THE SEARCH, DETECTION AND THE TIME DELAY ESTIMATION OF THE WIDEBAND SIGNAL IN THE ACOUSTOOPTIC CORRELATIVE RECEIVER.

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Abstract. The wideband signal reception by acoustooptic receiver (AOR) against the background of noises is considered. AOR contains two acoustooptic correlators with time integration (AOCTI). The reception signal duration does not exceed the sound propagation time along apertures of light ultrasound modulators (USML), which are signal introductory arrangements in AOCTI. The processing algorithm of the integrated photodeviced output signals is given. The reception signal time delay estimation and the decision on the useful signal presence in the AOCTI entrance is formed. The efficiency of the given algorithm is analyzed.

Acoustooptic correlator with the time integration (AOCTI), ultrasound modulator of the light (USML), wideband signal, time delay, photodiode, statistical characteristics.

1. INTRODUCTION

The wideband signals with a great base are employed in various modern radiosystems. The difficulties, attached to the construction of such systems are bound with the working out and realization of the signal search and synchronization operations in the optimum receivers. These difficulties may be overcome by using the acoustooptic correlators with the time integration (AOCTI), working in real time in the receivers and carrying out the search and the time delay estimation of the received signals — Refs 1,2. However, one AOCTI carries out the search of the wideband signals in the time interval, determined by the sound propagation time along the aperture of the USML — Ref.3. Therefore, the time interval of the search and signal time delay estimation a big duration extension presents an important practical problem.

2. SYSTEM MODEL

Let the wideband signal (WS) with a big duration be taken by the acoustooptic receiver (AOR) with two AOCTI and a general photodevice matrix scheme of the output signal processing. The structural scheme of AOR is presented on figure number one, where 1 is the source of coherent optical radiation (laser diode), 2 — beam collimators, 3 — USML, 4 and 6 — integrating lenses with the focal distances $f_{\text{len}\,1}$ and $f_{\text{len}\,2}$ accordingly, 5 — space filters, placed in the Fourier transform planes, 7 — linear array of the integrating photodiodes, placed in the AOCTI output plane, 8 — primary processing device of the array photodiode output signals, 9 — the device, which forms the signal time delay estimation and the decision on the signal presence in the input of AOR, 10 — delay line.

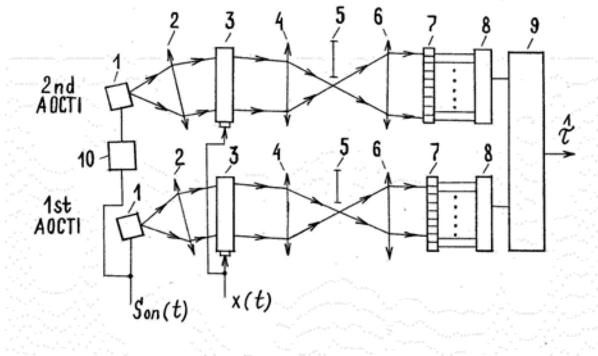

Fig. 1

Let the additive blend

$$x(t) = s(t) + n(t) \qquad (1)$$

be given on the inputs of AOCTI's dimensions $D \times H \times L$ (length of aperture $\times$ width of aperture $\times$ length of acoustooptic interaction). In (1) $s(t)$ — analyzed signal with duration greater than the sound propagation time along an aperture of USML $T_M = D/V$, but smaller than $2T_M$; $n(t)$ — a stationary gaussian interference with zero mean $\langle n(t) \rangle = 0$ and the correlation function $\langle n(t_1) n(t_2) \rangle = B(t_1 - t_2)$. The light stream falls on the USML aperture flatness under the angle θ_b to the normal to flatness. The light intensity of the source 1 is modulated by the supporting signal $s_{\sup}(t)$ in such away, that the light stream intensity, illuminating USML's 3 are written accordingly

$$I_i(t) = B_1 + C_1 s_{\sup}[t - (i-1)T_M], \qquad (2)$$
$$i = 1, 2.$$

B_1 and C_1 are always positive where B_1 is displacement and C_1 is modulation depth. The expressions for the diffracted on USML and transformed by lenses 4 and 6 light stream intensity distributions in the output planes of AOCTIs along the axis $O\xi$ are written accordingly — Ref.4

$$I_i(\xi, t) = I_i(t) \left| 1 + \Psi\, x\left(t - \frac{\xi}{V} + \frac{T_M}{2} - \tau_{\text{del}}\right) \right|^2, \qquad (3)$$
$$i = 1, 2.$$

In (3) $\Psi = 2\pi \Delta n_M L/\lambda$ — index of the phase modulation; L — length of the acoustooptic interaction (thickness of USML); Δn_M — acoustooptic interaction medium refraction coefficient change amplitude relatively the mean value for the unit power signal influence; λ — length of the light wave, illuminating the USML; τ_{del} — received signal time delay relatively the starting moment of the first AOCTI USML lightening $t_{start} = T_M/2$ by the light bundle. The expressions for the output signals of ν photodiode with the breadth b and the center coordinate $\nu\Delta\xi$ along the axis $O\xi$ may be presented as

$$y_{i\nu}(T) = k_{tran} \int_{(i-1)T_M}^{T+(i-1)T_M} dt \left[\int_{\nu\Delta\xi - b/2}^{\nu\Delta\xi + b/2} I_i(t,\xi)\, d\xi + n_{i\nu\, ins}(t) \right], \qquad (4)$$
$$i = 1, 2, \quad \nu = 1, \ldots, n.$$

Here $\Delta\xi$ — interval of the photodiode place along the axis $O\xi$, $n_{i\nu}(t)$ — inside noise of i's AOCTI ν's photodiode with the zero mean and the correlative function

$$\left\langle n_{i\nu\, ins}(t) \right\rangle = 0,$$
$$\left\langle n_{i\nu\, ins}(t_1)\, n_{j\lambda\, ins}(t_2) \right\rangle = \frac{N_{ins}}{2} \delta_{ij}\, \delta_{\nu\lambda} \delta(t_1 - t_2) \qquad (5)$$

N_{ins} — spectrum density of inside noises.

By the substituting (3) in (4) and transformating with the calculation that $\Psi << 1$ and $b << D$ it is not difficult to get

$$y_{i\nu}(T) = B_1\, k_{tran}\, bT + S_{i\nu}(T) + N_{i\nu}(T), \qquad (6)$$
$$i = 1, 2, \quad \nu = 1, \ldots, n.$$

The first term determines the level of the photodiode output signal, conditioned by the invariable lightening

$$S_{i\nu}(T) = 2\, k_{tran} \Psi\, b\, C_1 \int_0^T s_{sup}(t)\, s\left[t - \frac{\nu\Delta\xi}{V} + \frac{T_M}{2} + (i-1)T_M - \tau_{del} \right] dt,$$

and (7)

$$N_{i\nu}(T) = 2\, k_{tran} \Psi\, b \int_0^T n\left[t - \frac{\nu\Delta\xi}{V} + \frac{T_M}{2} + (i-1)T_M \right] \times$$
$$\times \left(B_1 + C_1 s_{sup}(t) \right) dt + k_{tran} \int_0^T n_{i\nu\, ins}(t)\, dt$$

are accordingly the signal and noise on the ν's photodiode output of i's AOCTI.

If $s_{sup}(t) = s(t)$, the output signal of ν_0's photodiode in i's AOCTI reaches the maximum value

$$S_{i\nu_0\, max} = 2\, k_{tran} \Psi\, b\, C_1\, E, \qquad E = \int_0^T s^2(t)\, dt,$$

when

$$\nu_0 \Delta\xi = \frac{D}{2} + (i-1) D - V \tau_{del}, \qquad i = 1, 2\,. \qquad (8)$$

From (8) it is seen, that for $0 < \tau_{del} < T_M$ the maximum value output signal of ν_0's photodiode reaches in the first AOCTI, when

$$\nu_0 = \frac{D - 2\,\tau_{del} V}{2\Delta\xi}$$

and for $T_M < \tau_{del} < 2T_M$ in the second AOCTI.

$N_{i\nu}(T)$ has the zero mean and correlative function

$$\left\langle N_{i\nu}(T)\, N_{j\lambda}(T) \right\rangle = k_{tran}^2 \frac{T}{2}\, \delta_{ij}\, \delta_{\lambda\nu} \times$$
$$\times \left\{ 4\Psi^2 b^2 N_0 B_1^2 \left(1 + \frac{C_1^2 E}{B_1^2 T} \right) + N_{ins} \right\} \qquad (9)$$

The first term in (6) depends on the level of the invariable lightening and is compensated by the following processing on the photodiode output.

3. SIGNAL TIME DELAY ESTIMATION

The signals $p_{i\nu}(T) = y_{i\nu}(T) - B_1\, b\, k_{tran}\, T$ act on the threshold devices and are compared with the threshold γ. The decision on the presence and absence of signals in the every processing channel is determined by

$$\xi_\nu^{(i)} = \begin{cases} 1, & p_{i\nu}(T) > \gamma, \text{ signal presences} \\ 0, & p_{i\nu}(T) < \gamma, \text{ signal absences} \end{cases} \qquad (10)$$
$$i = 1, 2, \quad \nu = 1, \ldots, n.$$

The time delay estimation with the help of the weight summing of the threshold devices signals is determinated as

$$\hat{\tau}^{(i)} = \frac{T_M}{n} \sum_{\nu=1}^{n} \nu\, \xi_\nu^{(i)}, \qquad i = 1, 2. \qquad (11)$$

The noise component on the input of the threshold device is supposed to be gaussian. The supporting modulating intensity of the lightening bundle signal is equal to the received signal.

4. STATISTICAL CHARACTERISTICS OF THE SIGNAL TIME DELAY ESTIMATION AND THE DETECTION PROBABILITIES

The expression for the time delay estimation statistical characteristics may be presented as

$$\left\langle \hat{\tau}^{(i)} \right\rangle = T_M (i-1) + \nu_0 \frac{T_M}{n} \left[1 - \Phi(a_0) + (\chi - 1)(1 - \Phi(a)) \right],$$
$$\sigma_\tau^2 = \left(T_M \frac{\nu}{n} \right)^2 \left\{ D_0 + D \left(\chi \frac{2n+1}{3\nu_0} - 1 \right) \right\}, \qquad (12)$$

where

$$\chi = \frac{n(n+1)}{2\nu_0}, \qquad D_0 = \Phi(a_0) \left[1 - \Phi(a_0) \right],$$

$$D = \Phi(a)\left[1 - \Phi(a)\right],$$

$$a = \hat{\gamma}\left[Q_s\left(1 + \phi + Q_n^{-1}\right)^{-1}\right]^{1/2},$$

$$a_0 = \left(\hat{\gamma} - 1\right)\left[Q_s\left(1 + \phi + Q_n^{-1}\right)^{-1}\right]^{1/2},$$

$\Phi(x) = \dfrac{1}{\sqrt{2\pi}} \int\limits_{-\infty}^{x} \exp\left[-\dfrac{t^2}{2}\right] dt$ — integral of probability; $Q_n = \Psi^2 b^2 N_0 C_1^2 E / N_{ins} T$ — the interference to noise ratio on the input of the threshold device; $\phi = B_1^2 T / C_1^2 E$ — square of the ratio the invariable composing of the USML lightening bundle intensity to the mean amplitude square of the variable component of it; $Q_s = 2E / N_0$ — the signal to interference ratio; $\hat{\gamma} = \gamma / 2\, k_{tran} \Psi C_1 b E$ — threshold, normalized on the output signal maximum.

The signal detection probabilities for AOCTI recording the signal time delay and for another AOCTI are determinated accordingly as

$$D_0 = \int\limits_{-\infty}^{\gamma} \ldots \int\limits_{-\infty}^{\gamma} dp_1 \ldots dp_{\nu_0 - 1}\, dp_{\nu_0 + 1} \ldots dp_n \times$$

$$\times \int\limits_{\gamma}^{\infty} dp_{\nu_0}\, w_0(\vec{p}) = \Phi^{n-1}(a)\left[1 - \Phi(a_0)\right],$$

$$D_{error} = 1 - \int\limits_{-\infty}^{\gamma} \ldots \int\limits_{-\infty}^{\gamma} w_1(\vec{p})\, d\vec{p} = 1 - \Phi^n(a), \qquad \vec{p} = \{p_1, \ldots, p_n\},$$

where $w_0(\vec{p})$ and $w_1(\vec{p})$ are the combined probability gaussian densities of the AOCTI photodiode array output signals for the presence and the absence of the time delay received signal recording.

From (3) it is clear, when $Q_s \to \infty$ and $\Phi(a_0) \to 0$, $\Phi(a) \to 1$. Therefore the mean and dispersion of the signal time delay estimation are speeding to $\langle \hat{\tau} \rangle = \nu_0 T_M / n$, $\sigma_\tau^2 \to 0$. The threshold exceeding probability on the determinator output of AOCTI recording received signal time delay $D_0 \to 1$ and on the another AOCTI determinator output $D_{error} \to 0$.

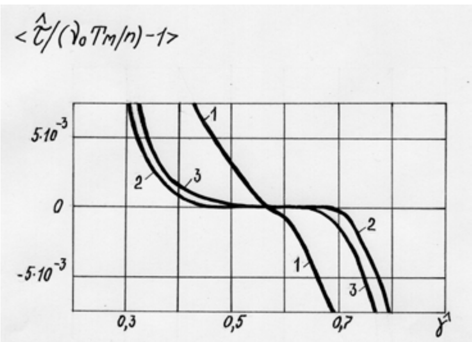

Fig. 2

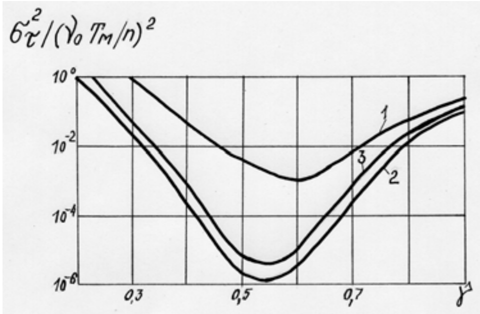

Fig.3

At the fig.2 and fig.3 accordingly the dependences of the normalized displacement $\left\langle \hat{\tau} / \left(\nu_0 T_M / n\right) - 1 \right\rangle$ and dispersion $\sigma_\tau^2 \left(\nu^2 T_M^2 / n^2\right)^{-1}$ as function of the normalized threshold $\hat{\gamma}$ are presented. The dependences are calculated for the cases:

1 — $Q_n = 4$, $Q_s = 200$;
2 — $Q_n = 4$, $Q_s = 400$;
3 — $Q_n = 2$, $Q_s = 400$.

From figs.2 and 3 it follows, that the maximum signal time delay estimation accuracy is reached $\hat{\gamma} = 0{,}4 \div 0{,}7$ and is increased with the growing of the signal to interference ratio and the interference to noise ratio.

5. CONCLUSIONS

In this paper the wideband signal time delay by the acoustooptic receiver with some acoustooptic correlators with time integration is considered. The processing algorithm of the integrating photodiodes output signals is given. The statistical characteristics expressions for the processing algorithm signal time delay estimation and the estimating acoustooptic correlator true detection probability are obtained. The conditions for the biggest signal time delay estimation accuracy and true detection probability are found.

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