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**VIRTUAL HYDROACOUSTIC SYSTEM OF THE TIME REVERSAL MIRROR WITH USE COMPLEX PHASE-MANIPULATED SIGNALS**

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*In this work results of experiments with virtual hydroacoustic system of the time reversal mirror (TRM) are presented. In this virtual TRM processing in spatial area is replaced by temporary processing the complex phase-manipulated signals (M-sequences) with addition modulation by short sequences with good correlation properties. Experiments were spent in 2005-2006 on stationary path at Sea of Japan.*

The method of TRM finds application for the decision of a lot of applied problems of hydroacoustics. It is focusing of a field, active nulling, communication, etc. For the characteristic of scale of works in this direction, it is possible to specify that fact, that for the researches connected with various aspects of a method, are actively used specialized ranges of the Center of underwater researches of NATO (Spezia, Italy) and Marine physical laboratory (San Diego, the USA), and results of researches have found reflection in V.A. Kuperman's numerous publications, etc. [1-7]. In this connection it is necessary to note works in M. Finn [8-11] and V.A.Zverev [12-14]. In particular, considered in [14] opportunity, under some conditions to replace processing in spatial area with processing in time, it is put in a basis of the present work.

The classical principle of the TRM assumes transmitting of a signal $s(t)$ a probe source; receiving of a signal $r_i(t)$, the past through waveguide with the pulse characteristic $h_i(t)$, *i-th* element of the vertical receiving-transmitting array and retransmitting the signals turned by time in a point of an arrangement of a probe source where the passive vertical array registers a signal $\tilde{s}(t)$. The sequence of stages of the classical TRM is represented by means of the operator of convolution * as follows:

$$s(t)\,;\; r_i(t) = s(t) * h_i(t)\,;\; r_i(-t)\,;\; \tilde{s}(t) = s(-t) * \sum_{i=1}^{N} h_i(-t) * h_i(t)\,.$$

Work of considered virtual hydroacoustic system of the TRM consist in transmitting by a probe source of signals $s_i(t)$, $i$=1, 2, … and $s'(t)$, receiving of these signals by single-element receiving system and the subsequent processing in time area according to algorithm:

$$s_i(t)\,,\; s'(t)\,;\; r_i(t) = s_i(t) * h_i(t)\,,\; r'(t) = s'(t) * h'(t)\,;$$

$$r'(-t)\,;\; \tilde{s}_i(t) = s'(-t) * s_i(t) * h'(-t) * h_i(t)\,.$$

Assuming $h_i(t)=h'(t)=h(t)$, that is a constancy of conditions of propagation of signals $s_i(t)$ and $s'(t)$, we shall estimate influence of the factor $q(t)=h(-t)*h(t)$, and it is describing the basic idea of a TRM-method actually. We shall present the accepted signal in the form:

$$r(t) = \sum_{k=1}^{M} a_k s(t-\tau_k)\,,$$

where $a_k$, $\tau_k$ - amplitude and a time lag *of i-th* arrival излученного a signal accordingly. We shall assume, that number of arrivals $M=3$, and we shall present transformation of a signal $s(t)$ to a signal $r(t)$ in the form of vectors of amplitudes and the relative delays describing influence of the pulse characteristic $h(t)$ for a case of three arrivals:

$$\{a_0; a_1; a_2\}\,,\; \{0; \tau_1; \tau_2\}\,.$$

Let's put for definiteness $\tau_2 > 2\tau_1$ then for the factor $q(t)$ we shall have:

$$\{a_0a_2; a_1a_2; a_0a_1; a_0^2 + a_1^2 + a_2^2; a_0a_1; a_1a_2; a_0a_2\}\,,\; \{-\tau_2; \tau_1-\tau_2; -\tau_1; 0; \tau_1; \tau_2-\tau_1; \tau_2\}\,.$$

It is visible, that the signal $\tilde{s}(t)$ can occupy in temporary area an interval $[-\tau_2, T+\tau_2]$ at duration of a signal of probe source $T$ if to not make the further processing: spatial, for a classical method of the TRM, or temporary. We shall note, that the level of side lobes of function $q(t)$ at the best can make 1/M from a level of the main lobe in which arrivals are summarized energetically.

Temporary processing in experiment with virtual hydroacoustic system of TRM provided focusing - compression of the time interval occupied by a signal $\tilde{s}(t)$ - due to a corresponding choice of signals $s_i(t)$ and $s'(t)$. In our case the pair preferred 511-symbol M-sequences for signals $s_i(t)$ was used, and the signal $s'(t)$ was formed according to expression:

$$s'(t) = \sum_i s_i(t) * p_i(t),$$

where $p_i(t)$ - signals of updating. More precisely, formation of a signal $s'(t)$ was made all over again at a discrete level, symbol-by-symbol:

$$s'(k) = \sum_i \sum_j s_i(j) p_i(k+1-j),$$

then, after some additional transformations, it was carried out on carrier frequency of 360 Hz. The principle of formation of a signal $s'(t)$ is explained by figure 1.

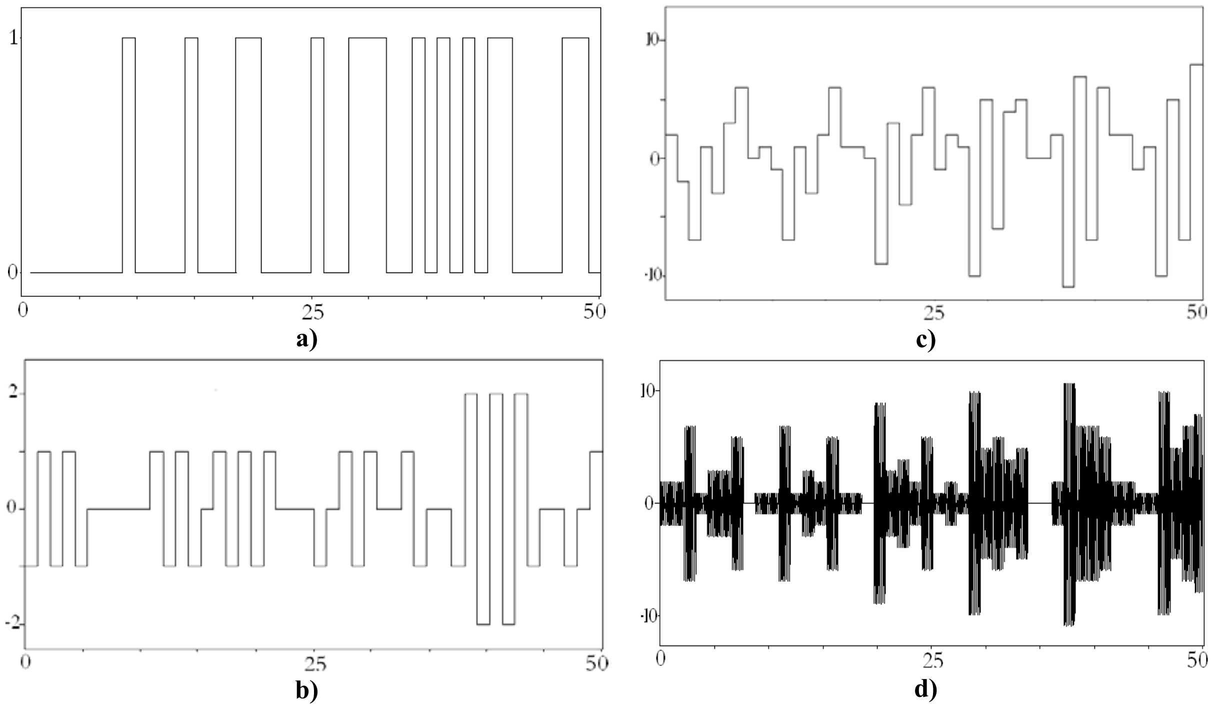



***Fig. 1.*** Formation of a signal *s'(t)*: a) - initial M-sequence the-first 50 symbols;
b) - updating by a code [100001]; c) - updating by a code [1(00001111)(00001111)…(00001111)] - 505 zero and units; d) - modulation of carrier frequency by final sequence.

The ensemble of signals $s_i(t)$ can be expanded due to Gold sequences or Kasami, generated on the basis of the chosen preferred M-sequences [15]. As modifying any sequences, however a prize in additional processing can be used can give orthogonal or quasyorthogonal sequences, for example, Walsh functions, Barker signals, etc. In our experiment we used Sherman sequences [110010100] and [001100101] for signals $p_1(t)$ and $p_2(t)$ accordingly [16]. The given sequences differ from each other shift on two symbols, the main lobe of their autocorrelation functions also are shifted on two symbols and have quadruple excess over a level of side lobes.

The scheme of one of experiments is presented in figure 2. The broadband acoustic source (S) has been placed in 400 m from a coastal line on depth of 39 m at depth of a place of 40 m. Receiving of signals carried out on a deepwater hydrophone of drifting receiver system (R), the distance up to which from a source made about 80 km. The path in a direction on bank of the Kita-Yamato passed through a shelf zone in length of 15 km with difference of depths of 40-100 m, shelf dump and the deep sea with depths of the order of 3000 m. Hydrological conditions were characterized by the sound channel near bottom - on a shelf and the underwater sound channel - in a deep-water part of a path.

Signals have been included in structure of the alarm frame $s_1(t)$, $s_2(t)$ and $s^{'}(t)$, which beginnings of transmitting have been displaced for 10 seconds and which represented preferred M-sequences and their updating with number of symbols 511 and duration of a symbol of carrier frequency equal to four periods of 360 Hz. Duration of initial signals made 5.678 seconds, modified - 5.789 seconds the Modified signal repeatedly was duplicated for representative statistics: its transmitting repeated each 10 seconds. The frame, the common duration of 3 minutes, included also other signals and was transmitted in a point (R) about an hour.

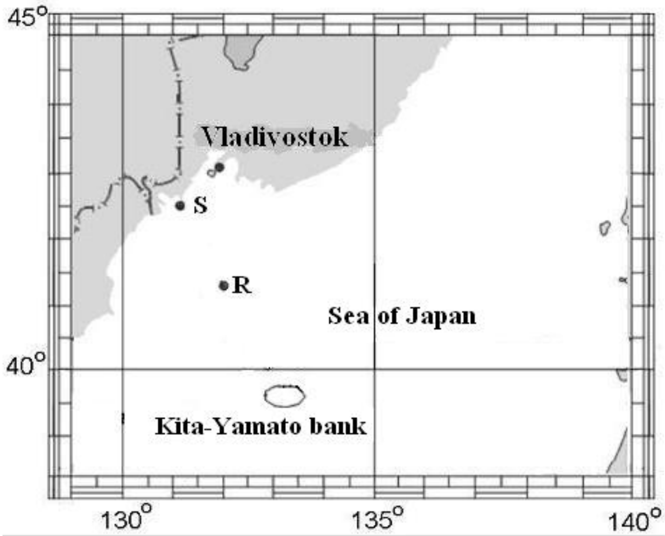



***Fig. 2.*** The scheme of experiment.

Results of signal processing of one of realizations are presented in figures 3 and 4.

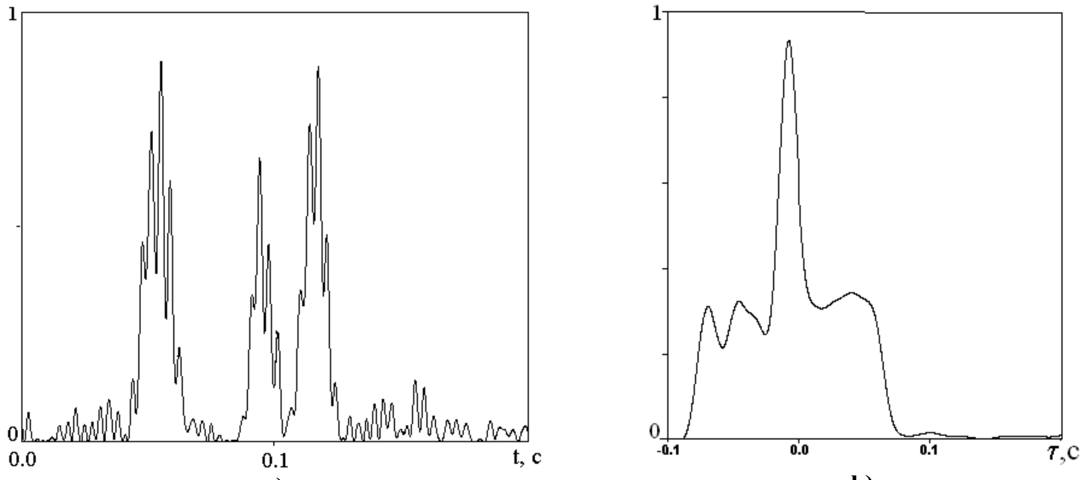
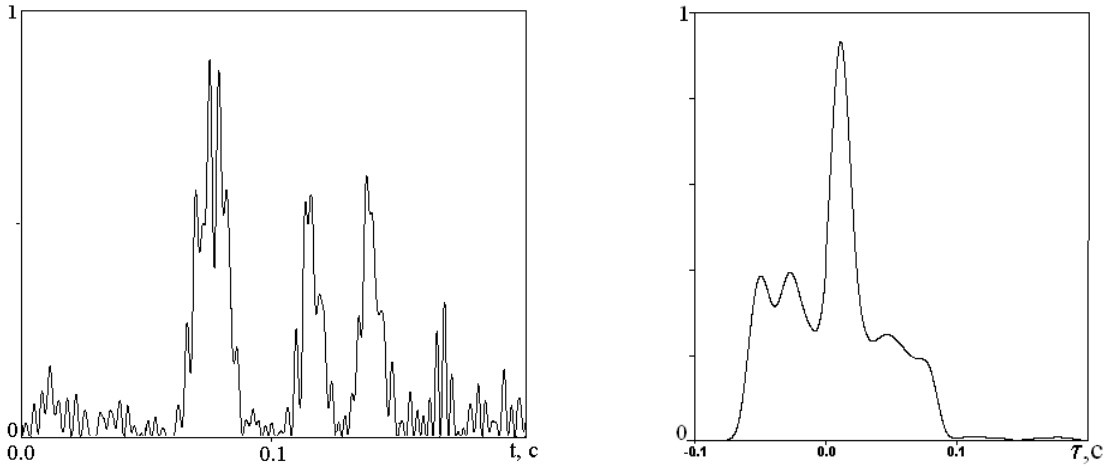



***Fig. 3.*** Result of processing: a) - signal $\tilde{s}_1(t)$; b) - convolution $\tilde{s}_1(t)$ with $p_1(t)$.




**а)** **б)**

***Fig. 4.*** Result of processing: a) - signal $\tilde{s}_2(t)$; b) - convolution $\tilde{s}_2(t)$ with $p_1(t)$.

The analysis of results of experiment shows, that application complex phase-manipulated signals as signals of a probe source provides focusing in time in enough difficult conditions of propagation (a hydrology, a variable path on depth). The signals allocated as a result of primary processing are well turned off with initial modifying sequences, strengthening effect of focusing. As a whole experiment has shown working capacity and efficiency of virtual hydroacoustic system of the TRM which can be used in various areas of underwater acoustics, such as wireless communication, long-range measurement, etc.

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