_{0m}/\vartheta\right)\right]\cdot \cos\Omega_{0m}\left(t - x_{0m}/\vartheta\right) \ , \tag{16}$$

where $c_2 = c_1 d$ is new constant factor.

From the comparison of the relations (11) and (16) follows, that the output signal m-th BF, to within a constant factor, corresponds to a m-th entering radiosignal delaying on time x_{om}/ϑ, i.e.:

$$u_{2.m}(t) = c_3 u_m\left(t - x_{om}/\vartheta\right) \ , \tag{17}$$

where c_3 is constant factor.

The width of a pass band of each channel of panoramic acoustooptic receiver is determined by the relation [2]:

$$2 \cdot \Delta f \approx 2{,}792 \cdot \vartheta \; / \left(\pi \; d\right) \qquad (18)$$

3. Experimental results

The possibility of construction of 4 channel panoramic acoustooptic receiver was checked experimentally. The measurements were executed for each channel separately. As PEM was used TF-7 (ϑ = 3,5 km/s), and as EAT - $LiNbO_3$. The central frequency AOM has made 32 MHz, the width of the passband of each channel - 2,2 MHz, and appropriate range of working frequencies of panoramic acoustooptic receiver envelops from 26 MHz up to 38 MHz.

We mark, that the heterodyne method of registration of an optical signal allows increasing the sensitivity of the photoreception device on 3-4 orders in comparison with direct detection and approaches this sensitivity to a quantum limit.

4. Conclusion

The proposed device is distinguished by simplicity and does not require special set-up. Besides, the visualization of basic processes in AOM (a laser radiates in visible range) considerably simplifies a specification of separate parameters of the device in whole. During last years AOM with satisfactory maintenance and engineering by indices (low power of an elastic wave excitations, high effectiveness of a diffraction etc.) and semiconductor lasers with a sufficient coherence of a radiation have been developed. Taking into account all this it is possible to state, that in the nearest future some compact acoustooptic device of handling of signals considerably exceeding their electronic analogs in characteristics will be created.

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[1] *J. N. Lee, A. Vanderlugt.* Acoustooptic signal processing and computing. Proc. of the IEEE, 1989, vol. 77, N.10, p.1528-1557.

[2] *A.M. Pashaev and A.R. Gasanov.* Acousto-optic method of tracking reception of frequency modulated signals. "Radiotekhnica", 1996,8,28-31. (in Russian).

HETERODİN NÖVLÜ AKUSTOOPTİK PANORAM QƏBULEDİCİSİ

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Fotoelastik mühitlərdə akustooptik qarşılıqlı təsirin xüsusiyyətləri, onların geniş radiotezlikli diapazonun panoram öyrənilməsində tətbiqi baxımından, analiz edilir.

АКУСТООПТИЧЕСКИЙ ПАНОРАМНЫЙ ПРИЕМНИК ГЕТЕРОДИННОГО ТИПА

ПАШАЕВ А.М., ГАСАНОВ А.Р.

Особенности акустооптического взаимодействия в фотоупругих средах анализируются в контексте их применимости для панорамного обзора широкого диапазона радиочастот.