JPRS L/10015

25 September 1981

Translation

WORKS OF THE 10TH ALL-UNION SCHOOL-SEMINAR ON STATISTICAL HYDROACOUSTICS

Ed. by

V.V. Ol'shevskiy, et al.

FBIS FOREIGN BROADCAST INFORMATION SERVICE

FOR OFFICIAL USE ONLY

APPROVED FOR RELEASE: 2007/02/09: CIA-RDP82-00850R000400050065-1

NOTE

JPRS publications contain information primarily from foreign newspapers, periodicals and books, but also from news agency transmissions and broadcasts. Materials from foreign-language sources are translated; those from English-language sources are transcribed or reprinted, with the original phrasing and other characteristics retained.

Headlines, editorial reports, and material enclosed in brackets [] are supplied by JPRS. Processing indicators such as [Text] or [Excerpt] in the first line of each item, or following the last line of a brief, indicate how the original information was processed. Where no processing indicator is given, the information was summarized or extracted.

Unfamiliar names rendered phonetically or transliterated are enclosed in parentheses. Words or names preceded by a question mark and enclosed in parentheses were not clear in the original but have been supplied as appropriate in context. Other unattributed parenthetical notes within the body of an item originate with the source. Times within items are as given by source.

The contents of this publication in no way represent the policies, views or attitudes of the U.S. Government.

APPROVED FOR RELEASE: 2007/02/09: CIA-RDP82-00850R000400050065-1

JPRS L/10015

25 September 1981

WORKS OF THE 10TH ALL-UNION SCHOOL-SEMINAR ON STATISTICAL HYDROACOUSTICS

Novosibirsk TRUDY DESYATOY VSESOYUZNOY SHKOLY-SEMINARA PO STATISTICHESKOY GIDROAKUSTIKE in Russian 1980 (signed to press 23 Oct 80) pp 2-144

[Complete contents of collection of works "Works of the 10th All-Union School-Seminar on Statistical Hydroacoustics", edited by V.V. Ol'shevskiy, N.G. Zagoruyko, S.V. Pasechnyy and L.Ya. Taradanov, Institute of Mathematics, Siberian Department, USSR Academy of Sciences, 400 copies, 144 pages]

CONTENTS

 [I - USSR - E FOUO]

ANNOTATION

/Text/ This collection contains materials from the 10th anniversary All-Union School-Seminar on Statistical Hydroacoustics, which was organized by the Scientific Council on Hydrophysics of the USSR Academy of Sciences' Presidium, the USSR Academy of Sciences' Acoustics Institute, the Mathematics Institute of the USSR Academy of Sciences' Siberian Department and the Kiev Polytechnic Institute.

The seminar was held in Sukhumi, from 17 to 21 October 1978.

This collection's subject matter includes methodological questions on modern statistical acoustics; questions on the study of a hydroacoustic channel and its characteristics; questions on the processing of signals against a background of noise and the transmission and processing of information on biological objects.

The materials in this work will be of interest to scientific workers and specialists in the field of hydrophysical research and information processing, as well as graduate students, engineers and senior students.

STATISTICAL HYDROACOUSTICS AND OCEANOGRAPHY: REVIEW OF MODELS AND OPERATORS AND CLASSIFICATION OF PROBLEMS

[Article by V. V. Ol'shevskiy pp 3-15]

/Text/ 1. Introduction. The development of the theory and methods of statistical hydroacoustics, particularly in the last 10-15 years (see, for example, /1-6, 12, 13/), made it possible, on the one hand, to solve a whole series of scientific problems related to the development of statistical models, the analysis and synthesis of algorithms for the processing of hydroacoustic information, the formulation and conduct of simulated computer experiments and so on; on the other hand, the development of statistical hydroacoustics engendered new problems directed at a more thorough examination of various hydrophysical phenomena and the mechanisms of their functioning, as well as the study of the interaction of hydroacoustic information systems with the ocean. Primarily, these types of problems have to do with investigations of acoustico-oceanographic models--namely, the determination of the special features of their formation, the analysis of the interrelationships of special and general models, and the solution of different statistical problems emanating from the need for a more thorough understanding of the acoustical situation, the acoustic weather and the acoustic climate in the ocean /13/.

Generally speaking, acoustico-oceanographic research as a scientific field appeared quite long ago. It is sufficient to point out the fundamental works /1, 7-10/ to make clear the definite direction of different investigators: for more than 30 years now, steps have been taken toward a joint (integrated) examination of oceanographic and acoustic phenomena. In the 10 years since 1969, the annual All-Union School-Seminars on Statistical Hydroacoustics have been playing a significant role in the formation of these outlooks / 6 /, along with the First Congress of Soviet Oceanographers /11/, which was held in 1977, the annual regional seminar on "Acoustical Methods of Investigating the Ocean" /12/, which has been held since 1976, and the First Seminar on "Acoustic Statistic Models of the Ocean" /13/, which was conducted in 1976. Along with development in this direction, the last 10-15 years have also seen the development of a general methodology and constructive computer programs for image identification (see, in particular, /14-17/ and others). In these methods we have synthesized many heuristic ideas about searching for and making quantitative descriptions of regularities and ideas about classifying objects of various types and identifying them, in connection with which statistical analysis was improved, procedures and programs for computer modeling were developed and so on. At the same time, ideas about computer data banks have also been developed intensively in recent years: methods for forming them have been created, along with information retrieval programs, interpreting programs, operational control systems for computers and so forth. All of this--the development of acoustico-oceanographic statistical models, the accumulation of experimental data about the ocean, the development of image identification methods and the theory of data banks, as well as methods for creating and using them--makes it possible, from a rather general viewpoint, to form an opinion about contemporary statistical acoustico-oceanographic problems, to review the models and operators that have been created up until now and, finally, to formulate several problems on the formal level. On the whole, this work is of a systems (integrated) nature: essentially, it seems to us, it is only such an approach that can make it possible to tie special and general models together into a unified whole, indicate the position of individual problems in the general problem of investigating the ocean and, finally, determine the current level of development of the problem, while noting the near and remote prospects in connection with this.

2. Formal Description. Let us introduce the following sets: Θ_Z = the set of oceanographic characteristics; Θ_Y = the set of the ocean's acoustic characteristics; Θ_X = the set of characteristics of the acoustic fields in the ocean; Θ_R = = the set of output data of a hydroacoustic information system. The elements of these sets are the vector functions

$$\vec{Z}(\vec{\gamma}) \in \Theta_Z,\ \vec{Y}(\vec{\beta}) \in \Theta_Y,\ \vec{X}(\vec{\alpha}) \in \Theta_X,\ \vec{R}(\vec{\eta}) \in \Theta_R, \qquad (1)$$

it being the case that each of these vector functions describes the following objects: $\vec{Z}(\vec{\gamma})$ = oceanographic characteristics; $\vec{Y}(\vec{\beta})$ = acoustical characteristics of the ocean; $\vec{X}(\vec{\alpha})$ = the acoustic fields in the ocean; $\vec{R}(\vec{\eta})$ = the information system's output data. Let us further introduce the transfer statements between pairs of vector functions, so that

$$\vec{Y}(\vec{\beta}) = Q_{YZ}\{\vec{Z}(\vec{\gamma})\},\ \vec{X}(\vec{\alpha}) = Q_{XY}\{\vec{Y}(\vec{\beta})\},\ \vec{R}(\vec{\eta}) = Q_{RX}\{\vec{X}(\vec{\alpha})\}. \qquad (2)$$

In a more compact form, system of equations (2) can be written as the following sequence:

$$\left.\begin{aligned} \vec{Y}(\vec{\beta}) &= Q_{YZ}\{\vec{Z}(\vec{\gamma})\}, \\ \vec{X}(\vec{\alpha}) &= Q_{XYZ}\{\vec{Z}(\vec{\gamma})\} = Q_{XY}Q_{YZ}\{\vec{Z}(\vec{\gamma})\}, \\ \vec{R}(\vec{\eta}) &= Q_{RXYZ}\{\vec{Z}(\vec{\gamma})\} = Q_{RX}Q_{XY}Q_{YZ}\{\vec{Z}(\vec{\gamma})\}, \end{aligned}\right\} \qquad (3)$$

in connection with which the introduced operators correspond to the following couplings: operator Q_{YZ} couples the oceanographic characteristics with the ocean's acoustic characteristics; operator Q_{XY} couples the ocean's acoustic characteristics with the characteristics of the acoustic fields in it; operator Q_{RX} couples the hydroacoustic information system's output data with the acoustic fields; in addition, from (3) it follows that $Q_{XYZ} = Q_{XY}Q_{YZ}$ and $Q_{RXYZ} = Q_{RX}Q_{XY}Q_{YZ}$. Let us mention here that since, in the general case, operators Q_{RX}, Q_{XY} and Q_{YZ} are a combination of linear (smoothing) and nonlinear (modulating) operators, their rearrangement when determining the combined operators Q_{XYZ} and Q_{RXYZ} is not permissible. Further, in the space of the vector functions (1) under discussion, it is necessary to introduce distance or the degree of proximity. Let us write the distance functionals as follows:

$$\left.\begin{aligned} d_Z(k,\ell) &= d[\vec{Z}_k(\vec{\gamma}),\vec{Z}_\ell(\vec{\gamma})],\ d_Y(k,\ell) = d[\vec{Y}_k(\vec{\beta}),\vec{Y}_\ell(\vec{\beta})], \\ d_X(k,\ell) &= d[\vec{X}_k(\vec{\alpha}),\vec{X}_\ell(\vec{\alpha})],\ d_R(k,\ell) = d[\vec{R}_k(\vec{\eta}),\vec{R}_\ell(\vec{\eta})], \end{aligned}\right\} \tag{4}$$

where k, ℓ = numbers of the vector functions, the distances between which are being determined. Let us now discuss the form of the description of the vector functions. When investigating acoustic phenomena and information systems in the ocean according to model (2) and (3), the original vector function is the random one $\vec{Z}(\vec{\gamma})$, which characterizes the oceanographic situation. A completely probable description of the vector functions in the group of sets Θ_Z, Θ_Y, Θ_X and Θ_R is given by the combined probability distribution law

$$P_r(\vec{Z},\vec{Y},\vec{X},\vec{R}/\vec{\lambda}) \tag{5}$$

of the vector functions under discussion, as well as by the distribution law

$$P_r(\vec{\lambda}), \tag{6}$$

it being the case that in the general case, the multidimensional value $\vec{\lambda}$ characterizes the complete set of acoustico-oceanographic conditions: in this sense, probability distribution (5) is provisional. It is obvious that the construction of the complete acoustico-oceanographic probability model (5) and (6) is a practically unrealizable task at the present time. Therefore, the first constructive step in this direction is the construction of partial probability models of the type:

$$P_r(\vec{Z}/\vec{\lambda}_Z),\ P_r(\vec{Y}/\vec{\lambda}_Y),\ P_r(\vec{X}/\vec{\lambda}_X),\ P_r(\vec{R}/\vec{\lambda}_R) \tag{7}$$

together with the probability models of the operators

$$P_r(Q_{YZ}/\vec{\lambda}_Y,\vec{\lambda}_Z),\ P_r(Q_{XY}/\vec{\lambda}_X,\vec{\lambda}_Y),\ P_r(Q_{RX}/\vec{\lambda}_R,\vec{\lambda}_X), \tag{8}$$

where $\vec{\lambda}_Z$, $\vec{\lambda}_Y$, $\vec{\lambda}_X$ and $\vec{\lambda}_R$ characterize the corresponding oceanographic and acoustic conditions, the probability distributions of which must also be determined:

$$P_r(\vec{\lambda}_Z),\ P_r(\vec{\lambda}_Y),\ P_r(\vec{\lambda}_X),\ P_r(\vec{\lambda}_R). \tag{9}$$

A second approximation to a full probability description of acoustico-oceanographic conditions (5) and (6) is the assignment of the first joint distribution laws of the type

$$P_r(\vec{Z},\vec{Y}/\vec{\lambda}_Z,\vec{\lambda}_Y),\ P_r(\vec{Y},\vec{X}/\vec{\lambda}_Y,\vec{\lambda}_X),\ P_r(\vec{X},\vec{R}/\vec{\lambda}_X,\vec{\lambda}_R), \tag{10}$$

which are possibly the probability distributions of operators (8), as well as the conditions

$$P_r(\vec{\lambda}_Z,\vec{\lambda}_Y),\ P_r(\vec{\lambda}_Y,\vec{\lambda}_X),\ P_r(\vec{\lambda}_X,\vec{\lambda}_R). \tag{11}$$

This, as is the case with approximation (7)-(9), is an incomplete (partial) probability description of the acoustico-oceanographic models, although it is much more difficult to realize it than description (7)-(9). Among the other approximations to a complete probability model it is necessary to mention the correlational level of the description of the acoustico-oceanographic phenomena. In connection with this, of course, an estimate of the degree of completeness of the description is not guaranteed in the general case, although in a number of cases correlational models prove to be quite effective. This type of correlational model of the vector functions under discussion is presented in the form

$$\left.\begin{aligned} &K[\vec{Z}(\vec{\gamma})/\vec{\lambda}_Z] = K_Z(\vec{\gamma}',\vec{\gamma}''/\vec{\lambda}_Z),\ K[\vec{Y}(\vec{\beta})/\vec{\lambda}_Y] = K_Y(\vec{\beta}',\vec{\beta}''/\vec{\lambda}_Y),\\ &K[\vec{X}(\vec{\alpha})/\vec{\lambda}_X] = K_X(\vec{\alpha}',\vec{\alpha}''/\vec{\lambda}_X),\ K[\vec{R}(\vec{\eta})/\vec{\lambda}_R] = K_R(\vec{\eta}',\vec{\eta}''/\vec{\lambda}_R) \end{aligned}\right\} \quad (12)$$

together with the correlational models of the corresponding paired operators

$$K(Q_{YZ}/\vec{\lambda}_Y,\vec{\lambda}_Z),\ K(Q_{XY}/\vec{\lambda}_X,\vec{\lambda}_Y),\ K(Q_{RX}/\vec{\lambda}_R,\vec{\lambda}_X), \quad (13)$$

it being the case that as in the other cases under discussion, correlational models are provisional in the sense of the acoustico-oceanographic situation $\vec{\lambda}_Z$, $\vec{\lambda}_Y$, $\vec{\lambda}_X$ and $\vec{\lambda}_R$, for which its own probability description must be given at (for example) the level of (9).

3. Interpretation. Let us now discuss and give an acoustico-oceanographic interpretation of the formal concepts of vector functions that were introduced in Section 2.

3A. Vector function

$$\vec{Z}(\vec{\gamma}) = [z_1(\vec{\gamma}_1), z_2(\vec{\gamma}_2), \ldots, z_q(\vec{\gamma}_q)] \quad (14)$$

is understood to mean the set of scalar functions $z_i(\vec{\gamma}_i)$, $i = \overline{1,q}$, of vector arguments $\vec{\gamma}_i$ that describe the oceanographic--in the broad sense (atmospheric, aqueous and geological)--phenomena affecting the ocean's acoustic characteristics. Primarily, this means:

the characteristics of the layer of atmosphere adjacent to the ocean's surface: in connection with this, $z_1(\vec{\gamma}_1)$ describes the dependence of the instantaneous wind velocity on the spatiotemporal coordinates, $\vec{\gamma}_1 = (\vec{\rho},t)$;

the characteristics of the state of the water surface: in connection with this, $z_2(\vec{\gamma}_2)$ describes the displacement of the water surface as a function of the spatiotemporal coordinates, $\vec{\gamma}_2 = (\vec{\rho},t)$;

the characteristics of the air bubbles in the layer of water near the surface: in connection with this, $z_3(\vec{\gamma}_3)$, $z_4(\vec{\gamma}_4)$ and $z_5(\vec{\gamma}_5)$ describe, respectively, the number of air bubbles in a certain volume, their sizes and their rate of motion as a function of the spatial and temporal coordinates, $\vec{\gamma}_3, \vec{\gamma}_4, \vec{\gamma}_5 = (\vec{\rho},t)$;

the characteristics of the solid particles in the ocean layer: in connection with this, $z_6(\vec{\gamma}_6)$, $z_7(\vec{\gamma}_7)$ and $z_8(\vec{\gamma}_8)$ describe, respectively, the number of particles in a certain volume, their sizes and their rate of motion as a function of the spatial and temporal coordinates, $\vec{\gamma}_6, \vec{\gamma}_7, \vec{\gamma}_8 = (\vec{\rho},t)$;

the characteristics of the mixing of water masses and currents: in connection with this, $z_9(\vec{\gamma}_9)$ describes the rate of motion as a function of the spatial coordinates /sic/, $\vec{\gamma}_9 = (\vec{\rho},t)$;

the ocean's temperature characteristics, including both its surface and subsurface waves: in connection with this, $z_{10}(\vec{\gamma}_{10})$ describes the temperature's dependence on the spatial and temporal coordinates, $\vec{\gamma}_{10} = (\vec{\rho},t)$;
the ocean's salinity characteristics: in connection with this, $z_{11}(\vec{\gamma}_{11})$, $z_{12}(\vec{\gamma}_{12}),\ldots,z_z(\vec{\gamma}_z)$ describe the concentrations of different salts in the ocean as a function of the spatial and temporal coordinates, $\vec{\gamma}_{11},\vec{\gamma}_{12},\ldots,\vec{\gamma}_z = (\vec{\rho},t)$;
the characteristics of biological objects: in connection with this, $z_{z+1}(\vec{\gamma}_{z+1})$, $z_{z+2}(\vec{\gamma}_{z+2}),\ldots,z_\rho(\vec{\gamma}_\rho)$ describe the species composition of biological objects as a function of the spatial and temporal coordinates, $\vec{\gamma}_{z+1},\vec{\gamma}_{z+2},\ldots,\vec{\gamma}_\rho = (\vec{\rho},t)$;
the characteristics of the ocean's bottom: in connection with this, $z_{\rho+1}(\vec{\gamma}_{\rho+1})$, $z_{\rho+2}(\vec{\gamma}_{\rho+2}),\ldots,z_q(\vec{\gamma}_q)$ describe the relationships of the different components of the bottom, including its surface, as a function of the spatial coordinates, $\vec{\gamma}_{\rho+1}$, $\vec{\gamma}_{\rho+2},\ldots,\vec{\gamma}_q = (\vec{\rho})$.

All of these functions $z_i(\vec{\gamma}_i)$ are random in nature, so their description is given with the help of probability laws or their parameters.

3B. Vector function

$$\vec{Y}(\vec{\beta}) = [y_1(\vec{\beta}_1),y_2(\vec{\beta}_2),\ldots,y_p(\vec{\beta}_p)] \tag{15}$$

is understood to mean the set of scalar functions $y_j(\vec{\beta}_j)$, $j = \overline{1,p}$, of vector arguments $\vec{\beta}_j$ that describe the acoustic characteristics of the ocean that affect the formation of acoustic fields in it. Primarily, this means:
the scattering characteristics, also including coherent scattering, on irregularities in the water surface: in connection with this, $y_1(\vec{\beta}_1)$ describes the dependence of the undulating surface's scattering function on the spatial and temporal coordinates and the acoustic signal's frequency, $\vec{\beta}_1 = (\vec{\rho},t,\omega)$;
the water surface's reflection characteristics: in connection with this, $y_2(\vec{\beta}_2)$ describes the dependence of the surface's scattering function on the spatial and temporal coordinates and the signal's frequency, $\vec{\beta}_2 = (\vec{\rho},t,\omega)$;
the scattering characteristics, also including coherent scattering, on air bubbles in the layer near the surface: in connection with this, $y_3(\vec{\beta}_3)$ describes the dependence of the layer's scattering function on the spatial and temporal coordinates and the signal's frequency, $\vec{\beta}_3 = (\vec{\rho},t,\omega)$;
the characteristics of scattering on the solid particles in the ocean layer: in connection with this, $y_4(\vec{\beta}_4)$ describes the dependence of the particles' scattering function on the spatial and temporal coordinates and the frequency, $\vec{\beta}_4 = (\vec{\rho},t,\omega)$;
the characteristics of scattering on temperature irregularities in the ocean: in connection with this, $y_5(\vec{\beta}_5)$ describes the dependence of the irregularities'

scattering function on the spatial and temporal coordinates and the frequency, $\vec{\beta}_5 = (\vec{\rho}, t, \omega)$;

the scattering characteristics, also including coherent scattering, on biological objects in the ocean: in connection with this, $y_6(\vec{\beta}_6)$, $y_7(\vec{\beta}_7), \ldots, y_z(\vec{\beta}_z)$ describe the dependences of the scattering functions of different types of biological objects on the spatial and temporal coordinates and the frequency, $\vec{\beta}_6, \vec{\beta}_7, \vec{\beta}_8, \ldots, \vec{\beta}_z = (\vec{\rho}, t, \omega)$;

the refraction characteristics related to the nonuniformity of the ocean's temperature and salinity: in connection with this, $y_{z+1}(\vec{\beta}_{z+1})$, $y_{z+2}(\vec{\beta}_{z+2}), \ldots, y_m(\vec{\beta}_m)$ describe the dependences of the acoustic wave refraction parameters (during their propagation) on the spatial and temporal coordinates and the frequency, $\vec{\beta}_{z+1}, \vec{\beta}_{z+2}, \ldots, \vec{\beta}_m = (\vec{\rho}, t, \omega)$;

the absorption characteristics related to the effect of the ocean's temperature and salinity, irregularities in its boundaries, air bubbles, biological objects and the structure of the bottom: in connection with this, $y_{m+1}(\vec{\beta}_{m+1}), y_{m+2}(\vec{\beta}_{m+2}), \ldots, y_\lambda(\vec{\beta}_\lambda)$ describe the dependence of the absorption functions on the spatial and temporal coordinates and the frequency, $\vec{\beta}_{m+1}, \vec{\beta}_{m+2}, \ldots, \vec{\beta}_\lambda = (\vec{\rho}, t, \omega)$;

the scattering characteristics, also including coherent scattering, on irregularities on the bottom and nonuniformities in its structure: in connection with this, $y_{\lambda+1}(\vec{\beta}_{\lambda+1}), y_{\lambda+2}(\vec{\beta}_{\lambda+2}), \ldots, y_\mu(\vec{\beta}_\mu)$ describe the dependences of the indicated objects' scattering functions on the temporal and spatial coordinates and the frequency, $\vec{\beta}_{\lambda+1}, \vec{\beta}_{\lambda+2}, \ldots, \vec{\beta}_\mu = (\vec{\rho}, t, \omega)$;

the reflection characteristics of the ocean bottom and its different structural formations: in connection with this, $y_{\mu+1}(\vec{\beta}_{\mu+1}), y_{\mu+2}(\vec{\beta}_{\mu+2}), \ldots, y_\nu(\vec{\beta}_\nu)$ describe the dependences of the reflection functions on the spatial and temporal characteristics and the frequency, $\vec{\beta}_{\mu+1}, \vec{\beta}_{\mu+2}, \ldots, \vec{\beta}_\nu = (\vec{\rho}, t, \omega)$;

the characteristics of the sources of underwater noises in the ocean, including wave action from the water's surface, cavitation phenomena in the ocean, sources of biological origin, manmade underwater equipment and seismic sources related to the dynamics of the water masses: in connection with this, $y_{\nu+1}(\vec{\beta}_{\nu+1}), y_{\nu+2}(\vec{\beta}_{\nu+2}), \ldots, y_p(\vec{\beta}_p)$ describe the dependences of the sources' functions on the spatial and temporal coordinates and the frequency, $\vec{\beta}_{\nu+1}, \vec{\beta}_{\nu+2}, \ldots, \vec{\beta}_p = (\vec{\rho}, t, \omega)$.

The functions $y_j(\vec{\beta}_j)$ under discussion--as was the case with $z_i(\vec{\gamma}_i)$--are random, so their description is given with the help of probability laws and their parameters.

3C. The vector function

$$\vec{X}(\vec{\alpha}) = [x_1(\vec{\alpha}_1), x_2(\vec{\alpha}_2), \ldots, x_m(\vec{\alpha}_m)] \quad (16)$$

is understood to mean the set of scalar functions $x_k(\vec{\alpha}_k)$, $k = \overline{1,m}$, of vector arguments $\vec{\alpha}_k$ that describe the acoustic fields in the ocean that affect hydroacoustic information systems. Primarily, this means:

the field of direct signals: in connection with this, $x_1(\vec{\alpha}_1)$ describes these fields as a function of the spatial coordinates of the observation point, time and the frequency, $\vec{\alpha}_1 = (\vec{\rho}, t, \omega)$;

the field of reverberation signals: in connection with this, $x_2(\vec{\alpha}_2)$ describes these fields as a function of the spatial coordinates of the observation point, time and frequency, $\vec{\alpha}_2 = (\vec{\rho}, t, \omega)$;

the field of return signals: in connection with this, $x_3(\vec{\alpha}_3)$ describes these fields as a function of the spatial coordinates of the observation point, time and frequency, $\vec{\alpha}_3 = (\vec{\rho}, t, \omega)$;

the field of underwater noises: in connection with this, $x_4(\vec{\alpha}_4)$ describes these fields as a function of the spatial coordinates of the observation point, time and frequency, $\vec{\alpha}_4 = (\vec{\rho}, t, \omega)$.

3D. The vector function

$$\vec{R}(\vec{\eta}) = [r_1(\vec{\eta}_1), r_2(\vec{\eta}_2), \ldots, r_n(\vec{\eta}_n)] \tag{17}$$

is understood to mean the set of scalar functions $r_k(\vec{\eta}_k)$, $k = \overline{1,n}$, of vector arguments $\vec{\eta}_k$ that describe the processes at the hydroacoustic information systems' outputs. Since these systems are of a measuring type, $\vec{R}(\vec{\eta})$ usually means a set of statistical evaluations of different probability characteristics of the acoustic fields for which one or more features are being studied. These can be evaluations of mathematical expectations, moment functions of different orders, probability densities, characteristic functions, correlation functions and others.

4. Data Banks. The basis of the solution of many informational acoustico-oceanographic problems is data banks. Information on the sets Θ_Z, Θ_Y, Θ_X and Θ_R is stored in them. In connection with this, the information is represented by the subsets

$$\hat{\Theta}_Z \subset \Theta_Z,\ \hat{\Theta}_Y \subset \Theta_Y,\ \hat{\Theta}_X \subset \Theta_X,\ \hat{\Theta}_R \subset \Theta_R, \tag{18}$$

since the sets themselves are ideal (complete) models, while the actual information in them (indicated by the sign "^" above) essentially corresponds to the working models; that is, models obtained on the basis of experimental investigations, constructive theories and modeling. Along with these data banks (18), there are also other banks in which information on the operators Q_{YZ}, Q_{XY}, Q_{RX}, Q_{XYZ} and Q_{RXYZ} is stored. In a manner analogous to (18), the banks of operators naturally contain information on the working operators, which are subsets of the ideal ones; that is,

$$\hat{Q}_{YZ} \subset Q_{YZ},\ \hat{Q}_{XY} \subset Q_{XY},\ \hat{Q}_{RX} \subset Q_{RX},\ \hat{Q}_{XYZ} \subset Q_{XYZ},\ \hat{Q}_{RXYZ} \subset Q_{RXYZ}, \tag{19}$$

since we do not know the ideal operators.

Acoustico-oceanographic information of the following types is stored in the data banks:

1. The results of experimental investigations, including:

samples of random values, processes, fields and vector functions characterizing the

phenomena observed in the ocean;
statistical estimates of the probability characteristics, as obtained by processing the samples.
2. Empirical regularities about the acoustico-oceanographic situation.
3. Equations (and their solutions) describing acoustico-oceanographic phenomena, as well as the characteristics of the hydroacoustic information systems.

5. Statistical Methods. The development of mathematical statistics methods, which took place intensively over the course of many decades, resulted in the emergence of a powerful (and one that has already become the classical) apparatus for processing the results of observations and testing hypotheses. However, two fundamental questions concerning the use of statistical methods have still not received full and constructive answers. The first question concerns the use of statistical procedures under dynamic conditions of observation of investigated phenomena and objects: these are problems of the statistical analysis of heterogeneous samples, nonstationary processes, nonisotropic and nonstationary fields and so on. The second question concerns multidimensional statistical procedures. These two fields are being developed at the present time, primarily within the framework of the overall problem of an artificial intellect /14-17/. Despite the fact that in connection with this many methods are heuristic and in a number of cases even nonrigorous, the successes and constructive results of the area of statistical analysis are obvious.

6. Formulations of Several Typical Problems. As follows from what was explained above, most problems in the field of the investigation of acoustico-oceanographic models include the following main aspects: first, each problem must be given a clear acoustico-oceanographic interpretation; second, it is necessary to formulate a problem on the basis of clearcut formal definitions and concepts; third, it is not mandatory to look for the solution of a problem with the help of analytical methods, since image identification and similar methods are more appropriate here; fourth, the solution of a problem will most likely be obtained with the help of a computer (that is, with the help of numerical methods, modeling and computer simulation methods. Below we will discuss several typical acoustico-oceanographic problems, following the concepts explained in Sections 2-5 and keeping in mind the methods from identification theory developed in the works of N.G. Zagoruyko and his colleagues (see /15,16,18.19/ and others).

6A. Filling Spaces in a Data Bank and Editing Its Elements. A data bank--particularly a set of acoustico-oceanographic situation banks that are in accordance with (18) and (19)--cannot, of course, be full. The reasons for this lack of fullness are, in the first place, the practical impossibility of obtaining exhaustive experimental data on an entire set of acoustico-oceanographic conditions; in the second place, the presence of errors when conducting experimental research; in the third place, incomplete monitoring of the acoustico-oceanographic situation during experiments; finally, in the fourth place, the lack of general acoustico-oceanographic models at the present time. All of this results in a situation where a bank of acoustico-oceanographic conditions is a set of tables (files) containing spaces in the elements, the lines and the columns. The primary processing assignments of such a bank are /15,16,18,19/:
filling the available spaces with the "most probable," "most nearly correct" image;
detecting errors in the data bank's tables; that is, "editing" it.

Both these problems are solved by image identification methods that have now been developed, in connection with which the objective redundancy of the information in the data bank is used and the information content of the effect of some parts of the tables (lines, columns) on the different elements is investigated beforehand.

Thus, according to (18) and (19), a bank of acoustico-oceanographic conditions consists of sets (see Sections 3 and 4) characterizing the properties of the four vector functions

$$\hat{\Theta} = \hat{\Theta}_Z \cup \hat{\Theta}_Y \cup \hat{\Theta}_X \cup \hat{\Theta}_R, \tag{20}$$

as well as the bank of operators of their interaction

$$\hat{Q} = \hat{Q}_{YZ} \cup \hat{Q}_{XY} \cup \hat{Q}_{RX} \cup \hat{Q}_{XYZ} \cup \hat{Q}_{RXYZ}. \tag{21}$$

After the solution of the problems under discussion by image identification methods, we obtain the improved banks Θ^* and Q^*, which satisfy the conditions

$$\Theta \supset \hat{\Theta}^* \supset \hat{\Theta}, \quad Q \supset \hat{Q}^* \supset \hat{Q}, \tag{22}$$

where Θ and Q are ideal (complete) models of the sets of vector functions and operators, which, of course, are not known precisely.

6B. Determination of Classes of Oceanographic Characteristics According to Acoustic Features. One of the problems in image identification theory is the determination of classes (groups, taxons or clasters that are equivalent /15-17,19/) into which several objects in a space of features can be divided. For a whole series of propositions it is necessary to divide oceanographic characteristics into classes. The main problem in connection with this is selecting the features in the space of which the classification will be made. Keeping in mind the hydroacoustic aspects and the final purpose of the solution of such a problem, as the features it is necessary to take acoustical ones; that is, according to (1)-(3) and Section 3 (see 3C and 3D) they can be vector functions

$$\vec{X}^*(\vec{\alpha}) \in \hat{\Theta}_X^* \tag{23}$$

or

$$\hat{R}^*(\vec{n}) \in \hat{\Theta}_R^*, \tag{24}$$

which are available in the data bank (see above, problem 6a).

With the help of taxonomic methods /15-17,19/, by introducing distance $d_X(k,\ell)$, $d_R(k,\ell)$ in the spaces of vector functions (23) or (24) in accordance with (4), the set $\hat{\Theta}_Z^*$ of oceanographic characteristics can be divided into the following subsets:

$$\bigcup_i \hat{\vartheta}_{Zi}^* = \hat{\Theta}_Z^*; \quad \hat{\vartheta}_{Zi}^* \cap \hat{\vartheta}_{Zj}^* = \phi, \ i \neq j, \tag{25}$$

where $\hat{\vartheta}_{Zi}^*$, $i = 1, N_Z$, will also be the unknown, nonintersecting classes of oceanographic characteristics. Let us mention here that when solving this problem, it is necessary to give either the allowable values of distance d_{X0}, d_{R0} corresponding to any of the classes $\hat{\vartheta}^*_{ri}$ or the desirable number of classes N_Z into which set $\hat{\Theta}^*_Z$ is divided.

Thus, the division of set $\hat{\Theta}^*_Z$ into classes $\hat{\vartheta}^*_{Zi}$ according to acoustic features (for example, according to vector functions $\vec{R}(\vec{\eta})$) is done according to the following algorithm: into class $\hat{\vartheta}^*_{Zi}$ enter all the vector functions

$$\hat{Z}_{k,\ell,i}(\vec{\gamma}) \in \hat{\vartheta}_{Zi},\ k,\ell = \text{var}, \tag{26}$$

for which the condition

$$\sup_{k,\ell} d_R(k,\ell) \leqslant d_{R0} \tag{27}$$

occurs. It goes without saying that in connection with this, one keeps in mind the maximally complete utilization of information about the coupling operators (19) of the vector functions under discussion.

6C. Determination of Classes of Acoustic Characteristics According to Oceanographic Features. By its nature, this problem is similar (symmetrical) to problem 6B, the only difference being that the space of the features is the set of vector functions describing the oceanographic characteristics (see Sections 3 and 3A):

$$\hat{Z}^*(\vec{\gamma}) \in \hat{\Theta}^*_Z, \tag{28}$$

while set (23) or (24) corroborates the division into classes.

In connection with this, the division of (for example) set $\hat{\Theta}^*_R$ into classes $\hat{\vartheta}^*_{Rj}$ according to oceanographic features (that is, vector functions $\vec{Z}^*(\vec{\gamma})$) is done according to the following algorithm: into class $\hat{\vartheta}^*_{Rj}$ enter all vector functions

$$\hat{R}_{k,\ell,i} \in \hat{\vartheta}^*_{Ri},\ k,\ell = \text{var}, \tag{29}$$

for which the condition

$$\sup_{k,\ell} d_Z(k,\ell) \leqslant d_{Z0} \tag{30}$$

occurs.

For class $\hat{\vartheta}^*_{Ri}$ there must occur conditions of the type of (25):

$$\bigcup_i \hat{\vartheta}^*_{Ri} = \hat{\Theta}^*_R;\ \hat{\vartheta}^*_{Ri} \cap \hat{\vartheta}^*_{Rj} = \phi,\ i \neq j, \tag{31}$$

where $\hat{\vartheta}^*_{Ri}$, $i = \overline{1,N_R}$, are the unknown, nonintersecting classes; N_R = the total number of these classes.

6D. Identification of the Acoustic Situation. Problems of this type are formulated in the following manner: the classes of objects to be identified are given (in this case, the classes $\hat{\vartheta}^*_{Ri}$ of the hydroacoustic systems' output effects, $\bigcup_i \hat{\vartheta}^*_{Ri} = \hat{\Theta}^*_R$, $i = \overline{1,N_R}$, or the classes $\hat{\vartheta}^*_{Xj}$ of the acoustic fields, $\bigcup_i \hat{\vartheta}^*_{Xj} = \hat{\Theta}^*_X$, $j = \overline{1,N_X}$); also given is the space of identification features (in this case, the vector functions $\hat{Z}^*(\vec{\gamma}) \in \hat{\Theta}^*_Z$ of the oceanological characteristics). When solving this problem, for the given realizations $\hat{Z}^*_\ell(\vec{\gamma})$, $\ell = \overline{1,L}$, it is necessary to establish the classes $\hat{\vartheta}^*_{R\ell}$ or $\hat{\vartheta}^*_{X\ell}$ to which $\hat{Z}^*_\ell(\vec{\gamma})$ belong; that is, to determine the correspondence

$$\hat{Z}^*_\ell(\vec{\gamma}) \rightarrow \hat{\vartheta}^*_{R\ell} \qquad (32)$$

or

$$\hat{Z}^*_\ell(\vec{\gamma}) \rightarrow \vartheta^*_{X\ell}. \qquad (33)$$

Such a problem is solved by standard image identification methods /14-18/, and its specific nature in the acoustico-oceanographic interpretation under discussion is only that it is necessary to allow correctly for the following operator couplings:

$$\hat{R}^*(\eta) = \hat{Q}^*_{RXYZ}\{\hat{Z}^*(\vec{\gamma})\} \qquad (34)$$

or

$$\hat{X}^*(\vec{\alpha}) = \hat{Q}^*_{XYZ}\{\hat{Z}^*(\vec{\gamma}) \ , \qquad (35)$$

keeping in mind the fact that $\hat{Q}^*_{RXYZ}$ and $\hat{Q}^*_{XYZ}$ are of a stochastic nature.

6E. Identification of the Oceanographic Situation. This problem is similar (symmetrical) to problem 6D, the only difference being that what is given is the classes $\hat{\vartheta}^*_{Zi}$ of oceanological characteristics, $\bigcup_i \hat{\vartheta}^*_{Zi} = \hat{\Theta}^*_Z$, while the features are the space $\hat{R}^*(\vec{\eta}) \in \hat{\Theta}^*_R$ of the hydroacoustic information system's output effects or the space $\vec{\hat{X}}^*(\vec{\alpha}) \in \hat{\Theta}^*_X$ of the acoustic fields. The solution here is the determination of the affiliation of realizations $\vec{\hat{R}}^*_p(\vec{\eta})$, $p = \overline{1,P}$, or $\hat{X}^*_q(\vec{\alpha})$, $q = \overline{1,Q}$, to one of the classes $\hat{\vartheta}^*_{Zp}$ or $\hat{\vartheta}^*_{Zq}$; that is, determination of the correspondence

$$\hat{R}^*_p(\vec{\eta}) \rightarrow \hat{\vartheta}^*_{Zp} \qquad (36)$$

or

$$\hat{X}^*_q(\vec{\alpha}) \rightarrow \hat{\vartheta}^*_{Zq}. \qquad (37)$$

6F. Hierarchy of Classes: Acoustical Situation, Acoustic Weather and Climate. Above (see problems 6B-6E) classes of acoustico-oceanographic models with some boundary distances d_0 given in the space of the selected features, such as d_{R0} (according to (27)) or d_{Z0} (according to (30)) and so on. In connection with this analysis, however, the spatiotemporal coordinates (that is, the different regions of the world ocean) were not figured in explicit form. We will assume that the acoustic characteristics that are of interest to us are described by the vector function $\vec{\hat{R}}^*(\vec{\eta})$, although the entire discussion can also be applied, in full measure, to the acoustic fields' vector function $\vec{\hat{X}}^*(\vec{\alpha})$. Let us introduce the concept of spatiotemporal limitations

$$V = (\rho \in (R_V \pm \Delta R_V);\ t \in (T_V \pm \Delta T_V)), \qquad (38)$$

where $\vec{R}_v$ determines the spatial coordinates of the center of the selected region; $\Delta\vec{R}_v$--its area; T_v--the initial moment of time; ΔT_v--the observational time interval. We will call the acoustic situation that set of realizations of the vector functions $\hat{\vec{R}}^*_{v0}(\vec{\eta})$ that is defined for the limitations $\vec{V}_0$:

$$V_0 = (\vec{\rho} \in (\vec{R}_v \pm \Delta\vec{R}_{v0});\ t \in (T_v \pm \Delta T_{v0})):\{\hat{\vec{R}}^*_{v0}(\vec{\eta})\}, \qquad (39)$$

where $\Delta\vec{R}_{v0}$ and ΔT_{v0} are selected on the basis of the statistical uniformity of the ensemble of realizations $\{\vec{R}^*_{v0}(\eta)\}$. In connection with this,

$$\hat{\vec{R}}^*_{v0}(\vec{\eta}) \in \hat{\vartheta}^*_{Rv0}(\vec{R}_v, T_v); \qquad (40)$$

that is, the vector functions under discussion form a set depending on the initial coordinates $\vec{R}_v$ and the current time T_v. The determination of classes (40) must be made in the space of oceanographic features $\hat{\vec{Z}}^*(\vec{\gamma})$ according to the technique described in problem 6C, using taxonomic methods. Let us mention here that the choice of limitations V_0 according to (39) can be made on the basis of the introduction of a boundary value of distance d_{Z00} in the space $\hat{\vec{Z}}^*(\vec{\gamma})$, which essentially also determines class (40) as a function of the spatiotemporal coordinates. We will consider the term "acoustic weather in the ocean" to mean seasonal changes in the acoustic situation in some region of the ocean. This means that, according to (40), acoustic weather corresponds to the set

$$\bigcup_{\vec{R}_v, T_v} \hat{\vartheta}^*_{Rv0}(\vec{R}_v, T_v) = \hat{\vartheta}^*_{Rvw}(\vec{R}_{vw}), \qquad (41)$$

where $\vec{R}_{vw}$ defines a region with homogeneous (in the statistical sense) acoustic weather satisfying the condition

$$\vec{R}_{vw} = \arg\,[\sup_{k,\ell} d_{R0}(k,\ell) \leqslant d_{Rw}],\ T_v \in (0,\infty), \qquad (42)$$

where $d_{R0}(k,\ell)$ = distance between corresponding vector functions (40) with numbers (k,ℓ); d_{Rw} = permissible level of the difference in these vector functions within the limits of a single weather region $\vec{R}_{vw}$. Thus, set (41) determines the weather changes in the given region. "Acoustic climate in the ocean" means durable changes in the acoustic weather in some region of the ocean. This means that, according to (41), acoustic climate corresponds to the set

$$\bigcup_{\vec{R}_{vw}} \hat{\vartheta}^*_{Rvw}(\vec{R}_{vw}) = \hat{\vartheta}^*_{Rvk}(\vec{R}_{vk}), \qquad (43)$$

where $\vec{R}_{vk}$ determines a zone in the ocean with homogeneous (in the statistical sense) acoustic climate satisfying the condition

$$\vec{R}_{vk} = \arg\,[\sup_{k,\ell} d_{R0}(k,\ell) \leqslant d_{Rk}], \qquad (44)$$

where (in addition to the definitions used above) d_{Rk} = permissible level of difference in vector functions (40) within the limits of a single climatic zone $\vec{R}_{vk}$. Thus, according to (40), (41) and (43), the hierarchy of acoustico-oceanographic classes has the following form:

$$\bigcup_{\vec{R}_{vk}}\{\bigcup_{\vec{R}_{vw}}[\bigcup_{\vec{R}_v, T_v}\hat{\vec{R}}_{v\eta}(\vec{\eta}) \in \hat{\vartheta}^*_{Rv0}(\vec{R}_v, T_v) = \hat{\vartheta}^*_{Rvw}(\vec{R}_{vw})] = \hat{\vartheta}^*_{Rvk}(\vec{R}_{vk})\} = \Theta^*_R. \quad (45)$$

7. Resume. In this article we have discussed some contemporary statistical aspects of the investigation of acoustico-oceanographic models, using image identification methods and methods from adjacent fields as tools to solve the corresponding problems. The problems formulated above naturally require additional specific definition and the development of constructive methods for their computer realization. In this area there are, of course, certain difficulties that, it is to be hoped, will be overcome.

BIBLIOGRAPHY

1. Chernov, L.A., "Rasprostraneniye voln v srede so sluchaynym neodnorodnostyami" /Wave Propagation in a Medium With Random Irregularities/, Moscow, Izdatel'stvo AN SSSR /USSR Academy of Sciences/, 1958.

2. Ol'shevskiy, V.V., "Statisticheskiye svoystva morskoy reverberatsii" /Statistical Properties of Marine Reverberation/, Moscow, Izdatel'stvo "Nauka", 1966.

3. Middleton, D., "A Statistical Theory of Reverberation and Similar First-Order Scattered Fields," IEEE TRANS. INF. THEORY, IT-13, 1967, pp 372-392, 394-414 (Parts I and II), IEEE TRANS. INF. TH., IT-18, 1972, pp 35-67, 68-90 (Parts III and IV).

4. Ol'shevskiy, V.V., "Statisticheskiye metody v gidrolokatsii" /Statistical Methods in Hydrolocation/, Leningrad, Izdatel'stvo "Sudostroyeniye", 1973.

5. Middleton, D., "Characterization of Active Underwater Acoustic Channels," TECH. REP. ARL-TR-74-61, Applied Research Labs, University of Texas at Austin, 1974.

6. "Trudy Vsesoyuznykh shkol-seminarov po statisticheskoy gidroakustike" /Works of the All-Union School-Seminars on Statistical Hydroacoustics/, Novosibirsk, Institute of Mathematics, Siberian Department, AN SSSR, 1969-1978.

7. Mleshchev, V.I., editor, "Fizicheskiye osnovy podvodnoy akustiki" /Physical Principles of Underwater Acoustics/, Moscow, Izdatel'stvo "Sovetskoye radio", 1955 (translated from English).

8. Shuleykin, V.V., "Ocherki po fizike morya" /Essays on the Physics of the Sea/, Moscow-Leningrad, Izdatel'stvo AN SSSR, 1949.

9. Tolstoy, N., and Kley, K., "Akustika okeana" /Ocean Acoustics/, Moscow, Izdatel'stvo "Mir", 1969 (translated from English).

10. Brekhovskiy, L.M., editor, "Akustika okeana" /Ocean Acoustics/, Moscow, Izdatel'stvo "Nauka", 1974.

11. "I s"yezd sovetskikh okeanologov. Referaty dokladov" /First Congress of Soviet Oceanographers: Abstracts of Reports/, Moscow, 1977.

12. "Akusticheskiye metody issledovaniya okeana" /Acoustic Methods of Investigating the Ocean, collection of works/, Leningrad, Izdatel'stvo "Sudostroyeniye", No 237, 1976; No 255, 1977 (materials on exchange of experiences).

13. "Trudy pervogo seminara 'Akusticheskiye statisticheskiye modeli okeana'" /Works of the First Seminar on "Acoustic Statistical Models of the Ocean"/, Moscow, Acoustics Institute, AN SSSR, 1977.

14. Sebestian, G.S., "Protsessy prinyatiya resheniya pri raspoznavanii obrazov" /Decision-Making Processes in Image Identification/, Kiev, Izdatel'stvo "Tekhnika", 1965 (translated from English).

15. Zagoruyko, N.G., "Metody raspoznavaniya i ikh primeneniye" /Identification Methods and Their Use/, Moscow, Izdatel'stvo "Sovetskoye radio", 1972.

16. Zagoruyko, N.G., "Iskusstvennyy intelekt i empiricheskoye predskazaniye" /Artificial Intellect and Empirical Prediction/, Novosibirsk, Novosibirsk State University, 1975.

17. Dyuran, B., Odell, P., "Klasternyy analiz" /Claster Analysis/, Moscow, Izdatel'stvo "Statistika", 1977.

18. Zagoruyko, N.G., Yelkin, V.N., and Timerkayev, V.S., "The '75' Algorithm for Filling Spaces in Empirical Tables," in "Vychislitel'nyye sistemy" /Computer Systems/, Novosibirsk, No 67, 1975, pp 3-28.

19. Yelkin, V.N., and Zagoruyko, N.G., "Quantitative Quality Criteria From Taxonomy and Their Utilization in the Decision-Making Process," in "Vychislitel'nyye sistemy", Novosibirsk, No 61, 1975, pp 3-27.

APPLIED ASPECTS OF THE THEORY OF LINEAR RANDOM PROCESSES

[Article by B. G. Marchenko pp 16-18]

/Text/ Introduction. An orderly and compact statement of many questions in the theory of stochastic integrals can be obtained within the framework of the class of linear random processes. In the extensive propagation of linear random processes for the solution of applied problems, an essential role is played by the fact that for linear random processes presented in an integral form, the general form of the characteristic functional is known and the physical meaning of the parameters and functions that are part of it is described /1,2/, which in a number of cases makes it possible to obtain the moments and semi-invariants of such processes comparatively simply or, speaking in the language of physics, for such processes there is a generalized theorem on the imposition of random disturbances.

2. Linear Random Processes: Definition. An actual, random, separable process $\xi_\omega(t)$ in a probability space $\{\Omega,B,P_T\}$, where T is a unidimensional set with separability set $T_0 = \{t_j,\ j = 1,2,\ldots,t_j \in T\}$, is called linear if it can be represented as a limit in the sense of weak convergence of the distributions in the for

$$\xi_\omega(t) = \lim_{n\to\infty} \sum_{j=1}^{n} \eta_{nj}(t,\omega), \quad (1)$$

where $\{\eta_{nj}(t,\omega),\ j = \overline{1,n},\ n = 1,2,\ldots\}$ is an infinite sequence of processes that are independent for each fixing of n, the sequential sums of which satisfy the condition of uniform infinite smallness; that is,

$$\lim_{n\to\infty} \max_j P\{|\eta_{nj}(t,\omega)| \geqslant \varepsilon\} = 0 \quad (2)$$

for each $\varepsilon > 0$ and $t \in T_0$.

2. Processes With Independent Increments. We will define them in terms of $\eta(t)$ and give them on the semiaxis or the entire number-scale axis. These processes' increments are independent in nonintersecting time intervals and the general form of their characteristic function's logarithm is

$$\ln f(u,t) = \ln M \exp\{iu[\eta(t_2) - \eta(t_1)]\} =$$
$$= iu[\mu(t_2) - \mu(t_1)] - \frac{u^2}{2}[D(t_2) - D(t_1)] + \int_{-\infty}^{\infty} (e^{iux} - 1 - \frac{iux}{1+x^2})\frac{1+x^2}{x}G(dx \times [t_1,t_2]), \quad (3)$$

where $\mu(t)$, $D(t) \geqslant 0$ = some numerical functions determined unambiguously by $\eta(t)$, while $G(dx \times [t_1,t_2])$ = Poisson measure of the discontinuities. It can be said that separable random processes with independent increments satisfy the definition of linear random processes formulated above.

4. Integral Representations of Linear Random Processes. The linear processes that have been most thoroughly studied are (Gil'bert) linear processes represented by a stochastic integral in the form

$$\xi(t) = \int_{-\infty}^{\infty} \zeta(\tau,t)d\eta(\tau), \quad t \in T, \quad (4)$$

where $\zeta(\tau,t)$ is a nonrandom numerical function satisfying the condition $\int_{-\infty}^{\infty} \zeta^2(\tau,t)d\tau < \infty$ for all $t \in T$; $\{\eta(t),\eta(0) = 0,\ t \in (-\infty,\infty)\}$ = a Gil'bert process with independent increments; T = an arbitrary set of real numbers, including the multi-dimensional spaces R^n. The logarithm of the characteristic function of process (4) is determined by the expression

$$\ln f(u,t) = \ln Me^{iu\xi(t)} = iu\int_{-\infty}^{\infty} \zeta(\tau,t)d\mu(\tau) - \frac{u^2}{2}\int_{-\infty}^{\infty} \zeta^2(\tau,t)dD(\tau) +$$
$$+ \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} [e^{iux\zeta(\tau,t)} - 1 - \frac{iux\zeta(\tau,t)}{1+x^2}]\frac{1+x^2}{x}G(dx \times d\tau), \quad (5)$$

where $\mu(\tau)$, $D(\tau)$ and $G(dx \times d\tau)$ are defined as in formula (3) and characterize a process with independent increments $\eta(t)$.

The general form of the characteristic function (5) of process (4) makes it possible to conduct a complete analysis of the responses of linear systems: find the semi-invariants and density of the probability distribution or the response distribution function, and study the distribution of discontinuities in its realizations.

5. Connecting Linear Random Processes With Other Processes. The convenience of the utilization of a model of a linear random process consists not only of the fact that practically all the characteristics can be obtained for such processes, but also in its close relationship with other, no less important models such as--for example--harmonizable and periodically correlational random processes (PKSP).

If, in representation (4), the nucleus satisfies the condition

$$\zeta(\tau,t) = \zeta(\tau + T,t + T),\ t \in (0,\infty), \quad (6)$$

for all τ and $t \in (-\infty,\infty)$, process (4) will be a PKSP; that is, its correlation function will also satisfy a condition analogous to (6). Such processes are encountered quite frequently in practice and are used to describe rhythmic phenomena.

As is known, a process permitting a representation in the form

$$\xi(t) = \int_{-\infty}^{\infty} e^{i2\pi\lambda t}dz(\lambda), \quad (7)$$

where $z(\lambda)$ = some random process, the correlation function of which has limited variation, is said to be (Loev) harmonizable.

If we assume that $z(\lambda)$ in (7) is some process with independent increments (not necessarily uniform ones), (7) will then be a harmonizable, linear random process with complex signs.

5. Physical Processes Described With the Help of Linear Random Processes. Along with the solution of the problems mentioned above, which are related to linear and nonlinear transformations of random processes, linear random processes also prove to be extremely useful when creating primary, original models of different real physical processes, which models can be constructed starting with an elementary pulse structure and the physics of the formation of such processes.

In conclusion let us note that a model of linear random processes can be used to obtain series of pseudorandom numbers, with previously assigned characteristics and interconnections, with the help of a computer. Such series can be used in the solution of problems by the statistical modeling method.

BIBLIOGRAPHY

1. Marchenko, B.G., "Metod stokhasticheskikh integral'nykh predstavleniy i yego primeneniye v radiotekhnike" /The Method of Stochastic Integral Representations and Its Use in Radio Engineering/, Kiev, Izdatel'stvo "Naukova dumka", 1973.

2. Marchenko, B.G., and Shcherbak, L.N., "Lineynyye sluchaynyye protsessy i ikh prilozheniya" /Linear Random Processes and Their Applications/, Kiev, Izdatel'stvo "Naukova dumka", 1975.

3. Ol'shevskiy, V.V., "Statisticheskiye svoystva morskoy reverberatsii" /Statistical Properties of Marine Reverberation/, Moscow, Izdatel'stvo "Nauka", 1966.

SYNTHESIS OF DETERMINATIVE SYSTEMS IN PROBLEMS INVOLVING INVESTIGATION OF THE WORLD OCEAN

[Article by Yu. Ye. Sidorov pp 18-26

/Text/ 1. Introduction. Every year there is more interest in problems concerning the investigation and mastery of the world ocean, which--as far as its importance and the extent to which it is being studied--has become a "second space." In the opinion of both Soviet and foreign scientists, in the next few years the ocean will become an object for which it will be profitable to direct maximum efforts in order to investigate it and utilize its resources.

In connection with this, the question of equipment and methods for investigating the hydrosphere is an extremely urgent one. The basic facilities for collecting oceanographic information are: 1) buoy stations (sea buoys); 2) ships; 3) aviation (airplanes, helicopters); 4) artificial Earth satellites and other flying spacecraft (KLA). The information obtained with the help of buoy stations, ships and aviation is of a regional nature, while that obtained with the help of KLA is of the global type. Other facilities for gathering regional information are balloons (controlled and uncontrolled), dirigibles (automatic) and sounding balloons and rockets. Different equipment for remote investigation of the ocean (by, for example, photography) can be placed in the cars of balloons and sounding balloons and the bodies of rockets. The basic methods for obtaining oceanographic information are contact and remote (noncontact) methods; the latter include: 1) visual observations; 2) photographic and television surveying of the surface of a water area; 3) infrared and multispectral surveying (in the wave band $\lambda \cong 0.3$ μm to 1 mm); 4) radiophysical methods (radiothermal location, radar) with $\lambda \cong 1$ mm to 1 m; 5) acoustic location; 6) optical (laser) location. Remote sounding methods can also be divided into two groups: active and passive. The active methods include radar and acoustic and optical location, while the passive ones include visual observations, photographic and television surveying, radiometric measurements and images obtained with the help of scanning radiometers in the visible light, near infrared and microwave bands, and acoustic methods.

Each of the methods listed above can be used to obtain some bit or another of oceanographic information that is of interest to us. The most promising and informative methods are the remote methods for sounding the ocean, which are based on the emission and reflection of electromagnetic and/or acoustic waves by the aqueous medium.

A special place is occupied by radiohydroacoustic methods of investigating the world ocean in combination with aviation and KLA, which produce the basic flow of information about the ocean's depths (see Figure 3.1 in /1/).

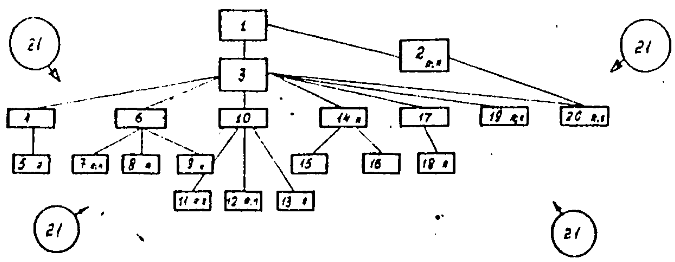


Figure 1. Illustration of problems and methods of investigating the world ocean: 1. world ocean; 2. investigations of the surface and the surface layer; 3. underwater hydroacoustic investigations; 4. hydrophysics problems; 5. temperature irregularities and layers; 6. dangerous phenomena; 7. underwater part of an iceberg; 8. reefs, shallows; 9. tsunamis; 10. biological products from the ocean; 11. sea life; 12. fish; 13. plankton; 14. structure of the bottom; 15. global; 16. local (for engineering purposes); 17. investigations of the nature of the Earth's surface beneath the world ocean; 18. search for useful minerals (marine geology); 19. special problems; 20. navigation problems; A. active methods; П. passive methods; 21. development of optimum algorithms for classifying and evaluating signal parameters (for different levels of prior information about probability models and their characteristics).

The possibilities of solving various scientific and national economic problems concerning the study and mastery of the world ocean's depths with the help of aerospace radiohydroacoustic sounding methods in active and passive hydrolocation modes are illustrated in the block diagram shown in Figure 1. As an example, Block 2 is concerned with the study of the water's surface (determining temperature, boundaries and types of ice covers, degree of wave action and pollution and so on) by the different methods listed above as Nos 1-4 and 6. The necessity of obtaining oceanographic information that is as nearly complete as possible (which is achieved by the integrated utilization of various sounding facilities and methods), its operational and objective processing (including the finding and supplying to the consumer of certain solutions), and the multibranch nature of the data supplied to the consumer all require an examination of the problems involved in creating an ASOAOI /automated system for processing asynchronous oceanographic information/.

2. Some Propositions of the Theory of Complex Hierarchical Systems. The need for a systems approach to the synthesis of an ASOAOI is dictated by the direction of the development of automated control systems toward the study of objects and processes of ever-increasing complexity. A clear example of this is the investigation of the ocean. The desire for an accurate and as nearly complete as possible accounting of the variegated phenomena and processes taking place in the ocean and the set of

factors affecting these phenomena and processes cannot be satisfied without constructing an appropriately complex automated system. This means that the researchers and developers are faced with new scientific and technical problems. These problems are the substance of a new scientific and technical field: systems analysis. The mathematical basis of systems analysis is the theory of complex (or large) systems /2-4/.

At the present time there is no clearcut (from the viewpoint of constructing a rigorous theory) definition of a complex system.

One special class of complex systems is information systems, the structure of which is adaptable to the implementation of special functions (such as receiving, storing, processing and publishing large masses of information) and which are intended for operation on especially large information flows /2/. In addition to this, an information system satisfies the following requirements /5/: 1) the nature of the input signals is random and is formalized within the framework of a theoretical-probability apparatus; 2) the system can be part of a larger system, but its function criterion can be formulated autonomously, to some degree; 3) the system operates according to an algorithm emanating from the function criterion that includes the extension of several statistical decisions.

The question of the presence or absence of a hierarchical organization in the systems is of extreme importance.

If we consider that the essential characteristics inherent in all hierarchical systems are /3/: a) sequential, vertical arrangement of the subsystems constituting the given system (vertical decomposition); b) priority of action or the right of interference by subsystems on a higher level; c) dependence of the higher-level subsystems' actions on the actual performance of their own functions by the lower levels, then any ergaticheskaya /translation unknown/ system is hierarchical, so that man--an upper level of hierarchy--can interfere in the operation of the system and monitor it, and his activities naturally depend on the results of the lower-level subsystems' operations. Here the concept "system" or "subsystem" (module) has the additional meaning of realizing the process of transforming input data into output.

Three levels of hierarchy are recognized: 1) the description or abstraction level (stratum); 2) the level of complexity of an accepted decision (layer); 3) the organizational level (echelon). The echelon concept refers to interlinking between the decision-making elements that form the system. It implies that 1) the system consists of a group of clearly defined interacting subsystems; 2) some of these subsystems are decision-making (determinative) elements; 3) the determinative elements are arranged hierarchically in the sense that some of them are affected or controlled by other determinative elements /3/. Such systems are called multi-echelon, multilevel or multipurpose.

The basic stages in the synthesis of determinative systems (in the methodology of systems analysis) can be defined as follows /3/: 1) description on the verbal level; 2) conceptualization and representation in the form of a block diagram; 3) formalization and formulation of problems (within the framework of the systems' general theory); 4) analysis (with the enlistment of additional mathematical constructs) and investigation of properties. The verbal (word) description of the system makes it possible to construct a block diagram of it that shows the interaction of the subsystems and the connections among them. The next stage is formalization of the block diagram's description and the obtaining of a model in the form of an abstract system. For this model it is possible to construct a mathematical description and study the system's behavior analytically or with the help of a computer.

3. Global Structure of the ASOAOI. This system is used to obtain information on the status, development and quantitative evaluation of various oceanographic processes and objects (such as water temperature, salinity and chemical composition, the location and direction of migration of biological objects, bottom relief, underwater storms, icebergs, tsunamis and many other things). The basic problems that the system must solve are: collection of primary information; classification and evaluation of the parameters of the processes and objects that are of interest to the consumer; presentation of solutions to the consumer. An ASOAOI has the following requirements: operativeness and accuracy of data processing and publication (in different forms); formulation of solutions with the fewest possible errors and maximum efficiency (probability that the solution is correct); the system must be of a minimum size and economically justified.

An ASOAOI's structural diagram must contain the following subsystems (modules): a measurement complex; an information reception, storage and processing system; an information transmission system; an information display system; a monitoring and coordination system; a system for detecting and eliminating malfunctions.

The equipment and methods for obtaining oceanographic information must be determined for the measurement complex (this was discussed in Section 1). The measurement complex naturally contains the appropriate surveying and measuring equipment. The information reception, storage and processing system must include: 1) a reception center; 2) storage devices; 3) a primary (preliminary) processing system; 4) a system for sorting information and tieing it in with some geographic region or another, transforming the scales and standardizing and interpreting the data; 5) a system for making decisions.

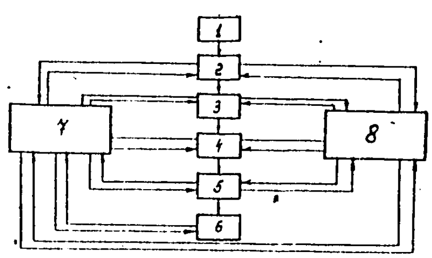


Figure 2. Block diagram of ASOAOI: 1. external environment (world ocean); 2. measurement complex; 3. information reception, storage and processing system; 4. information transmission system; 5. information display system; 6. information consumer; 7. monitoring-coordinating center; 8. repair and operating center.

On the basis of the verbal description it is possible to draw up a block diagram of the ASOAOI that reflects the system's global structure (Figure 2). From a preliminary familiarity with the basic problems solved in this system and its block diagram, the diversity of the functions performed by the system--the main ones of which are related to the stage-by-stage processing of large flows of information--is quite clear. Moreover, an ASOAOI satisfies requirements (1-3) for information systems that were formulated in Section 2; for instance, it can be part of a larger system (a system for remote sounding of the Earth). Therefore, our system can undoubtedly be assigned to the class of complex, cybernetic information systems; its special feature must be a high degree of automation based on the use of high-speed computers that are functionally joined into large computer complexes.

4. Formalization of the Description of the System. For purposes of description and analysis of its operation, a complex system must first be broken down into separate elements, with their functioning being studied first, it being the case that this division is not always carried out unambiguously and is largely determined by the specific purpose of the system. Our system can be assigned to the class of hierarchical, multilevel, multipurpose systems. This assignment agrees completely with the definition of such systems given in Section 2. For example, the purpose of the reception, storage and processing system is to distinguish useful information with the maximum probability, while the transmission system's function is to transmit this information undistortedly and with minimum error. It is also obvious that the ASOAOI's other subsystems have distinctive (local) purposes, it being the case that each of these subsystems has its own function criteria and criteria for evaluating the quality of its own actions. Thus, an ASOAOI is fundamentally a multicriterion system. A formalized mathematical representation of an ASOAOI is possible in terms of a relationship between sets X and Y:

$$S \subseteq X \times Y, \qquad (1)$$

where X = the input set; Y = the output set, while elements $x \in X$ and $y \in Y$ are inputs and outputs, respectively. If S is the function $S: X \rightarrow Y$, the system is called functional /3/. Thus, the representation of the system in the form of a relationship is a representation in the "input-output" form. It is possible to discuss the space of input signals (states) $\overset{o}{X} = X_1 \times X_2 \times \ldots \times X_n$ of the system; here X_i, $i = \overline{1,n}$ are the elementary axes (subspaces) and an input signal x is a point in the space $\overset{o}{X}$ described by the coordinates $x_1, x_2, \ldots, x_n$ (in the general case, X $\overset{o}{X}$). Analogously, the space of the system's output signals is the direct product $\overset{o}{Y} = Y_1 \times Y_2 \times \ldots \times Y_m$, $Y \subset \overset{o}{Y}$. Such operations are, naturally, also correct for each of the subsystems, so that $\overset{o}{Y}$ is the space of the output signals for a higher-level (such as the r-th level) subsystem and the space of the input signals for a lower-level ((r-1)-th) subsystem. It is particularly convenient to define the system in terms of a decision-making problem. The system $S \subseteq X \times Y$ is called determinant if the family of problems D_x, $x \in X$ is given, along with the set of solutions Z and the mapping $T: Z \rightarrow Y$, $\forall x \in X$ and $\forall y \in Y$ of the pair $(x, y) \in S$ only if there exists an ele-z Z such that it is the solution of the problem D_x and $T(z) = y$. In most cases the output is the solution of the formulated problem and $Z = Y$; that is, T is an identity mapping /3/.

Any system formalized in the form of an "input-output" model can be represented in the form of a determinant system, and vice versa. Systems possessing a hierarchical structure are distinguished by the fact that their subsystems' functions can be interpreted easily as the search for and making of decisions /3/. If the decision (operation) algorithm is determined for each of an ASOAOI's subsystems, the entire system's algorithm can be represented in the form of a combination of separate algorithms. This is possible because of the fact that an ASOAOI (as is the case with all technical hierarchical systems) belongs to the class of reflex systems, the reaction of which to a disturbance is completely unambiguous.

5. On Optimality and Evaluating a System's Efficiency. The concept of "optimality" of a hierarchical system is extremely diffuse, since there exists the possibility that each subsystem can independently make a decision; this applied, in particular, to maximizing its own functional. As we know, a hierarchical multipurpose system is a multicriterial system (an ASOAOI, for example). Therefore, here we need to find rational mathematical formulations of problems and give a reasonable meaning to the concept of optimality.

There are several possible ways to optimize such systems.

A. The problem of searching for satisfactory solutions. Let $g: X \times \Omega \to V$ and $\tau: \Omega \to V$, where X = the set of all solutions; Ω = the set of indeterminacies; V = the set of payoffs; g = the object function; τ = the permissibility function. The problem /3/: given subset $X^* \subseteq X$, it is necessary to find $\hat{x}$ in X^* such that $\forall \omega \in \Omega$ and

$$g(\hat{x}, \omega) \leqslant \tau(\omega). \qquad (2)$$

Criterion (2) is the satisfiability criterion. The quartet (g, τ, X^*, Ω) defines the problem of finding satisfactory solutions, while any $\hat{x}$ from X^* for which (2) realizes $\forall \omega \in \Omega$ is a solution to this problem.

2. The matched optimum principle ((Pareto's) principle). This principle appeared in the theory of nonantagonistic analystical games, which solves the problem of finding points that maximize several functions at the same time. An analytical game is understood to mean the following mathematical setup /6/. 1) In the game there are n players (subsystems, in our terminology) $S_1, \ldots, S_n$. The situation is described by n analytical gain functions $I_1 = f_1(x), \ldots, I_n = f_n(x)$, where I_i = gain of the i-th subsystem, while x is the vector of the control parameters. 2) the space of control parameters x X is continuous. The set of functions $\{f_i\}$ determines the "metrics" of this space. 3) The set of control parameters x is divided into n sets $x = (x_1, \ldots, x_n)$, where x_i is the set of parameters monitored by the i-th subsystem. 4) Each subsystem, by selecting the set of parameters monitored by it, strives to maximize its gain I_i.

Matched optimum means the conversion of a conflicting situation into one in which none of the subsystems can improve its status without causing "harm" to the others by its actions. Therefore, the matched optimum status is the best for all the subsystems; that is, it is optimal /6/. The matched optimum point is determined by the equation

$$Df/Dx = 0, \qquad (3)$$

where $f = (f_1, \ldots, f_n)$ = a vector composed of gain functions f_i, while D/Dx = the Jacobian of vector transformation I = f(x).

It is sufficiently optimal in the sense that any player (any subsystem) withdrawing from it can increase its own gain (improve its own quality functional) without thereby reducing the gain (without causing the quality functional to deteriorate) of the other participants (subsystems). Therefore, the disruption by any participant in the game of the matched optimum conditions is "punished" by all the other participants by measures directed against the "disrupter" (for example, by increasing the penalty function. This gives stability to the matched optimum point (providing, of course, that all the participants know each other's object functions, which are assumed to be stable).

3. Stage-by-stage synthesis of hierarchical systems, using different optimization methods. There is more information on methods for optimizing a system for making statistical decisions in /1/.

Since the ASOAOI's functioning (as is the case with any complex system) takes place under conditions where a significant effect is exerted by random external factors, the system's achievement of its final goal will be subject to the influence of these factors. Therefore, it is advisable to evaluate the system's efficiency with the help of various probability characteristics. In practice, the efficiency indicator /7/ is the probability characteristic that is frequently used as the quantitative measure for expressing a system's efficiency.

Any efficiency indicator is

$$\Psi = \Psi(\xi_1, \xi_2, \ldots, \xi_n; \eta_1, \eta_2, \ldots, \eta_n), \tag{4}$$

where $\xi_1, \xi_2, \ldots, \xi_n$ = the system's parameters; $\eta_1, \eta_2, \ldots, \eta_n$ = parameters characterizing the effect of the external environment.

Along with its dependence on the system's parameters and the external environment, which figure clearly in expression (4), the efficiency indicator also depends on the system's structure, the nature of the connections between elements, the form of the control actions and the functioning rules; that is, on factors that do not yield to description with the help of parameters. These factors are taken into consideration both by the form of the function Ψ (or the form of the algorithm that makes it possible to compute the values of Ψ if there is no explicit expression for it) and the introduction of additional structural parameters /2/. As a rule, expression (4) is awkward to derive, and the task of calculating it frequently requires the realization of a rather complex algorithm and the handling of a large amount of information, which can be done only with a modern, highly productive computer. Maximally simple models that take into consideration only those factors and connections of substantial significance are used in the experimental-theoretical calculation method /7/.

Let us mention here that in this article we have made an attempt to take a broader look at the problem of studying the hydrosphere, both from the viewpoint of solvable problems and investigative methods and facilities and from the viewpoint of methods for describing and formalizing the proposed global structure of a system for processing asynchronous oceanographic information. It seems that this approach to synthesizing an ASOAOI from the standpoint of the theory of complex hierarchical systems is quite convenient and effective and demonstrates graphically the utility of theoretical-set structures for the formalization of such systems.

BIBLIOGRAPHY

1. Sidorov, Yu.Ye., "Metody statisticheskogo sinteza algoritmov obrabotki aerokosmicheskoy informatsii" /Methods for the Statistical Synthesis of Aerospace Information Processing Algorithms/, Leningrad, Izdatel'stvo Leningrad Polytechnic Information imeni M.I. Kalinin, 1977.

2. Buslenko, N.P., Kalashnikov, V.V., and Kovalenko, I.N., "Lektsii po teorii slozhnykh sistem" /Lectures on the Theory of Complex Systems/, Moscow, Izdatel'stvo "Sovetskoye radio", 1973.

3. Mesarovich, M., Mako, D., and Takakhar, I., "Teoriya iyerarkhicheskikh mnogourovnevykh sistem" /Theory of Hierarchical Multilevel Systems/, Moscow, Izdatel'stvo "Mir", 1973.

4. Moiseyev, N.N., "Elementy teorii optimal'nykh sistem" /Elements of the Theory of Optimal Systems/, Moscow, Izdatel'stvo "Nauka", 1975.

5. Levin, B.P., introductory article to thematic issue of the magazine TIIER /expansion unknown/, No 5, 1970, pp 3-5.

6. Volgin, L.N., "Printsip soglasovannogo optimuma" /Principle of the Matched Optimum/, Moscow, Izdatel'stvo "Sovetskoye radio", 1977.

7. Sharakshane, A.S., and Zheleznov, I.G., "Ispytaniya slozhnykh sistem" /Tests of Complex Systems/, Moscow, Izdatel'stvo "Vysshaya shkola", 1974.

A LINGUISTIC-INFORMATION MODEL OF STATISTICAL HYDROACOUSTICS

[Article by V. P. Sochivko pp 26-28]

/Text/ 1. An analysis of the texts in a set of 10^3 publications on statistical hydroacoustics shows: a significant part of the texts consists of verbal (word), mathematically unexpressable elements; the linguistic structures of the titles, annotations, essays and conclusions inform the reader quite accurately of the basic results represented in the text; the final results of the symbolic (mathematical) transformations of the physical processes and structures of statistical hydroacoustics permit a verbal representation (although some part of--mainly--the physically unrealizable transformation operators "escape" an unambiguous verbal formulation).

2. The problem of constructing a linguistic-information model of statistical hydroacoustics was formulated. The model must satisfy the following requirements: explain the basic concepts and categories of statistical hydroacoustics with an unambiguous interpretation of the professional terminology; present the terminology of statistical hydroacoustics in the form of a unified, correlated system; describe the structure of the semantic field that has been built up in this field of knowledge; facilitate the accumulation of new knowledge and data on statistical hydroacoustics; create a foundation for standardizing the descriptions of prototypes of documents; assist in the formalization of information inquiries when searching for needed data; support the information search for needed documents and specific factographic data; support the information-logic processing of available data; unite the aggregate information on statistical hydroacoustics with the other parts of the entire spectrum of knowledge.

3. The following formalization is possible: there is a set of events Ω that can be discussed within the framework of statistical hydroacoustics. Set S of observations on the results of experiments $A:\Omega \to S$ gives a verbal-symbolic representation of texts $B:S \to T$ that are registered in documents (articles, reports and so on).

It is necessary to construct a model

$$\text{L-IM} = \{C, \Lambda, B \times A:\Omega \to T\},$$

where C = signature of the basic concepts of statistical hydroacoustics; Λ = the language of the theory; A, B = basic representations (an experiment and the symbol-sign formulation of the results).

4. It can be said that a linguistic-information model of statistical hydroacoustics is a specialized microthesaurus (a standardized reference dictionary in which all the descriptors and keywords that are synonymous with them are listed in general alphabetical order and in which there is also an explicit expression of the most important paradigmatic relationships among the basic concepts) that is linked with the general thesaurus "Hydroacoustics."

5. The first version of the "Hydroacoustics" thesaurus was worked out by the author in 1971. The most recent edition, published in 1977, contains more than 1,800 keywords, of which 1,400 are descriptors. The "Statistical Hydroacoustics" microthesaurus, the first version of which is being presented for discussion by the participants in this school-seminar, contains about 1,000 keywords, of which 900 are descriptors.

6. The "Statistical Hydroacoustics" thesaurus is an information retrieval one; that is, it makes it possible to index publications, formulate search samples of inquiries and documents and support linguistically the procedures used in information retrieval.

7. The thesaurus is a linguistic-information model in the sense of all the other requirements listed above. For example, its linguistic coupling with some other thesauri produces intersections, the results of which admit of interesting interpretations: in an intersection lie (Adamar's) and (Uyelsh's) transformations, which have proven themselves in general identification theory, statistical radio engineering and other fields. Within the framework of scientific organizational activity it is necessary to call the attention of investigators to these transformations; an analogous conclusion can be reached for discrete (digital) algorithms and other elements.

STOCHASTIC ALGORITHMS FOR INVESTIGATING NONCONVEX FUNCTIONS WITH MANY VARIABLES

[Article by V. I. Alekseyev pp 28-29]

/Text/ The identification of the structure of an investigated function with many variables by the well-known methods of regression analysis and experiment planning involves large material and computational outputs, particularly when planning second- and higher-order experiments.

Let us discuss stochastic methods for localizing the extreme areas of a multi-extreme function and identifying the structure of the extreme area. The method for identifying the extreme area's structure is based on regression analysis. The regression control factors are computed with the help of the nonlinear, nonparametric averaging operators

$$\hat{x}_i = \sum_{\ell=1}^{N} \frac{(x_i + \beta_i u_i^{\ell})\ (\varepsilon, Q(x + \beta u^{\ell}))}{\sum_{\ell=1}^{N} B(\varepsilon, Q(x + \beta u^{\ell}))}, \quad i, \ldots, u, \qquad (1)$$

with a random sampling of the experimental points. The following symbols are introduced in formula (1): x = vector of the parameters (factors) being evaluated; β = vector of the averaging interval; u = vector of the uniformly distributed random numbers from [-1,1]; Q(x + βu) = the function being investigated; B(ε,Q(x + βu)) = a bell-shaped weight function; ε = scalar parameter of the bell-shaped function that gives its width, such as ε = Q(x); N = number of experiments (computations) performed. When operator (1) is used, the greatest weight is given to those values of the factor (x + βu) for which Q(x + βu) has the smallest (largest) value.

In the most general case, ~~when~~ the investigation is carried out with incomplete knowledge of the mechanism of the phenomena being studied, it is natural to assume that the analytical expression of the function is unknown and is represented in the form of a polynomial:

$$y = \hat{b}_o + \sum_{i=1}^{n} b_i x_i + \sum_{i\ell j} b_{ij} x_i x_j + \sum_{i=1}^{n} b_{ii} x_i^2 + \ldots \quad (2)$$

with the theoretical regression coefficients b_o, b_i, b_{ii}, b_{ij}. Estimates of the regression control coefficients (2) are found by using operator (1); namely:

$$b_i = [\sum_{\ell=1}^{N} u_i^{\ell} B(\varepsilon, Q(x_o + \beta u^{\ell}))][\sum_{\ell=1}^{N} B(\varepsilon, Q(x_o + \beta u^{\ell}))]^{-1}, \; i = 1,\ldots,n,$$

$$\hat{b}_{ij} = [\sum_{\ell=1}^{N} u_i^{\ell} u_j^{\ell} B(\varepsilon, Q(x_o + \beta u^{\ell}))][\sum_{\ell=1}^{N} B(\varepsilon, Q(x_o + \beta u^{\ell}))]^{-1}, \; i = 1,\ldots,n, \; j = i,\ldots,n \quad (3)$$

$$b_{ijk} = [\sum_{\ell=1}^{N} u_i^{\ell} u_j^{\ell} u_k^{\ell} B(\varepsilon, Q(x_o + \beta u^{\ell}))][\sum_{\ell=1}^{N} B(\varepsilon, Q(x_o + \beta u^{\ell}))]^{-1},$$
$$i = 1,\ldots,n, \; j = i,\ldots,n, \; k = j,\ldots,n,$$

and so on, where x_o = value of the basic level's factor. An estimate of the free term b_o is found with the help of the linear smoothing operator /1/

$$\hat{b}_o = \sum_{\ell=1}^{N} Q(x_o + \beta u^{\ell}) h(\ell),$$

where $h(\ell)$ = a weight function.

The total number of coefficients in regression equation (2) is c_{n+d}^{d}, where d = the order of the polynomial. In the classical variant, in order to evaluate c_{n+d}^{d} it is necessary to have $N \geqslant c_{n+d}^{d}$ experiments. In the method under discussion, as is obvious from expressions (3), the number of experiments N can also be less than c_{n+d}^{d}.

Localization of the extreme areas of a multiextreme function is accomplished by conducting experiments at randomly selected points in the factor space and keeping in mind those values of the factor, with the help of operator (1), for which the experiment's value is less than that of a fixed level.

BIBLIOGRAPHY

1. Katkovnik, Ya.V., "Lineynyye otsenki i stokhasticheskiye zadachi optimizatsii" /Linear Evaluations and Stochastic Optimization Problems/, Izdatel'stvo "Nauka", 1976.

SIMULATION COMPUTER MODELING IN ACOUSTICO-OCEANOGRAPHIC RESEARCH: PURPOSES, SPECIAL FEATURES, SCIENTIFIC PROBLEMS

[Article by V. V. Ol'shevskiy pp 29-49]

/Text/ 1. Introduction. In the field of acoustico-oceanographic research, in recent decades we have seen the development of new areas related to the development of probability models of random values, processes and fields, the study of the methods and procedures of statistical measurements and quantitative experimental acoustico-oceanographic research, machine modeling and, finally, the creation of systems analysis methods for analyzing and synthesizing complex acoustico-oceanographic information measuring systems. Modern computers, which make it possible to solve multidimensional problems of vast complexity, have, in the last decade, created the structural basis for the development of the methods that combine the entire range of acoustico-oceanographic research into a unified system. All of this has resulted in the appearance of a new field of research that is called simulation computer modeling. Simulation computer modeling in acoustico-oceanographic research naturally did not appear out of the void. The basis of this approach lies primarily in the following areas:
the theory and methods of investigating special and general acoustico-oceanographic models /1-4,6,8,9,19,23-25,27-29,34,40,48-50,53,58,59/;
the theory and methods of experiment planning, including statistical measurements, as applied to different fields of research /7,10,13,24,32,41,43,54/;
the theory and methods of modeling in different branches of science and technology /5,11,14,17,18,22,56/;
the theory and methods of image identification /16,35,46/.

Having been born within the framework of several previously developed areas of science and technology, simulation computer modeling comparatively rapidly--basically in the last 8-10 years /36,39,44,45,49,51,52,55,57/--took shape as an independent research field, with a clearcut methodology, with the separation of heuristic and formalized problem-solving procedures, and with--which is obviously the most basic of all--a clearly expressed applied, constructive direction for the results that are obtained. At the present time the situation relative to simulation computer modeling is such that it has propagated as a fundamental research tool /36,45,55, 57/ in physics, economics, the social sciences, psychology, the solution of transportation problems, personnel policies, the planning of experimental research in the most diversified fields and so on. There is no doubt that simulation computer modeling will make it possible to solve many problems in the field of acoustico-oceanographic research, the moreso since, as has already become clear, with its help it has become possible to formulate and solve problems that it was not possible to solve correctly with traditional approaches or could be solved only on an intuitive level, which involves emotional judgments. The main thing here, perhaps, is that simulation computer modeling made it possible, for the first time, to approach the solution of the problem of complexity from fully clear and constructive viewpoints. Along with this, the development of simulation modeling naturally also gave birth to a whole series of new scientific problems that proved to be far from trivial and that still have to be solved.

Below we will discuss the special features of simulation modeling and some scientific problems that arise in connection with this in the field of acoustico-oceanographic research.

2. Some Definitions and the Inevitability of Using Simulation Computer Modeling /5-8,11-22,29-45,47-55,57-59/. Here we will give several definitions of the basic concepts that we will use later. In general, it is a well-known fact that there are few things that cause so much debate and pretentiousness (which is, by the way, most often correct) as definitions. Meanwhile, if anyone relies on concepts that are not clearly defined and make it possible to give an ambiguous treatment to questions under discussion, this creates an even more unsatisfactory position in comparison with the situation where there are definitions, even if they are not unquestionable from the viewpoints of various specialists. Therefore, some definitions will be given here, even though the author is aware that, from the viewpoint of the conjectural readers of this article, part of them may prove to be trivial, while part of them may be debated. In any case, the definitions presented below correspond to the author's convictions today and, it seems to him, do not contradict the content of most of the works cited at the beginning of this section.

A system is a group (set) of objects that is united by some form on interaction and that carry out certain functions in order to achieve a given goal. The greatest interest is evoked by the so-called large or complex systems, for which the following basic features are characteristic:
the system interacts with its environment, it being the case that some part of this environment can, when necessary, be included in the discussion of a complex system;
the system has several "inputs" and "outputs," as well as a definite structure;
the system's structure and characteristics can change as the result of the action of natural factors and as the result of purposeful activity;
on the whole, the system's properties are distinctive from the properties of the objects of which it is comprised.

An acoustico-oceanographic system is a complex system composed of water masses, including the atmospheric and bottom layers adjacent to them, and facilities for studying the oceanographic characteristics, the acoustic characteristics of the ocean and the acoustic fields in it.

Measurement is the establishment of quantitative relationships between two objects, one of which is the real object (of natural or artificial origin) that is being investigated, while the other is taken to be the pattern (standard).

Let us mention here that with such a generalized concept, measurements here, of course, also apply to the problem of detecting signals against a background of noise (binary measurement), problems of evaluating, recognizing and identifying parameters and so on.

An information measurement system is the set of measurement facilities that is necessary and sufficient for the conduct of a given experiment, as the result of which the measurement information on the quantitative values of the investigated object's characteristics should be obtained.

Starting with these definitions and considering the requirements and trends of acoustico-oceanographic research, let us mention here that values, functions, or probability characteristics of investigated objects may be subjected to measurement.

A model is an idealized image of the real object (or system) that is being investigated, in which image those properties of the object that are essential in the problem being solved are reflected.

In the problem we are discussing, our greatest interest is in analytical, algorithmic, empirical and descriptive (evaluational) models.

An acoustico-oceanographic model is a description of oceanographic phenomena, the acoustic characteristics of the ocean, the acoustic fields in it and the interrelated oceanographic and hydroacoustic information measurement systems that is adequate for the solution of a formulated scientific and/or applied problem.

From this it follows that an acoustico-oceanographic model is a description of a complex system consisting of hydrophysical and technical objects. Such an association is necessary for various reasons: first, no experimental investigation can be conducted without a measurement system; second, if the information processing procedures are not optimized with due consideration for changing measurement conditions, the conduct of full-scale investigations in the ocean can entail significant irrational expenditures of materials; third, to study the entire (or almost the entire) set of acoustico-oceanographic conditions when making direct measurements in the ocean is practically impossible, even in the distant future, as a result of which clear planning of future experimental research is required; fourth, the lack of acoustico-oceanographic models of this type makes it impossible to plan, at the present level, the appropriate information systems and to make substantiated decisions.

This is a far from complete list of reasons in accordance with which there has arisen the necessity of developing the acoustico-oceanographic models under discussion as complex systems.

Systems analysis (or, which is almost equivalent, the systems approach and the investigation of operations) comes to this: the investigator studies the behavior of a complex system as a whole, without concentrating all his attention only on some single element of this system, although this element may also be (under a more detailed examination) a complex system and is extraordinarily interesting in the scientific sense.

In systems analysis we are, naturally, dealing not with real objects and complex systems, but with models of them.

Further, we will make a single preliminary remark on acoustico-oceanographic models (later we will return again to a discussion of this extremely important question) that concerns several debatable aspects of this problem.

Hardly anyone would say that a satisfactory model of the ocean can be constructed if sufficient thoroughly investigated separate acoustico-oceanographic objects are not available. On the other hand, however, even having thoroughly studied special acoustico-oceanographic phenomena at our disposal, we undoubtedly cannot assume that a model of the ocean has already been constructed.

The situation with the investigation of information measurement systems is completely analogous: elements of these systems can each be studied separately in extreme detail, from the viewpoint of specialists in these elements, but, meanwhile, no one has yet succeeded in changing over to an examination of the functioning of an information system as a complex system that is a unified whole with the ocean and a mechanical association of the indicated elements.

An even more composite problem in connection with the systems approach is the combined discussion of acoustico-oceanographic phenomena, acoustic fields in the ocean and information measurement systems. Besides the complex structural interactions of the large number of objects in such a system, we should also remember the fact that these objects, in and of themselves, have been studied extremely inadequately: the specialists who are doing research in specific narrow areas can confirm this completely competently and convincingly.

In view of what has been said and possibly other subjective reasons, the impression can appear that it is practically impossible to create a model with such a degree of complexity and incompleteness of description. Moreover, since bad bricks cannot be used to erect a good building, the following question also arises: should not all the basic attention of investigators be concentrated exclusively on extending our knowledge about the elements of a complex system; that is, on the "bricks"? In connection with this, it is either explicitly or nonexplicitly assumed that it is too early to construct a generalized acoustico-oceanographic model, since the time for this has not yet arrived.

Without in any way disparaging this possible viewpoint that has been formulated, which draws much from natural scientific skepticism, let us examine the question of the creation and utilization of acoustico-oceanographic models (in our general formulation) from other viewpoints.

Cognitive activity in the field of acoustico-oceanographic research (this situation is analogous to other fields, also) has traditionally taken place according to this cycle: EXPERIMENT-ANALYSIS-MAKING OF DECISIONS-EXPERIMENT and so on.

In connection with this, between the analysis and decision-making stages the investigator studied possible variants, constructed hypotheses, examined the results previously obtained and, finally, made decisions and formulated further problems. This sequence fully satisfied scientific workers, in any case, until there appeared three important elements, as the result of analysis, in the field of acoustico-oceanographic research: multidimensionality of the results, their random nature and an understanding of the presence of complex interrelationships among many acoustico-oceanographic objects.

The situation that has been created is, of course, characteristic not only of the field of acoustico-oceanographic research. It arose in almost all the basic areas of human activity, primarily as the result of the scientific and technical revolution, the accumulation of specific knowledge and the increased complexity of the problems that the increasing practical requirements of people have placed before science.

And so the following cycle of cognitive activity appeared: EXPERIMENT-ANALYSIS-SIMULATION COMPUTER MODELING-MAKING OF DECISIONS-EXPERIMENT and so on.

What is simulation computer modeling as applied to the field of acoustico-oceanographic research?

Before formulating an appropriate definition, let us list those problems that (in the opinion of specialists in the field of computer simulation) can be solved by means of simulation computer modeling):
a more thorough and intelligent understanding of real activities;
an improvement in intercourse among specialists, primarily those whose investigative results are included in the simulation model;
training and practice on a large class of examples and simulated situations;
predicting the situation and behavior (evolution) of systems and their separate elements;
planning technical systems and their separate elements;
planning new experiments.

At the present time there are several definitions of simulation computer modeling that differ primarily in the special features of their applications, thanks to which formulated problems can be solved. As it applies to the field that we are discussing, this definition can be as follows.

Simulation computer modeling in acoustico-oceanographic research is the creation of a model of a real, complex acoustico-oceanographic system and the conduct, with the help of a computer, of numerical experiments with this model for the purpose of learning the regularities inherent in the system for different input data, limitations and criteria.

The following terms are synonyms here: simulation computer experiments, computer simulation, computer experimentation.

Simulation computer modeling is distinguished, of course, from the previously generally accepted use of computer methods and from the so-called modeling that is understood, in the normal narrow meaning, to be a numerical method for solving various analytical problems. In simulation modeling the model can contain both analytical and logical objects, and objects in the form of programs for computers, and the results of expert evaluations, and empirical rules. It goes without saying that such a model of a complex system can contain random values and field processes that are formulated in accordance with given probability characteristics.

3. Basic Stages in the Organization and Conduct of Simulation Modeling [36,39,42, 44,45,49,51,52,55,57]. Simulation computer modeling is a sequence of definite stages, each of which is--even by itself--a quite complex scientific problem. In this sense, the methodological principles of the organization and conduct of simulation modeling acquire special importance.

As in other fields of science and technology, when investigating acoustico-oceanographic models computer simulation includes the following six basic stages:
Stage 1: formulating the problem, determining the goals of computer simulation, introducing criteria.
Stage 2: developing mathematical models.
Stage 3: creating the software.
Stage 4: evaluating the quantitative degree of adequacy of the adopted model for the actual objects of the investigation.
Stage 5: planning and conducting simulation computer experiments.
Stage 6: processing and interpreting the results of the computer simulation.

These stages, as applied to simulation computer experiments with acoustico-oceanographic models, have different degrees of complexity and problematicness. Below we will discuss each of these stages briefly and formulate those scientific tasks that simulation modeling is capable of performing at the present time as far as acoustico-oceanographic research is concerned.

4. Formulating the Problem /24,30,36,45,51,55,57/. Computer simulation, as in any scientific investigation, begins with the formulation of the problem; that is, with the compilation of a list of problems that it is necessary to solve as the result of simulation experiments. It should not be assumed that this stage is quite simple in the substantive and quantitative sense, although it sometimes seems that the purposes of an investigation are, it goes without saying, clear, otherwise the actual formulation of the problem and the performance of the investigation would not make any particular sense; that is, there would be no need for it. In much research of a physical nature--exploratory research, in particular--it is sufficient to describe these purposes qualitatively, in the form of some scientific areas trends and unformalized hypotheses. Such a descriptive formulation is frequently sufficient for an investigator of a specific physical area (at any rate, many investigators are convinced of this).

When formulating simulation computer experiments, the situation is different. Since the investigator is dealing with a computer in this case, the problem and the goals of the computer simulation must be formulated specifically and unambiguously, in a quantitative form that is expressed in mathematical concepts. In connection with this, the following scientific problems arise in the field of acoustico-oceanographic research.

1. Substantiation, selection and formalization of the hypotheses that it is necessary to test during the conduct of simulation modeling.

2. Substantiation, selection and formalization of the quality criteria for the information systems that give an adequate description of the requirements placed on them from systems of a higher order (supersystems).

3. Determination of the special and general quality criteria for the systems that reflect, respectively, the solution of individual special problems and sets of them (solution of the criteria convolution problem).

4. Determination of limitations (individual and combined) that must be placed on both the acoustico-oceanographic conditions that will later be simulated by the computer and the systems characteristics of the information systems.

5. Determination of the temporal evolution of the criteria and limitations: an analysis of their dynamics in the past, present and future.

At first glance these problems can be solved quite simply by (for example) using the method of expert evaluations by competent specialists in different areas. This is partially so, however (let us emphasize again this important factor) it is necessary to represent the results of the solution of these problems in a quantitative, mathematical form that is suitable for use in a computer.

Let us also mention that here we are talking not about the solution of any specific set of problems concerning systems and acoustico-oceanographic models, but about general methods for solving such problems and their theoretical (systems, physical and mathematical) interpretation.

5. Determining Simulation Models /1-59/. In the next stage after the machine simulation problem has been formulated and the purposes and goals of the investigation have been determined, it is necessary to construct acoustico-oceanographic and systems mathematical models. To determine a mathematical model means to substantiate and formulate the set of equations, relationships, algorithms and conditions with the help of which the acoustico-oceanographic conditions' quantitative characteristics would be related to the information systems' quality indicators. Since the overwhelming majority of acoustico-oceanographic problems permit a formal, parametric description (although, it is true, it may be an extremely multidimensional one), the mathematical model must relate the following groups of parameters to each other in spatial-frequency-temporal coordinates: a. parameters characterizing oceanographic characteristics; b. the ocean's acoustic parameters; c. the acoustic parameters of signal sources; d. the parameters of the acoustic fields in the ocean; e. the information systems' parameters; f. the information systems' quality indicators.

From this list, as well as from an analysis of the state of acoustico-oceanographic and systems research, it is clear that the models under discussion will be composite deterministic-statistical ones. It is also obvious that these models will be depressingly complex, particularly from the viewpoint of traditional analytical methods of solving physical and systems problems. The construction of such a simulation model is a task of exceptional complexity, since here it is necessary to combine the most diversified viewpoints of specialists, analyze experience, make use of expert estimates and so on. In the opinion of the author of /57/, such a task is more an art than scientific research in the generally accepted meaning. In any case, the heuristic beginnings during the construction of a model are clearly expressed. It should be mentioned that far from all scientific workers regard such problems as being worthy of serious attention. Moreover, both in the area of acoustico-oceanographic research and in other areas of science and technology, it was not so long ago assumed that the only serious scientific research was, in some classical sense, "pure"; that is, a correctly formulated and specific physical, systems or technical investigation, but in no case a composite one. Many scientific workers regarded (and frequently still do) combined (complex) investigations as some compilation that was of no particular scientific interest.

There is some common sense in this, since in the creation of models of complex systems their basis is always a set of results of special investigations. But how is it in the case where these special investigations were conducted from different viewpoints, their results explained in different forms and frequently with the use of different concepts, parameters and methods of description? In our opinion, the combination of special models into a general one is undoubtedly a creative scientific activity that does not contradict research in special areas. Essentially this is the so-called systems analysis, theory of operations and allied cybernetic and information fields mentioned above.

In many respects, the mathematical model creation and formalization stage is the key stage in this problem of computer simulation, since it is on to what degree this model corresponds to the actual investigated objects (hydrophysical phenomena and the characteristics of technically realized information systems) that the success and scientific validity of simulation experiments as a whole depend. It is completely obvious that computer experiments with a low-quality and inadequate model are not useful, even if they are realized on a computer at an extremely high level with respect to the software used.

Everything is far from clear as far as the development of acoustico-oceanographic mathematical models is concerned, although explicit progress has been made in this area in recent years. Let us now formulate several more scientific problems that still need to be solved in connection with this.

1. The creation of acoustico-oceanographic data banks into which the results of experimental research, empirical regularities and theoretical relationships for the entire set of studied objects in the ocean must be entered.

2. The investigation of regularities in the progress of different phenomena in the ocean, including combined, multidimensional deterministic and statistical regularities.

3. Classification of acoustico-oceanographic conditions and determination of the acoustic situation and acoustic weather and climate.

4. The development of a mathematical model for predicting the ocean's acoustic characteristics, including multidimensional modeling of acoustico-oceanographic conditions.

5. The development of mathematical models for the spatial-frequency-temporal processing of information with the help of an extensive set of algorithms, including the determination of the quality indicators (special and general) of the systems for all known models of the fields affecting the antenna systems.

6. The development of optimization models for multiparametric, multiextreme problems.

The question of the formulation of mathematical models, as has already been said, is the key question in the entire problem of computer simulation. Of course, the problems related to the construction of such models require a maximum concentration of efforts from investigators with the most diversified profiles and styles. True, another opinion is sometimes expressed: since scientific research was always directed at the construction of some models or another of phenomena and elements of systems when solving specific acoustico-oceanographic problems, here nothing new appears in the scientific plan. Unfortunately, this is not the case. Moreover, in the field of acoustico-oceanographic research we cannot complain about an excess of special models (mathematical models, in the strict meaning of systems analysis). The construction of an acoustico-oceanographic model as a complex system (see Section 2) is a task that is much more laborious and no less creative than the construction of any special hydrophysical or systems model. Many specialists working in other areas of science and technology became convinced of this as soon as they started to construct models of complex systems (see, for example, /36,45,55,57/). It very quickly turned out to be the case that even with the presence of special models--which, by the way, have been being developed for decades--at the stage of the creation of a model of a complex system (on the basis of the indicated special ones, of course), it is especially important to utilize the erudition and physical-systems intellect and to realize the creative capabilities of many investigators. Generally, the creation of generalized (integrated) models on the basis of special ones that are developed by individual investigators in their plan for the solution of specific scientific problems proved to be a most interesting scientific-heuristic problem in systems analysis. Here everything is in dialectic interrelationship: the special models determine the level of description of the generalized ones, while the latter affect the examination of the former from the viewpoint of the demands made on them. It frequently proves to be the case (such experience is already available in other areas of research) that special models are developed on different levels in the space of different, unmatched parameters, so that in the generalized model they do not "adjoin." Such a matching of models is a creative scientific problem in an of itself, without even mentioning the necessity of reviewing the formulations of separate special problems and enlarging the "spheres of influence" of different investigators.

The formulation of models is a unique creative process that, of course, neither now nor in the foreseeable future can be performed by even the most productive computers, although the researcher will continue to become more and more free from having to carry out many computational and logical procedures.

6. Creating the Software /5,11,14,17,18,22,36,45,55,57/. The next stage in the organization of computer simulation experiments (after the creation of the mathematical model) is the compilation of computer programs; that is, the creation of the appropriate software. At the present time many computer languages that are suitable in different degrees for the solution of computer simulation problems have appeared. They include FORTRAN, ALGOL, PL/I, KOBOL, AUTOCODERS of various types and others.

The creation of software for simulation computer experiments goes beyond the framework of compiling standard programs for the solution of individual mathematical problems by numerical methods. Here we are talking about the creation of a system of programs that are informationally interrelated with due consideration, of course, for the real memory and high-speed operating capabilities of modern computers. Actually, the problem comes down to the so-called systems programming for a general, integrated mathematical simulation model, allowing for the possible simplications allowable errors and capabilities of modern computers.

The following scientific problems arise when creating the software for simulation modeling.

1. Development of machine methods for multidimensional modeling on a computer for given probabilities or empirical joint /word illegible/ of the distribution of probabilities or a set of random values.

2. Creation of "fast" algorithms for solving problems during integral, differential and mixed transformations for large masses of information.

3. Development of methods for evaluating the errors in a computer's computational procedures with respect to given mathematical models; that is, the creation of metrological facilities for simulation computer experiments.

4. Development of systems programming ideas in the direction of creating complexes of programs for the simulation modeling of acoustico-oceanographic processes and information systems.

5. Creation of information retrieval programs and programs for controlling computer simulation experiments, with due consideration for the "man-computer" system, using rational combinations of different programming languages and information display forms.

The solution of these and several other software problems will make it possible to create rational systems of programs, organize the entry of the necessary data in computers and the output of results from them and, finally, conduct the experiments themselves at the appropriate time. The latter question is an extremely important one, since the requirements for machine time in multidimensional statistical modeling are frequently so great that complete computer experiments become unrealistic (this problem of multidimensional investigations long ago received the title of "the curse of dimensionality").

In concluding this section, let us emphasize one important fact that is not always taken into consideration when conducting theoretical research by traditional analytical methods. The fact of the matter is that the compilation of programs for computers places certain requirements on the methods used to develop models of phenomena and systems: these models, no matter how much we talk about their programmed realization on a computer, must not be simplified formulated mathematically, but must be created with consideration for their embodiment in the form of computer programs. This is a far from simple question and possibly /words illegible/, in the final account, will lead to a review of the original /word illegible/ during the solution of many special acoustico-oceanographic and systems problems. There is nothing surprising here, since the formulation and solution of scientific problems were always matched with the necessity of obtaining constructive results during their solution. In the case under discussion, the constructive result of the solution of the scientific problems is computer programs, and not just any programs, but reliable, compact and high-speed ones.

7. Evaluating the Quantitative Degree of Adequacy of a Model for the Actual Objects of the Investigation /20,24,26,32,33,36,39-45,49-52,54,55,57/. The problem of establishing the suitability of a simulation model and reducing to a quantitative evaluation the degree of adequacy of the adopted model for the actual investigated objects (phenomena and systems) is extremely complicated in general form: the solution of this problem involves mathematical, hydrophysical, experimental, technical and even philosophical questions. As a matter of fact, how can the question of the quantitative degree of difference between a mathematical model of an object and the actual object be answered if a true (complete) description of the object is in no way known to the investigator? Further: can we count on the adequacy of a generalized integrated model of a complex system if the degree of adequacy of the

special models is known? And yet one more question: is it possible to plan and carry out in the ocean a statistical experiment that in structure and size is similar to a computer experiment? This list of questions could, of course, be continued by building the appropriate analogies between the ocean and its mathematical simulation model.

It is clear that it is not so easy to answer such questions from either the general or the practical (applied) viewpoint, the moreso since here we are not talking about a qualitative discussion of the questions (even by extremely competent experts), but about the correct evaluation of adopted decisions in a quantitative form and with a known degree of accuracy. Thus, obviously, this problem is a complicated one. However, this indication of the complexity of its solution is, of course, little comfort for researchers who are conducting simulation computer experiments.

Actually, if the quantitative degree of adequacy has not been established, the whole idea of conducting simulation computer experiments does not withstand the most elementary criticism. As is correctly noted in /36/, in the first place, "...it is necessary to determine whether or not a model describes the system's behavior correctly. Until this problem is solved the value of the model remains insignificant and the simulation experiment is converted into a simple exercise in the field of deductive logic." Later in this work: "...experimentation on a computer with an inadequate model is of little use, since we will simply be simulating our own ignorance."

Thus, what can be said about the possibilities of evaluating the adequacy of an adopted model and the actual object of investigation?

Starting from the general concepts of the dialectic theory of knowledge, let us mention that when evaluating the adequacy of a model we should start with the fact that the model must the main property of enabling us to predict (forecast) real facts. Here, of course, two variants of prediction are possible: predicting experimental facts that were previously obtained (retrospective prediction) and predicting future facts (prospective prediction). In view of the statistical nature of a simulation model and in view of the fact that the ideally accurate monitoring of acoustico-oceanographic conditions during the conduct of full-scale experiments in the ocean is practically impossible, and also because of the finiteness of our resources (a finite number of samples, a finite time for observing them), the comparison of experimental data with results obtained with the help of simulation models must be based on the use of statistical criteria. With retrospective prediction according to a simulation model the question is more or less clear (in its fundamental sense, of course): here it is necessary to organize the statistical processing of the available experimental data correctly and reduce it to the level of a measurement procedure. Less clear is the question of prospective prediction: here, apparently, we cannot be satisfied with traditional methods of obtaining acoustico-oceanographic experimental data, but must create a new foundation for experiments in the ocean, the basic purpose of which will be to confirm and correct the model that has been developed. In general, quite a lot has already been done in this field, although there is still a whole series of scientific problems that require substantial development work. We will point out some of these problems.

1. Development of special and general criteria for matching a simulation model to real acoustico-oceanographic and phenomena and hydrophysical signals (degrees of

difference and convergence, the distance in the space of multidimensional functions and other factors).

2. Development of a theory and methods for determining the representativeness of the final selections of multidimensional random values and multidimensional deterministic series in connection with their nonlinear interaction in a simulation model.

3. Creation of a general theory and constructive methods for planning purposeful full-scale experiments in the ocean that in nature and volume are sufficient to establish the quantitative degree of accuracy of a simulation model.

It is obvious that each of these problems is actually a whole scientific field and cannot be solved by researchers in any narrow field: here we need a concentration of efforts by specialists in different areas and their close creative interaction in discussions and matching of positions, which can sometimes prove to be mutually exclusive propositions.

8. Planning Simulation Computer Experiments /7,13,36,45,55,57/. Computer simulation experiments must be planned just as physical experiments must. The basic reason for this necessity is the practical impossibility of conducting computer simulation for an entire set of acoustico-oceanographic conditions and systems parameters; consequently, in the planning under discussion an effort is made to provide the greatest information content for such experiments, with permissible expenditures (of human, material, technical and temporal resources). While noting that several quite effective methods (stochastic search methods with adaptation, gradient methods, nonlinear filtration and prediction methods, nonparametric statistical procedures and other) have been developed in recent years in the area of planning simulation computer experiments, we must nevertheless mention several problems that still remain to be solved in this area.

1. A search for methods of solving extreme multiparametric problems for randon functionals (criteria) when the original functions are not given analytically but are calculated on a computer, while in the area of optimizable parameters there exist common dynamic, nonlinear limitations.

2. The development of constructive computer methods for evaluating the stochastic convergence of the results of statistical experiments on a computer with finite volumes of sampling data for multidimensional, modeled initial data.

In the solution of these problems, we must naturally use the powerful and well-developed methods of the theory of statistical hypothesis testing and the theory of experiment planning, which has already become a classical method.

9. Statistical Processing of the Results of Simulation Computer Experiments /10,13, 17,24,32,36,38-41,55,57/. The result of the conduct of a simulation computer experiment is some set of values that it is necessary to process for the purpose of reaching some conclusion or another and making the appropriate decisions. Let us stress this important fact: the result of a computer simulation is some statistical regularity inherent in the simulation model, and the utilization of this regularity is the proper business of the investigator or the people who are the consumers of the results that are obtained. In other words, making appropriate decisions

on the basis of the results of simulation modeling goes beyond the framework of the problem we are discussing.

Thus, the final stage in computer simulation is the processing of the results obtained by the computer. Generally speaking, all the classicial statistical procedures for analyzing random values, including multidimensional ones, are used to process the results of computer experiments. Moreover, during computer modeling a whole series of statistical methods of analysis can be realized substantially more nearly correctly than under the conditions of a full-scale hydrophysical experiment: by using a computer it is possible to obtain the necessary volumes of sampling data, observe the conditions of statistical homogeneity of experiments and so forth. Along with this, however, here there arise certain specific problems, some of which we will list below.

1. A search for effective quantitative congruence criteria that are adequate for the acoustico-oceanographic problems that are being solved and that should be used in the statistical processing of the results of simulation computer experiments.

2. The creation of a theory and methods for evaluating errors in simulation computer experiments, including the errors related to inadequacy of the adopted simulation model and the closeness of the realization of the modeling algorithms (other types of errors--finiteness of the samples, finiteness of the number of characters, temporal discreteness of the readings and so on--are analyzed by the usual methods).

3. A search for stable (robust) statistical analysis procedures based, in particular, on the methods of nonparametric statistics.

10. Summary. As follows from this brief review of the content, special features and scientific problems in simulation computer modeling, the problem under discussion is quite complicated in the scientific sense and--which is an extremely important factor--also an integrated one. Naturally, it cannot be solved without the efforts of specialists in hydrophysics, acoustics, cybernetics, computer mathematics and programming. The development of this field, of course, requires significant expenditures of creative and material resources for an extended period of time. Specialists in the field of simulation modeling have already analyzed the available experience in the conduct of research in this area (see, in particular, /36,45,55, 57/. At the present time it is considered that the creation of a single simulation model--from its conception to its realization on a computer in a form suitable for the conduct of simulation computer experiments--takes from 3 to 10 years, depending on the complexity of the system being modeled and the degree of development of the special models. In connection with this it is assumed that the number of specialists--highly qualified, of course--working on such a problem is 8-10 people, not counting approximately the same number of programmers with standard qualifications. It is interesting to mention also the amount of computer time needed (based on the most efficient computers in the early 1970's): the creation of a single simulation model requires from 10^4 to 10^5 hours of computer time (including the debugging of the special and general programs, the organization of computer data banks and service systems, the making of calculations for a set of situations and so on). Since the creation of acoustico-oceanographic simulation models is a problem of increased complexity, it is obvious that it will require significant efforts on the part of many researchers. However, such significant expenditures are justified by the bright prospects for the solution of many interesting (in the scientific sense) and important (in the applied sense) problems, the primary ones of which include:

the creation of generalized acoustico-oceanographic simulation models, including the corresponding computer data banks, and the determination of the regularities inherent in these models;
the planning of purposeful, full-scale experimental investigations in the ocean on the basis of the conduct of simulation computer experiments, including an evaluation of the quantity and value of the information obtained during the conduct of full-scale acoustico-oceanographic research;
systems-analysis planning of oceanographic and hydroacoustic information systems;
the prediction of the acoustic situation in the ocean and the evaluation of the quality of the functioning of information systems under these conditions.

Naturally, these and many other interesting and important problems can be solved only by using the most modern computers, providing that the appropriate software is created for them. In this sense it is no accident that it is precisely the powerful and highly efficient computers that have stimulated the most extensive development of simulation modeling projects abroad, where they have been going on for more than 10 years on extremely large scales and in the most variegated fields of science and technology. It should not, however, be thought (let us emphasize this one more time) that the question of the development of simulation modeling boils down only to the use productive computers. It is important, every time, to emphasize the attention that must be given to the necessity of conducting physical acoustico-oceanographic research on the broadest possible scale and in the most purposeful and thorough manner. In this respect, we cannot help but agree with the opinion of USSR Academy of Sciences Corresponding Member N.N. Moiseyev, who, in his foreword to the Russian edition of a book /36/, remarked:

"It is necessary, with total clarity, to understand that the problem of constructing a simulation model--as is the case with any other model--is a problem of the adequate description of the real world's objective laws. This problem has been before science for many centuries, and the appearance of the most powerful computer technology has still not solved it. I am convinced that now and in 20 years, as it was 20 years and 20 centuries ago, the discovery of new laws (that is, the construction of new models of the phenomena occurring in the world around us) will be worth the tense creative activity, will be worth the incredible expenditures of human intellect and spirit. No amount of computer time can replace them, since the computer merely makes this process easier by taking over the performance of more and more routine procedures."

What Moiseyev said needs no further comments.

BIBLIOGRAPHY

1. Myasishchev, V.I., editor, "Fizicheskiye osnovy podvodnoy akustike" /Physical Principles of Underwater Acoustics/, Moscow, Izdatel'stvo "Sovetskoye radio", 1955 (translated from English).

2. Brekhovskikh, L.M., "Volny v sloistykh sredakh" /Waves in Layered Mediums/, Moscow, Izdatel'stvo AN SSSR /USSR Academy of Sciences/, 1957.

3. Chernov, L.A., "Rasprostraneniye voln v srede so sluchaynymi neodnorodnostyami" /Wave Propagation in a Medium With Random Irregularities/, Moscow, Izdatel'stvo AN SSSR, 1958.

4. Ol'shevskiy, V.V., "Statisticheskiye svoystva morskoy reverberatsii" /Statistical Properties of Marine Reverberation/, Moscow, Izdatel'stvo "Nauka", 1966.

5. Buslenko, V.N., "Modelirovaniye slozhnykh sistem" /Modeling Complex Systems/, Moscow, Izdatel'stvo "Nauka", 1968.

6. Tolstoy, I., and Kley, K.S., "Akustika okeana" /Ocean Acoustics/, Moscow, Izdatel'stvo "Nauka", 1969.

7. Finni, D., "Vvedeniye v teoriyu planirovaniya eksperimenta" /Introduction to the Theory of Experiment Planning/, Moscow, Izdatel'stvo "Nauka", 1970.

8. Ol'shevskiy, V.V., "Mathematical Models and the Statistical Description of Hydroacoustic Signals," "Trudy Pervoy Vsesoyuznoy shkoly-seminara po statisticheskoy gidroakustike" /Works of the First All-Union School-Seminar on Statistical Hydroacoustics/, Novosibirsk, 1970, pp 3-33.

9. Middleton, D., "Multidimensional Detection and Discrimination of Signals in Random Mediums," TRUDY INSTITUTA INZHENEROV PO ELEKTROTEKHNIKE I RADIOELEKTRONIKE, Vol 58, No 5, 1970, pp 100-110 (translated from English).

10. Gol'tsman, F.M., "Statisticheskiye modeli interpretatsii" /Statistical Models of Interpretation/, Moscow, Izdatel'stvo "Nauka", 1971.

11. Bykov, V.V., "Tsifrovoye modelirovaniye v statisticheskoy radiotekhnike" /Digital Modeling in Statistical Radio Engineering/, Moscow, Izdatel'stvo "Sovetskoye radio", 1971.

12. Germeyyer, Yu.B., "Vvedeniye v teoriyu issledovaniya operatsiy" /Introduction to the Theory of Investigation of Operations/, Moscow, Izdatel'stvo "Nauka", 1971.

13. Fedorov, V.V., "Teoriya optimal'nogo eksperimenta" /The Theory of an Optimum Experiment/, Moscow, Izdatel'stvo "Nauka", 1971.

14. Pollyak, Yu.G., "Veroyatnoye modelirovaniye na EVM" /Probability Modeling on Computers/, Moscow, Izdatel'stvo "Sovetskoye radio", 1971.

15. Kontorov, D.S., and Golubev-Novozhilov, Yu.S., "Vvedeniye v radiolokatsionnuyu sistemotekhniku" /Introduction to Radar Systems Analysis/, Moscow, Izdatel'stvo "Sovetskoye radio", 1971.

16. Zagoruyko, N.G., "Metody raspoznavaniya i ikh primeneniye" /Identification Methods and Their Utilization/, Moscow, Izdatel'stvo "Sovetskoye radio", 1972.

17. Li, T.G., Adams, G.E., and Geynz, U.M., "Upravleniye protsessami s pomoshch'yu EVM. Modelirovaniye i optimizatsiya" /Controlling Processes With the Help of Computers: Modeling and Optimization/, Moscow, Izdatel'stvo "Sovetskoye radio", 1972.

18. Martin, F., "Modelirovaniye na vychislitel'nykh mashinakh" /Modeling on Computers/, Moscow, Izdatel'stvo "Sovetskoye radio", 1972.

19. Zavadskiy, V.Yu., "Vychisleniye volnovykh poley v otkrytykh oblastyakh i volnovodakh" /Calculation of Wave Fields in Open Areas and Waveguides/, Moscow, Izdatel'stvo "Nauka", 1972.

20. Ol'shevskiy, V.V., and Rozenberg, V.Ya., "The Problem of Evaluating the Adequacy of a Probability Model of a Random Process in Statistical Measurements", "Materialy Pervoy Vsesoyuznoy konferentsii 'Teoriya i praktika izmereniya statisticheskikh (veroyatnostnykh) kharakteristik'" /Materials of the First All-Union Conference on "Theory and Practice of the Measurement of Statistical (Probability) Characterstics"/, Leningrad, VNIIEP /All-Union Scientific Research Institute of Electrical Measuring Instruments/, 1973, pp 61-66.

21. Ol'shevskiy, V.V., "Statistical Measurements Under Conditions of Dynamic Models of Random Processes," "VI Vsesoyuznyy simpozium 'Metody predstavleniya i apparaturnyy analiz sluchaynykh protsessov i poley'" /Sixth All-Union Symposium on "Representation Methods and Equipment Analysis of Random Processes and Fields"/, Leningrad, VNIIEP, Section 1, 1973, pp 30-35.

22. Gold, B., and Reyder, I., "Tsifrovaya obrabotka signalov" /Digital Processing of Signals/, Moscow, Izdatel'stvo "Sovetskoye radio", 1973.

23. Makarov, S.S., "Zakonomernosti formirovaniya poley skorosti zvuka v okeane" /Regularities in the Formation of Speed-of-Sound Fields in the Ocean/, Moscow, TsNIITERKh /expansion unknown/, 1973.

24. Ol'shevskiy, V.V., "Statisticheskiye metody v gidrolokatsii" /Statistical Methods in Hydrolocation/, Leningrad, Izdatel'stvo "Sudostroyeniye", 1973.

25. Brekhovskikh, L.M., editor, "Akustika okeana" /Ocean Acoustics/, Moscow, Izdatel'stvo "Nauka", 1974.

26. Ol'shevskiy, V.V., "On the Role of Probability Models of Random Processes in Statistical Measurements," "VII Vsesoyuznyy simpozium 'Metody predstavleniya i apparatuynyy analiz sluchaynykh protsessov i poley" /Seventh All-Union Symposium on "Representation Methods and Equipment Analysis of Random Processes and Fields"/, Leningrad, VNIIEP, 1974, pp 61-66.

27. Middleton, D., "Characterization of Active Underwater Channels," Technical Report ARL-74-61, Applied Research Laboratories, University of Texas at Austin, 1974, Parts 1 and 2.

28. Middleton, D., "Doppler Effect for Random Moving Scatters and Platforms," J. ACOUST. SOC. AM., Vol 61, No 5, 1974, pp 1231-1250.

29. Monin, A.S., Kamenkovich, V.M., and Kort, V.G., "Izmenchivost' Mirovogo okeana" /Variability in the World Ocean/, Leningrad, Izdatel'stvo Gidrometeoizdat, 1974.

30. Kantyug, A.A., and Ol'shevskiy, V.V., "Mathematical Aspects of Modeling in Statistical Hydroacoustics With the Help of a Computer," "Trudy Shestoy Vsesoyuznoy shkoly-seminara po statisticheskoye gidroakustiki" /Works of the Sixth All-Union School Seminar on Statistical Hydroacoustics/, Novosibirsk, Institute of Mathematics, USSR Academy of Sciences, 1975, pp 33-44.

31. Ol'shevskiy, V.V., and Panfilov, V.A., "Digital Modeling of Marine Reverberation," "Trudy Shestoy Vsesoyuznoy shkoly-seminara po statisticheskoy gidroakustiki", Novosibirsk, Siberian Department, USSR Academy of Sciences, 1975, pp 59-65.

32. Rozenberg, V.Ya., "Vvedeniye v teoriyu tochnosti izmeritel'nykh sistem" /Introduction to the Theory of Measurement System Accuracy/, Moscow, Izdatel'stvo "Sovetskoye radio", 1975.

33. Ol'shevskiy, V.V., "Methodological Questions in the Modeling of Random Processes in Connection With Statistical Measurement Problems," "VIII Vseoyuznyy simpozium 'Metody predstavleniya i apparaturnyy analiz sluchaynykh protsessov i poley'" /Eighth All-Union Symposium on "Representation Methods and Equipment Analysis of Random Processes and Fields"/, Leningrad, VNIIEP, Section 4, 1975, pp 3-11.

34. Andreyeva, I.B., "Fizicheskiye osnovy rasprostraneniya zvuka v okeane" /Physical Principles of Sound Propagation in the Ocean/, Leningrad, Izdatel'stvo Gidrometeoizdat, 1975.

35. Zagoruyko, N.G., "Iskusstvennyy intellekt i empiricheskiye predskazaniye" /Artificial Intellect and Empirical Prediction/, Novosibirsk, NGU /Novosibirsk State University/, 1975.

36. Neylor, T., "Mashinnyye imitatsionnyye eksperimenty o modelyami ekonomicheskikh sistem" /Computer Simulation Experiments on Models of Economic Systems/, Moscow, Izdatel'stvo "Mir", 1975.

37. Ol'shevskiy, V.V., "Modeling in Statistical Hydroacoustics," "Trudy Shestoy Vsesoyuznoy shkoly-seminara po statisticheskoy gidroakustiki", Novosibirsk, Institute of Mathematics, Siberian Department, USSR Academy of Sciences, 1975, pp 3-24.

38. Tarasenko, F.P., "Neparametricheskaya statistika" /Nonparametric Statistics/, Tomsk, Izdatel'stvo TGU /Tomsk State University/, 1976.

39. Ol'shevskiy, V.V., "Simulation Experiments in Statistical Hydroacoustics," in "Akusticheskiye metody issledovaniya okeana" /Acoustical Methods for Investigating the Ocean/, Leningrad, Izdatel'stvo "Sudostroyeniye", 1976, pp 30-38.

40. Ol'shevskiy, V.V., "Vvedeniye v statisticheskuyu teoriyu aktivnoy gidrolokatsii" /Introduction to the Statistical Theory of Active Hydrolocation/, Taganrog, TRTI /Taganrog Radiotechnical Institute/, Part 1, 1971; Parts 2-5, 1976.

41. Ol'shevskiy, V.V., "Osnovy teorii statisticheskikh izmereniy. Konspekt lektsii" /Principles of the Theory of Statistical Measurements: Synopses of Lectures/, Taganrog, TRTI, 1976.

42. Ol'shevskiy, V.V., "Some Problems in the Computer Simulation of Random Processes in Connection With Statistical Measurement Problems," "IX Vsesoyuznyy simpozium 'Metody predstavleniya i apparaturnyy analiz sluchaynykh protsessov i

poley" /Ninth All-Union Symposium on "Representation Methods and Equipment Analysis of Random Processes and Fields"/, Leningrad, VNIIEP, Section 4, 1976, pp 3-6.

43. Ol'shevskiy, V.V., "Statistical Measurements Under Conditions of Dynamic Acoustic Experiments," "Trudy Vtoroy nauchno-technicheskoy konferentsii po informatsionnoy akustike" /Works of the Second Scientific and Technical Conference on Information Acoustics/, Moscow, Institute of Acoustics, USSR Academy of Sciences, 1976, pp 67-71.

44. Ol'shevskiy, V.V., "Simulation Experiments in Statistical Hydroacoustics: Selecting Models and Checking Their Adequacy for Real Phenomena," in "Akusticheskiye metody issledovaniya okeana," Leningrad, Izdatel'stvo "Sudostroyeniye", 1977, pp 6-17.

45. Buslenko, V.N., "Avtomatizatsiya imitatsionnogo modelirovaniya slozhnykh sistem" /Automation of the Simulation Modeling of Complex Systems/, Moscow, Izdatel'stvo "Nauka", 1977.

46. Dyuran, B., and Odell, P., "Klasternyy analiz" /Claster Analysis/, Moscow, Izdatel'stvo "Statistika", 1977.

47. Grubnik, N.A., and Ol'shevskiy, V.V., "An Acoustic Model of the Ocean," "Trudy Pervogo seminara 'Akusticheskiye statisticheskiye modeli okeana'" /Works of the First Seminar on "Acoustic Statistical Models of the Ocean"/, Moscow, Institute of Acoustics, USSR Academy of Sciences, 1977, pp 3-11.

48. Middleton, D., "A Statistical Acoustic Model of the Ocean," "Trudy Pervogo seminara 'Akusticheskiye statisticheskiye modeli okeana'", Moscow, Institute of Acoustics, USSR Academy of Sciences, 1977, pp 12-55.

49. Ol'shevskiy, V.V., "Models and Simulation Computer Experiments in Statistical Hydroacoustics," "Trudy Pervogo seminara 'Akusticheskiye statisticheskiye modeli okeana'", Moscow, Institute of Acoustics, USSR Academy of Sciences, 1977, pp 70-85.

50. Middleton, D., and Ol'shevskiy, V.V., "Contemporary Problems in Constructing Acoustic Statistical Models of the Ocean," "Trudy Pervogo seminara 'Akusticheskiye statisticheskiye modeli okeana'", Moscow, Institute of Acoustics, USSR Academy of Sciences, 1977, pp 86-90.

51. Ol'shevskiy, V.V., "Simulation Computer Experiments in Statistical Hydroacoustics: Models, Algorithms, Measurements," "Trudy Vos'moy Vsesoyuznoy shkoly-seminara po statisticheskoy gidroakustike" /Works of the Eighth All-Union School-Seminar on Statistical Hydroacoustics/, Novosibirsk, Institute of Mathematics, Siberian Department, USSR Academy of Sciences, 1977, pp 138-154.

52. Ol'shevskiy, V.V., "Vybor modeley pri imitatsionnykh mashinnykh eksperimentakh v statisticheskoy gidroakustike" /Selecting Models for Simulation Computer Experiments in Statistical Hydroacoustics/, Moscow, Institute of Acoustics, USSR Academy of Sciences, 1977, pp 23-32.

53. Zavadskiy, V.Yu., "Akustika i EVM. Voprosy sudostroyeniya. Seriya: akustika" /Acoustics and Computers: Questions in Shipbuilding. Acoustics Series/, TsNII "Rumb" /expansion unknown/, No 10, 1978, pp 80-90.

54. Ol'shevskiy, V.V., "Modeling in Statistical Measurements: Problems and Metrological Aspects," "X Vsesoyuznyy simpozium 'Metody predstavleniya i apparaturnyy analiz sluzhaynykh protsessov i poley" /10th All-Union Symposium on "Representation Methods and Equipment Analysis of Random Processes and Fields"/, Leningrad, VNIIEP, Section 4, 1978, pp 2-7.

55. Kleynen, Dzh., "Statisticheskiye metody v imitatsionnom modelirovanii" /Statistical Methods in Simulation Modeling/, Moscow, Izdatel'stvo "Statistika", 1st and 2nd editions, 1978.

56. Rabiner, L., and Gould, B., "Teoriya i primeneniye tsifrovoy obrabotki signalov" /Theory and Utilization of Digital Signal Processing/, Moscow, Izdatel'stvo "Mir", 1978.

57. Shannon, R., "Imitatsionnoye modelirovaniye sistem--iskusstvo i nauka" /Simulation Modeling of Systems--Art and Science/, Moscow, Izdatel'stvo "Mir", 1978.

58. Grubnik, N.A., and Ol'shevskiy, V.V., "Methodological Questions on the Construction of Acoustic Models of the Ocean," "Trudy Chetvertoy nauchno-tekhnicheskoy konferentsii po informatsionnoy akustike" /Works of the Fourth Scientific and Technical Conference on Information Acoustics/, Moscow, Institute of Acoustics, USSR Academy of Sciences, 1978, pp 3-10.

59. Ol'shevskiy, V.V., "Principles of the Investigation of Acoustico-Oceanographic Models," "Trudy Chetvertoy nauchno-tekhnicheskoy konferentsii po informatsionnoy akustike", Moscow, Institute of Acoustics, USSR Academy of Sciences, 1978, pp 11-22.

VOLUMETRIC NOISE SPATIAL CORRELATION FUNCTION FOR SURFACE ANTENNAS

[Article by Yu. B. Goncharov and I. L. Oboznenko pp 49-52]

/Text/ In this article we discuss the effect of the reflecting surface on which acoustic pressure receivers are located on the spatial correlation function of volumetric, isotropic noise. The receivers' inherent diffraction effects are not taken into consideration; that is, they are assumed to be point receivers.

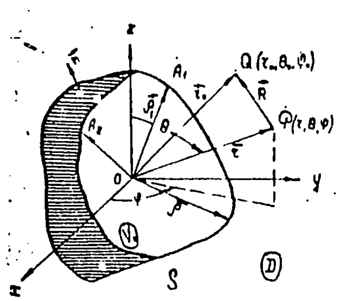


Figure 1.

Let us examine an unlimited space D that contains an arbitrary body S (Figure 1), on the surface of which are located point receivers $A_1(\rho_1,\theta_1,\phi_1)$ and $A_2(\rho_2,\theta_2,\phi_2)$ (ρ,θ,ϕ = spherical coordinates of the surface points relative to the center 0; $\vec{o\rho}$ = = radius vector describing the surface of S). Let space D - V_0, where V_0 is the volume of the scattering body, be continuous and filled uniformly with point noise sources $Q(\vec{r}_0)$, $\vec{r}_0 \in (D - V_0)$. Let us assume that the noise field on the outer surface of S is homogeneous and that the voltage at the outputs of point receivers A_1 and A_2, as well as that of an external (relative to the surface of S) point receiver $P(\vec{r}_0)$, $\vec{r}_0 \in (D - V_0)$, is proportional to the total pressure p at the indicated points. We will assume that each noise source creates a pressure in space D - V_0 that is characterized by identical statistical properties and that the noise formation process itself is ergodic. We assume that the phases of noise sources $Q(\vec{r}_0)$ are random for all $\vec{r}_0 \in (D - V_0)$ and that at a random frequency ω the amplitudes of the total pressure $p(\vec{r})$ are distributed relative to the average value and that the average for the ensemble equals the average with respect to time. By analogy with /1,2/ let us determine the normalized spatial correlation function of the noise interference at the two points

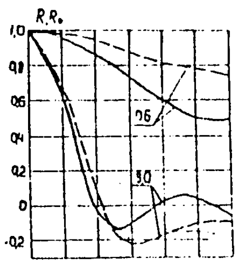


Figure 2.

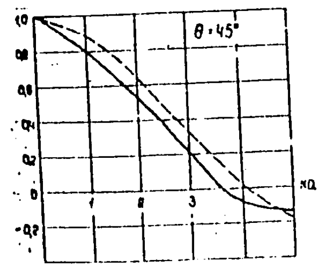


Figure 3.

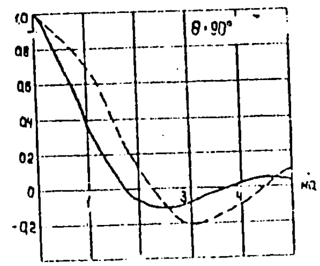


Figure 4.

$A_1(\vec{\rho}_1)$ and $A_2(\vec{\rho}_2)$ (Figure 1) in the form

$$R(|\vec{\rho}_1 - \vec{\rho}_2|,\tau) = R(d,0)\cos\omega\tau,\ d = |\vec{\rho}_1 - \vec{\rho}_2|, \quad (1)$$

where

$$R(d,0) = \frac{<p^2>_{12}}{2<p^2>_0} - 1 = \frac{<u^2>_{12}}{2<u^2>_0} = 1,\ u = \psi p, \quad (2)$$

τ = time lag of the process; ψ = sensitivity of the point receivers; $<u^2>_{12}$ and $<u^2>_0$ = mean squares of the voltages at the output, respectively, of the two (at points A_1 and A_2) and one (reduced to a certain point on the surface of S) receivers sensing noise from volume $D - V_0$.

As a reduction point, let us take one of the points on the surface $(\rho,0,0)$. Let us represent the pressure waves falling from point $Q(\vec{r}_0)$ and scattered at point $P(\vec{r}_0)$ in the form

$$\tilde{p}_i(\vec{r},t) = p_i(\vec{r})e^{-i\omega t};\ \tilde{p}_s(\vec{r},t) = p_s(\vec{r})e^{-i\omega t}, \quad (3)$$

where p_i, p_s = complex pressure amplitudes in the incident and scattered waves, respectively. At points A_1 and A_2, the total pressure amplitudes are

$$p_1(\vec{\rho}_1) = p_{i1}(\vec{\rho}_1) + p_{s1}(\vec{\rho}_1),\ p_2(\vec{\rho}_2) = p_{i2}(\vec{\rho}_2) + p_{s2}(\vec{\rho}_2). \quad (4)$$

If we select point A_1 on the surface of S as the reduction point, in accordance with the procedure /2/ for computing spatial correlation function (2), we obtain

$$R(d,0) = \frac{1}{2}\cdot\frac{\iiint_V |p_{12}|^2 dV}{\iiint_V |p_1|^2 dV} - 1. \quad (5)$$

Here,

$$p_{12} = p_1(\vec{\rho}_1) + p_2(\vec{\rho}_2) = p_{i1}(\vec{\rho}_1) + p_{i2}(\vec{\rho}_2) + p_{s1}(\vec{\rho}_1) + p_{s2}(\vec{\rho}_2). \quad (6)$$

Since the pressure in the incident wave is assumed to be known for any source $Q(\vec{r}_0)$, $\vec{r}_0 \in V$, at an arbitrary point $P(\vec{r})$, $\vec{r} \in V$, including points on the surface of S, in order to determine spatial correlation function (5) it is necessary to find the scattered field at point P (and, in particular, at the points on the surface of S).

For a spherical, acoustically stiff surface the expression for the spatial correlation factor of volumetric noise has the form

$$R(d,0) = \sum_{n=0}^{\infty} \frac{(2n+1)p_n(\cos\theta)}{D_n(ka)} \left| \sum_{n=0}^{\infty} \frac{(2n+1)}{D_n(ka)} \right|^{-1}, \quad D_n(ka) = |h_n'(ka)|^2. \qquad (7)$$

Figure 2 shows the dependences of the spatial correlation functions of isotropic, volumetric noise for acoustically stiff [R(d,0)] and acoustically transparent [R_0(d,0)] spherical antennas on the spatial location of the two receivers A_1 and A_2 for different values of the wave size ka. Figures 3 and 4 show the dependences of functions R and R_0 on wave size ka for fixed spatial positions of receivers A_1 and A_2. As is obvious from these figures, for average values of the scattering surface's wave sizes, functions R and R_0 can differ substantially. For large surface wave sizes, differences between functions R and R_0 are observed only in the area of weak correlation.

BIBLIOGRAPHY

1. Eckart, G., J. ACOUST. SOC. AM., Vol 25, 1953, p 195.

2. Kron, B., and Sherman, I., "Spatial Correlation Functions for Different Models of Noise," in "Nekotoryye problemy obnaruzheniya signala maskiruyemogo flyuktuatsionnoy pomekhoy" /Some Problems in Detecting a Signal Masked by Fluctuating Interference/, Moscow, Izdatel'stvo "Sovetskoye radio", 1965.

LOW-FREQUENCY REVERBERATION CAUSED BY THE SCATTERING OF SOUND ON THE FOAMY SURFACE OF THE OCEAN

[Article by V. P. Glotov pp 52-56]

/Text/ It is a well-known fact /1,2/ that resonance scatterers in the form of pulsing air bubbles form in a thin layer of water that is disturbed by wind-caused waves. What is of interest is the low-frequency surface reverberation (back scattering) that occurs under extreme meteorological conditions--a foamy, irregular ocean surface (wind speed $\bar{v}$ > 6-8 m/s)--when the scattering is great not only at high, but also at low frequencies (∿1 kHz). A characteristic feature of this statistical problem is accounting not only for the wave action, but also the acoustic interaction of a bubble with its mirror image. As the model of the scattering medium let us take a stochastic complex consisting of a large-scale irregularity (that is fluent and sloping) and an underlying layer of bubbles, the concentration of which is constant (throughout the layer) and the radii a of which are small in comparison with the wavelength $\lambda = 2\pi/k$ in the water and the distance between them. We will separate a layer of bubbles of thickness $H = 0.1\lambda$ that is adjacent to the surface and compute its contribution to the total scattering. The other part of the layer is of no interest, since its effect on the reverberation has already been studied in detail /3,4/.

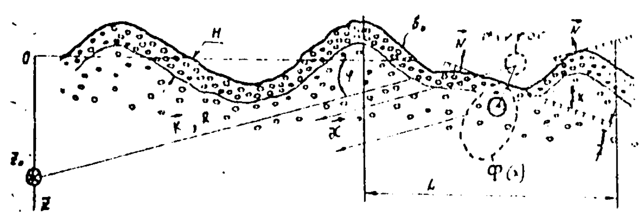


Figure 1.

Let a narrow-band pulse, the spatial length L of which exceeds the irregularities' correlation interval, strike an agitated surface at a glancing angle ϕ (to the plane z = 0, Figure 1). Now let us find the intensity of the reverberation from layer H.

At low frequencies (1 kHz and lower), $r_{rad} \equiv k^2a^2 \geqslant r_n$ (loss resistance) and the scattering cross-section of a bubble in a limitless space can be represented approximately as

$$\sigma = 4\pi a^2/r_{rad} = \lambda^2/\pi. \quad (1)$$

For the intensity of the reverberation from layer H we have [3,4]:

$$r_{rev} = (\bar{n}\sigma/4\pi)\langle\iiint |\Psi|^2|G|^2du\rangle, \quad (2)$$

where $\bar{n}$ = average concentration of bubbles in the layer; Ψ = disturbing sonic field under the irregular surface (in the layer); G = Green function; u = volume of the layer; $\langle\cdot\rangle$ = averaging with respect to the collective of irregularities.

In the propositions formulated above relative to the surface (soft, fluent and sloping), the field beneath it can be represented in the following form [6] (we ignore the contribution of the bubbles):

$$|\Psi(\vec{R})| \simeq 2\xi(\vec{R})\cdot\frac{(\vec{k}\vec{N})}{R}, \quad (3)$$

where $\vec{N}$ = unit normal vector to the irregular surface at the current point $\vec{R}$; $\xi(\vec{R})$ = distance from volume du to the irregular surface along the normal to it; R = = distance from du to the observation point.

Let us now determine the Green function. From the figure it is obvious that the indicatrix of the dipole (the bubbles plus their mirror image) has the form:

$$\Phi^2(\chi) = \sin^2(k\xi\cdot\sin\chi), \quad (4)$$

where χ = the scattered wave's angle of yaw to the tangent plane.

From formula (4) it is obvious that the indicatrix has maximums in different directions. For $k\xi \leqslant \pi/4$ (that is, $\xi_{max} \simeq H \simeq 0.1\lambda$) the indicatrix has a single maximum in a direction close to the tangent plane's normal. In this direction the oscillations of a bubble and its image are almost opposite in phase (the intensity equals the square of the sum of the pressures):

$$i_{max} = v^2W_s\frac{\sin^2(k\xi)}{4\pi R^2m} \simeq \frac{(k\xi)^2}{\pi R^2}\cdot\frac{W_s}{m}, \quad (5)$$

where v = the number of oscillations (v = 2); W_s = a bubble's scattering power in a limitless space; m = a factor ($0 \leqslant m \leqslant 1$) allowing for the change in a bubble's resistance in the presence of an absolutely soft interface ($r_{rad} = mk^2a^2$).

Factor m can be related to the axial scattering concentration [7]:

$$m = \int_{-\pi/2}^{\pi/2}\sin^2(k\xi\cdot\sin\chi)\cos\chi d\chi = 1 - (\sin 2k\xi/2k\xi). \quad (6)$$

We see that for $k\xi \geqslant \pi$, $m \simeq 1$ (there is no interaction). On the contrary, however, for $k\xi \leqslant \pi/4$ the interaction is great, since $m = 2/3(k\xi)^2$, which means a sharp intensification of a bubble's pulsations and, consequently, scattering. For a thin layer $kH \lesssim \pi/4$, according to (5) and (6) the intensity of the scattering at the indicatrix's maximum will be

$$i_{max} \simeq 6(W_s/4\pi R^2); \quad (7)$$

that is, 7.8 dB more than in a limitless space under the same conditions. For the intensity at angle χ we obtain ($k\xi \lesssim \pi/4$):

$$i(\chi) = i_{max} D^2(\chi) \equiv (W_s/4\pi)|G|^2, \quad (8)$$

where $D^2(\chi) = (k\xi)^{-2}\phi^2(\chi) \simeq k^2(\vec{\varkappa}\vec{N})^2$ = normalized indicatrix; $\vec{\varkappa}$ = wave vector of the scattering of the wave; $|G|$ = absolute value of the Green function:

$$|G| \simeq \sqrt{6}[(\vec{\varkappa}\vec{N})/kR]. \quad (9)$$

Considering expressions (3) and (9) and integrating (2) with respect to the thickness of the layer, we obtain

$$(r_{rev})_{\vec{\varkappa}=\vec{k}} \simeq 8\bar{n}\frac{H_3}{k^4R^4}\langle\iint(\vec{k}\vec{N})^4 ds_0\rangle, \quad (10)$$

where s_0 = the surface limiting the scattering volume ($s_0 = 2\pi RL$).

Further calculations of the reverberation level can be made only if the statistical properties of the agitated surface are given. Assuming that the slopes of the large-scale isotropic irregularities are distributed according to the normal law, according to (10) we obtain

$$r_{rev} \simeq 8H_3 s_0 R^{-4} C(\phi,\delta), \quad (11)$$

where $C(\phi,\delta)$ = a function depending on the incident wave's glancing angle and the root-mean-square angle of the irregular surface's slope /6/.

Let us calculate function $C(\phi,\delta)$ for the reverberation aspect of the glancing angles ($\phi \to 0$). We have:

$$C(\phi,\delta)_{\phi\to 0} \simeq \phi^4[1 + 6(\frac{\delta}{\phi})^2(1 + \frac{\delta^2}{2\phi^2})] \simeq 3\delta^4. \quad (12)$$

Substituting expression (12) into (13) and converting to the surface reverberation factor $m_p(\phi) = 4\pi r_p R^2/r_0 s_0$, where $r_0 \simeq R^2$ is the intensity of the direct wave, for $\phi \to 0$ we obtain

$$m_p(\phi) \simeq 96\pi\bar{n}H^3\phi^4. \quad (13)$$

Thus, for small glancing angles the value of the factor $m_p(\phi)$ does not depend on the angle, but on the root-mean-square angle of the irregular surface's slope (a linear dependence on $\bar{v}$ /8/) and the average concentration of bubbles (an exponential dependence on $\bar{v}$ /1,2/). It is easy to see, however, that formula (13) gives an exaggerated reverberation value, since part of the bubbles are "shaded" by the irregularities in the surface when $\phi \to 0$. Let us introduce the appropriate correction factor. For the "shading" function at glancing angles we have /5/:

$$Q(\phi,\delta) \equiv S(\phi,\delta)/s_0 \simeq 2.5\phi\delta^{-1}, \quad (14)$$

where $S(\phi,\delta)$ = the effective area.

Allowing for (14), we will finally have

$$m_p(\phi) \simeq 240\pi\bar{n}H^3\delta^3\phi; \quad (15)$$

that is, the reverberation's spatial subsidence follows the law R^{-4}, since $\phi \simeq z_0/R$, where z_0 is the depth of submergence of the hydroacoustic system.

Let us evaluate the equivalent radius of the surface reverberation for an undirected hydroacoustic system. Assuming that f = 1 kHz, z_0 = 100 m, H = 15 cm, $\delta \simeq 0.17$ ($\bar{v} \simeq 15$ m/s), $\bar{n} \simeq 10^{-6}$-10^{-7} cm^{-3} (the extrapolation value of the concentration of resonance bubbles according to the optical data in /2/ and L = 50 m, we obtain $\alpha_{equ} \simeq 4$-12 m (independent of distance).

Thus, the contribution of a thin layer of bubbles (foam) can be extremely significant.

BIBLIOGRAPHY

1. Glotov, V.P., Kolobayev, P.A., and Nauyman, G.G., "Investigation of the Scattering of Sound by Bubbles Created in Seawater by an Artificial Wind and the Statistical Distribution of the Bubbles' Dimensions," AKUSTICHESKIY ZHURNAL, Vol 7, No 4, 1961, pp 421-427.

2. Kolobayev, P.A., "Investigation of the Concentration and Statistical Distribution of the Sizes of Bubbles Created in the Surface Layer of the Ocean by Wind," OKEANOLOGIYA, Vol 15, No 6, 1975, pp 1013-1017.

3. Glotov, V.P., and Lysanov, Yu.P., "On Surface Reverberation Caused by Resonance Air Bubbles," TRUDY AKUSTICHESKOGO INSTITUTA, No 2, 1967, pp 26-32.

4. Glotov, V.P., and Lysanov, Yu.P., "On the Relative Role of Air Bubbles and an Agitated Sea Surface in the Formation of Reverberation," AKUSTICHESKIY ZHURNAL, Vol 14, No 3, 1968, pp 371-375.

5. Bass, F.G., and Fuks, I.M., "Rasseyaniye voln na statisticheskoy nerovnoy poverkhnosti" /Wave Scattering on a Statistical, Irregular Surface/, Moscow, Izdatel'stvo "Nauka", 1972, pp 183, 351, 243.

6. Kur'yanov, B.F., "Scattering of Sound on a Rough Surface With Two Types of Irregularities," AKUSTICHESKIY ZHURNAL, Vol 8, No 2, 1962, pp 325-333.

7. Skuchik, Ye., "Osnovy akustiki" /Principles of Acoustics/, Moscow, Izdatel'stvo Inostrannoy literatury, 1958, Part 1, p 293.

8. Cox, C., and Munk, W., "Measurement of the Roughness of the Sea Surface From Photographs of the Sun Glitter," J. OPT. SOC. AMER., Vol 44, 1954, pp 838-850.

INFORMATION CHARACTERISTICS OF REVERBERATION CAUSED BY WIDE-BAND SOURCES IN A SHALLOW SEA

[Article by T. V. Polyanskaya pp 56-57]

/Text/ An analysis of works devoted to the study of the characteristics of reverberation in lakes and a shallow sea when wide-band sources are used showed that at the present time insufficient attention is being devoted to establishing a connection between the reverberation signal's characteristics and the spatial-structural characteristics of the medium's boundaries, with the low-frequency area being the least studied of all.

In this article we study the information characteristics of low-frequency ($f < 1$ kHz) reverberation (which include duration, the shape of the signal's envelope and its spectral characteristics) caused by an explosive source in lakes and a shallow sea. In order to obtain the initial data, we made experimental recordings of reverberation signals under different conditions (in Lake Svityaz' in Volynskaya Oblast and in Lake Ladoga, as well as shallow bays in the Barents Sea, with the average depths for all of this work being 10-130 m). Different geometric arrangements of the monostatic and bistatic sound sources and receivers were used. As a signal source we used explosive charges of various sizes, while the receivers were nondirectional hydrophones, the depth of submergence of which equaled the depth at which the charges were detonated. The wide-band reverberation signals that were received were recorded on a tape recorder. The characteristics that were analyzed were duration, envelope shape and signal spectrum. The spectral characteristics were obtained during the processing of the signals, using a BPF /expansion unknown/, for frequency values of 0-5,000 Hz and a 2-Hz band, in connection with which the realization was divided into sections lasting 0.5 s. The analysis that was made of the experimental results showed that the geometric characteristics of the body of water can be determined from the duration of the reverberation. We constructed an empirical law for the dependence of the duration of reverberation on the area of the sonicated water area (for those cases where the area of the basin was evaluated preliminarily with certain reflectors) that showed that the duration of the reverberation is almost directly proportional to the area of the basin. The experimentally obtained reverberation duration values were compared with theoretical ones calculated with Yu.M. Sukharevskiy's formula /1/ for boundary reverberation. The best correspondences were obtained for the regions with the least broken land profiles, when small charges were used, and for depths not exceeding 15-20 m. In the general case the experimental values are always higher than the calculated ones, which can be explained by the fact that the formula used does not allow for such essential (in this case) parameters as the size of the body of water, the land profile and the simultaneous presence of both bottom and surface reverberation. Periodic brokenness of the spectrum of a reverberation signal with an amplitude of 8-10 dB and a frequency of 25-45 Hz is seen in the spectrograms of recordings made in open areas and rather wide bays. This can be explained by the effect of the pulsations of the gas bubble appearing in connection with the detonation of the explosive charge, since the frequency of the pulsations diminishes with a decrease in the depth at which the charge is detonated and in increase in the weight of the explosive used. This makes it possible to link a reverberation signal's characteristics with the working conditions and the depth of detonation of the charge. The statistical regularities of a reverberation signal were studied with the help of a discrete, canonical model of reverberation for broad-band emissions /2/. V.V. Ol'shevskiy showed that in such a case, the reverberation process is essentially nonstationary, since the form of the correlation function (and not only its dispersion) depends on the current time. Research conducted by us and reported in detail in /3/ showed that reverberation from an explosive source in a shallow sea is a process that leads to a stationary one, in connection with which the stationary component of the reverberation signal is distributed according to the normal law.

Thus, our research demonstrated the promise of the study of the information characteristics of reverberation caused by broad-band sources for the study of the spatial and structural characteristics of the boundaries of a medium. The development of this area of research can move along the path of predicting marine reverberation, as well as the study of the effect of the frequency characteristics of the scatterers and the marine medium on the temporal and spatial correlation of reverberation.

BIBLIOGRAPHY

1. Sukharevskiy, Yu.M., "Theory of Marine Reverberation Caused by the Scattering of Sound," DOKLADY AN SSSR, Vol 55, No 9, 1947, pp 825-828.

2. Ol'shevskiy, V.V., "Statisticheskiye metody v gidrolokatsii" /Statistical Methods in Hydrolocation/, Leningrad, Izdatel'stvo "Sudostroyeniye", 1973.

3. Gonopol'skiy, A.L., Gronskiy, Ya.I., and Polyanskaya, T.V., "Some Results of Experimental Investigations of Reverberation Caused by Broad-Band Sources in a Shallow Sea," in "Trudy 9-oy Vsesoyuznoy shkoly-seminara po statisticheskoy gidroakustiki" /Works of the Ninth All-Union School-Seminar on Statistical Hydroacoustics/, Novosibirsk, 1978.

STATISTICAL ANALYSIS OF ACOUSTIC SIGNALS SCATTERED BY A SEA SURFACE

[Article by Ya. P. Dragan and I. N. Yavorskiy pp 58-59]

/Text/ Let us examine the methods for obtaining statistical evaluations of the characteristics of biperiodically correlated random processes (BPKSP) and the algorithms used to compute them. Algorithms for determining evaluations of the characteristics of periodically correlated random processes (PKSP) are derived from them as special cases. A BPKSP is a random process, the mathematical expectation $m_\xi(t) = E_\xi(t)$ and correlation function $B_\xi(t,\tau) = E[\xi(t+\tau) - m_\xi(t+\tau)][\xi(t) - m_\xi(t)]$ of which are almost periodic functions of time with Fourier indicators $\Lambda_{n\ell} = n(2\pi/T_1) + \ell(2\pi/T_2)$, where n and ℓ are whole numbers, so that they can be represented in the form

$$m_\xi(t) = \sum_{n,\ell=-\infty}^{\infty} m_{\ell n} \exp j\Lambda_{n\ell} t, \quad B_\xi(t,\tau) = \sum_{\ell,n=-\infty}^{\infty} B_{\ell n}(\tau) \exp j\Lambda_{n\ell} t.$$

Evaluations of these characteristics can be found by calculating the evaluations of components $m_{\ell n}$ and $B_{\ell n}(\tau)$, and when the periods of correlatability of the process T_1 and T_2 are commensurate (that is, when $qT_1 = pT_2$) they can also be calculated directly. Unskewed evaluations of the components are the statistics

$$\hat{m}_{\ell n} = \lim_{T\to\infty} \frac{1}{T} \int_0^T \xi(t) \exp(-j\Lambda_{n\ell} t)dt,$$
$$\hat{B}_{\ell n}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_0^T \dot{\xi}(t+\tau)\dot{\xi}(t) \exp(-j\Lambda_{n\ell} t)dt. \qquad (1)$$

These evaluations will be valid for certain conditions that are imposed on the correlation function and the fourth moment (see, for example, /3/). The direct evaluation of the characteristics of a BKPSP is based on the properties of readings at points that are multiples of the value pT_2, $T_1 < T_2$. Unskewed and valid evaluations of the mathematical expectation and covariation, under the conditions mentioned above, will be the statistics

$$\hat{m}_\xi(t_0) = \frac{1}{N} \int_{n=0}^{N=0} \dot{\xi}(t_0 + npT_2), \qquad (2)$$

. . . .

. . . .

$$\hat{B}_{\xi}(t_0,\tau) = \frac{1}{N}\sum_{n=0}^{N=0} \dot{\xi}(t_0 + npT_2 + \tau)\dot{\xi}(t_0 + npT_2), \ \ell = 0,qp. \quad (2)$$

In order to find the value of the correlation function, it is convenient to represent the data entered in a computer in the form of a matrix, the rows of which are sequences of readings: $\Xi = \|\dot{\xi}_{\ell p}\|$, $\dot{\xi}_{\ell p} = \dot{\xi}(t_0 + \ell\Delta + npT_2)$, Δ = quantification step.

BIBLIOGRAPHY

1. Dragan, Ya.P., and Yavorskiy, I.N., "Probability Description of Sea Waves," in "Trudy Sed'moy Vsesoyuznoy shkoly-seminara po statisticheskoy gidroakustike" /Works of the Seventh All-Union School Seminar on Statistical Hydroacoustics/, Novosibirsk, 1976.

2. Dragan, Ya.P., and Yavorskiy, I.N., "On the Representation of a Communication Link With Reflection From a Sea Surface in the Form of a Linear Filter," in "Trudy Sed'moy Vsesoyuznoy shkoly-seminara po statisticheskoy gidroakustike", Novosibirsk, 1976.

3. Gudzenko, D.I., "On Periodically Nonstationary Processes," RADIOTEKHNIKA I ELEKTRONIKA, Vol 4, No 6, 1959.

INVESTIGATION OF THE INTERFERENCE STRUCTURE OF THE ACOUSTIC FIELD OF A MODEL WAVEGUIDE

[Article by G. K. Ivanova, V. N. Il'ina, Ye. F. Orlov and G. A. Sharonov pp 59-61]

/Text/ In this work we conduct an experimental test of the method of generalized holograms /1/ during an investigation of the mode structure of the acoustic field in model waveguides of two types: a two-layer waveguide and a symmetrical sound channel with a deepened axis.

The sliding spectrum of an intensity hologram /1/ with temporal averaging, allowing only for the interference term at great distances, will be /2/:

$$B(\Omega,\omega,t) = \int_t^{t+T_B} F_T^2(\omega,t) \sum_{m,n} P_m(\omega,z,z_0)P_n(\omega,z,z_0)\cos \Delta\varkappa_{mn}(\omega)r^{-i\Omega t}dt. \qquad (1)$$

where z, z_0 = horizons of the source and the receiver; $r = vt$; $\Delta\varkappa_{mn}$ = equality of the longitudinal wave numbers of the modes m, n. Extreme values of the function $B(\Omega,\omega)$ will be seen at $\Omega = v\Delta\varkappa_{mn}(\omega)$. The lines of the extreme values of $B(\Omega,\omega)$ on the plane Ω,ω will correspond to the waveguide's characteristic curves, while the values of the function $B(\Omega,\omega)$ on the line $U = \Omega/v = \Delta\varkappa_{mn}(\omega)$ will be determined by the amplitudes of the excitation of the modes $P_m(\omega,z,z_0)P_n(\omega,z,z_0)$.

For a two-layer medium on the plane $\varkappa,\omega$, the area of modes encompassed by the waveguide is limited by the straight lines $\omega/\varkappa = C_1$ and $\omega/\varkappa = C_2$ /3/. On the plane u,ω the area of existence of a difference in the modes' longitudinal wave numbers will be bounded by the axis $\Delta\varkappa_{mn} = 0$ and the line $\Delta\varkappa_{mn} = \omega(C_2 - C_1)/(C_1C_2)$. The behavior of the lines $\Delta\varkappa_{mn} = \Delta\varkappa_{mn}(\omega)$ is such that as the frequency increases, the values of $\Delta\varkappa_{mn}(\omega)$ diminish for a given pair m, n /3/. The distribution of the values of $B(u,\omega)$ on the plane u,ω is determined by the amplitudes of the excitation of the modes $P_m(\omega,z,z_0)P_n(\omega,z,z_0)$, which depend on the horizons of the emission and reception points.

For a waveguide with a deepened channel axis with a profile

$$C(z) = (1/C_0^2 - qz)^{-1/2} \text{ for } z > 0;\ C(z) = (1/C_0^2 + q'z) \text{ at } z \quad 0,$$

in the VKB /expansion unknown/ approximation /3/ we have:

$$\Delta\varkappa_{mn}(\omega) = \frac{\omega}{C_0}\{[1 - 2\mu C_0'(\frac{m - 1/2}{\omega})^{2/3}]^{1/2} - [1 - 2\mu C_0(\frac{n - 1/2}{\omega})^{2/3}]^{1/2}\}, \qquad (2)$$

where

$$\mu = \frac{C_0}{2}[\frac{3}{2}\pi/(\frac{1}{q} + \frac{1}{q'})]^{2/3}.$$

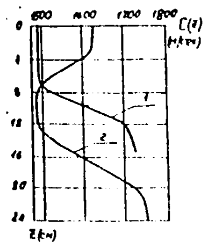


Figure 1.

The area of existence of differences in the modes' wave numbers lies beneath the straight line $\varkappa_{mn}(\omega) = \omega\Delta C/C_0^2$, where ΔC = = the maximum difference in the speeds of sound in the distribution C(z) for the link. From (2) it follows that the interference frequencies $\Delta\varkappa_{mn}(\omega)$ for fixed m, n increase as the frequency does. Let us examine the results of a modeled experiment. Figure 1 shows the profiles of the speed of sound in an experimental bath; these profiles were obtained by the method described in /4/. Curve 1 corresponds to the two-layer waveguide, curve 2 to the waveguide with a deepened axis.

The working range of frequencies in the experiment was chosen to be 300-720 kHz (λ = 4.2-2.1 mm). Figure 2 /not reproduced/ shows the hologram recordings for the two waveguides /5/. In a two-layer medium, the hologram recording was made for movement of the receiver away from the emitter (r = 0.3 cm) to distances of up to r = 500 cm ($\sim 1.2\cdot 10^3\cdot\lambda_{max}$), with horizons $z = z_0$ = 1 cm ($2.4\cdot\lambda_{max}$). Figure 3 /not reproduced/ gives the results of secondary processing of the hologram by a method presented in /6/ for the distances: a. 0.3-165 cm, b. 165-300 cm, c. 330-495 cm with averaging with respect to distance at 165 cm ($\sim 390\cdot\lambda_{max}$). In Figure 3b, the boundary of the existence of $B(u,\omega)$ is clearly visible: the line $\Delta\varkappa = A\omega$, where coefficient A, determined experimentally, equals $9.5\cdot 10^{-7}$ cm/s^{-1}, which coincides with the calculated value of δ ($9.3\cdot 10^{-7}$ cm/s^{-1}). The experimental determination of coefficient A makes it possible to determine the speed of sound in the underlying layer (C_2) if C_1 is known. The structure of the lines $u = \Delta\varkappa_{mn}(\omega)$, which correspond to the extreme values of $B(u,\omega)$--as is obvious from Figure 3--correspond to the theoretical structure as far as the nature of its dependence on ω is concerned /3/. The number of the interfering modes is determined experimentally according to the maximum value $\Delta\varkappa_{mn} = \Delta\varkappa_{1M}$. On the lower frequency of 360 kHz, $\Delta\varkappa_{1M}$ = 1.93 cm $^{-1}$ (Λ_{1M} = 3.3 cm), M = 18. Calculating M according to C(z) gives the same value. The distance between adjacent modes along the u axis is on the order of $\sim$0.1 cm^{-1} (at a frequency of $\sim$400 kHz). The areas of the greatest values of $B(u,\omega)$ on the plane u,ω are localized in accordance with the distribution of the amplitudes of excitation of the modes ($P_m(\omega,z,z_0)P_n(\omega,z,z_0)$) and their location does not depend on r.

In the channel with the deepened axis, the hologram recording was made at distances of up to 330 cm. The source's horizon and the receiver's trace were the same: z = = z_0 = 8 cm ($\sim 19\cdot\lambda_{max}$). Figures 4a and 4b /not reproduced/ show the sliding spectrum of the hologram of $B(u,\omega)$ for the following distances: a. 0.3-165 cm, b. 165-330 cm with averaging at 165 cm. A large number of interference bands are seen in the spectrum of $B(u,\omega)$ and $\Delta\varkappa$ increases as the emission frequency does.

BIBLIOGRAPHY

1. Orlov, Ye.F., "The generalized Hologram Method in Acoustical Investigations of the Ocean," this collection.

2. Brekhovskikh, L.M., "Volny v sloistykh sredakh" /Waves in Layered Mediums/, Moscow, Izdatel'stvo "Nauka", 1967.

3. Tolstoy, I., and Kley, K.S., "Akustika okeana" /Ocean Acoustics/, Moscow, Izdatel'stvo "Mir", 1969.

4. Barkhatov, A.N., "Modelirovaniye rasprostraneniya zvuka v more" /Modeling the Propagation of Sound in the Sea/, Leningrad, Gidrometeorologicheskoye izdatel'stvo, 1968.

MULTIDIMENSIONAL MODELING IN STATISTICAL HYDROACOUSTICS

[Article by V. V. Ol'shevskiy pp 61-64]

/Text/ 1. The special features of the mathematical modeling of acoustico-oceanographic problems /1-4/ lead to the necessity of carrying out multidimensional modeling of random variables, the functions of vector arguments, the vector functions of scalar arguments and, finally, the vector functions of vector arguments. However, even when the most productive computers are used, direct multidimensional modeling entails practically unsurmountable difficulties. It is sufficient to say that the sampling data volume N_n needed for the direct, combined modeling of n random variables, when each of them is represented by m values, is determined by the relationship

$$N_n = m^n. \quad (1)$$

In time these difficulties gained the name of "the curse of dimensionality," and for a long time now researchers have been asking the following question: how can the sampling data volume be reduced without discarding the essential regularities (statistical connections) among the random variables being modeled? The contradiction posed by these two tendencies (reducing the sampling data volume and losing statistical regularities) is obvious; nevertheless, simplified multidimensional models are now being introduced. In this article we propose one such simplified multidimensional model that is based on the assignment of a full set of two-dimensional distributions of random variables.

2. The "Mixing" of Random Variables. Let y_j, $j = \overline{1,M}$, be random variables for which the unidimensional probability densities $W(Y_j)$, $j = \overline{1,M}$ are given. Let us form a new random variable

$$z = \text{mix}(y_j, r_j), \ j = \overline{1,M}, \quad (2)$$

where "mix" is the "mixing" operator of the original random variables in proportions of r_j. According to (2), "mixing" essentially means the formation of a new random variable z from the set y_j, $j = \overline{1,M}$, it being the case that the sample Z_R consists of $R = \sum_{j-1}^{R} r_j$ values of the original variables y_j, each of which is represented in Z_R by r_j values. It can be shown that

$$W(Z) = \frac{1}{R}\sum_{j=1}^{M} r_j W(Y_j). \qquad (3)$$

3. Evaluating the Two-Dimensional Distributions. Let us discuss the sample

$$\vec{x}_N = (x_1,\ldots,x_n)_N \qquad (4)$$

where n = a dimensional random variable consisting of N values. We will be interested in the two-dimensional joint probability densities

$$W(X_k,X_\ell);\ k > \ell;\ \ell,k = \overline{1,n}, \qquad (5)$$

or, which is equivalent, the unidimensional unconditional and two-dimensional conditional probability densities

$$W(X_k),\ W(X_\ell/X_k);\ k > \ell,\ k,\ell = \overline{1,n}. \qquad (6)$$

These densities $\hat{W}(X_k,X_\ell)$, $\hat{W}(X_k)$ and $\hat{W}(X_\ell/X_k)$, $k > \ell$, $\ell,k = \overline{1,n}$, can be evaluated with the help of polygrams /5/ that minimize the error of the statistical evaluations for any sampling volume N.

Thus, about the n-dimensional random variable (4) we know only the pair statistical relationships of the type of (5) or (6) and according to these relationships, by solving the following problem we attempt to achieve the most likely model of the entire set of random variables. It is clear that such a description is incomplete; however, it is related to a significant economy of all the statistical procedures.

4. Modeling a Multidimensional Random Variable With the Help of Two-Dimensional Distributions. As soon as the distributions of type (5) and (6) are given for n-dimensional variable (4), it is necessary to organize the modeling procedure on the basis of the assignment of the two-dimensional probability distributions. As a basis for the modeling, let us examine conditional probability densities (6). In this case, the modeling procedure takes form as the following sequence:
random variable x_1 is modeled in accordance with $W(X_1)$;
variable x_2 is modeled in accordance with the conditional $W(X_2/X_1)$ and unidimensional $W(X_2)$ distributions;
variable x_3 is modeled in accordance with the conditional $W(X_3/X_1)$, $W(X_3/X_2)$ and unidimensional $W(X_3)$ distributions and so on.

Thus, in the general case the random variable x is modeled in accordance with the distributions

$$W(X_\ell),\ W(X_\ell/X_k);\ k = \overline{1,\ell-1};\ \ell = \overline{2,n}. \qquad (7)$$

And now for the essential part of the modeling procedure: its algorithm. Under the conditions that have been formulated, the choice of the multidimensional modeling algorithm is not an unambiguous problem. However, it is possible to suggest several heuristic procedures, one of which is being discussed here. This is the "mixing" of random variables (see Section 2), in connection with which--according to (2) and (3)--the resulting probability distribution equals the sum of the densities (with the appropriate weighting factors). Taking (7) into consideration, for the probability density $W_M(X_\ell/X_1,\ldots,X_{\ell-1})$ of the modeled random value x_ℓ, we have:

$$W_M(X_\ell/X_1,\ldots,X_{\ell-1}) = \frac{1}{\ell - 1}\sum_{k=1}^{\ell-1} W(X_\ell/X_k). \quad (8)$$

It is not difficult to show that, according to (8) and (9), the unconditional probability distribution

$$W_M(X_\ell) = \int_{-\infty}^{\infty}\cdots\int W_M(X_\ell/X_1,\ldots,X_{\ell-1})W(X_1,\ldots,X_{\ell-1})\prod_{i=1}^{-1} dXi \quad (9)$$

equals

$$W_M(X_\ell) = W(X_\ell). \quad (10)$$

Modeling algorithm (8) corresponds to the "mixing" that is being discussed and is formulated on the basis of statistical evaluations of the probability densities of, for example, the conditional two-dimensional polygrams.

Let us mention here that for the modeling of n random variable with the help of two-dimensional distributions on the condition that each of them is realized by m values, the sampling data volume N_2 will be

$$N_2 = \frac{n(n - 1)}{2} m^2. \quad (11)$$

From a comparison of the values of N_2 with the case of full n-dimensional modeling (1), for n = 10 and m = 10 there is a vast savings (about 5 orders of magnitude) in the amount of sample values of the random variables during multidimensional modeling with the help of two-dimensional probability distributions.

BIBLIOGRAPHY

1. Ol'shevskiy, V.V., "Simulation Experiments in Statistical Hydroacoustics: Selecting Models and Testing Their Adequacy for Real Phenomena," in "Akusticheskiye metody issledovaniya okeana" /Acoustic Methods of Investigating the Ocean/, Leningrad, Izdatel'stvo "Sudostroyeniye", No 255, 1977.

2. Grubnik, N.A., and Ol'shevskiy, V.V., "An Acoustic Model of the Ocean," in "Trudy Pervogo seminara 'Akusticheskiye statistichekiye modeli okeana'" /Works of the First Seminar on "Acoustic Statistical Models of the Ocean"/, Moscow, Institute of Acoustics, USSR Academy of Sciences, 1977.

3. Ol'shevskiy, V.V., "Models and Simulation Computer Experiments in Statistical Hydroacoustics," in "Trudy Pervogo seminara 'Akusticheskiye statisticheskiye modeli okeana'", Moscow, Institute of Acoustics, USSR Academy of Sciences, 1977.

4. Middleton, D., and Ol'shevskiy, V.V., "Contemporary Problems in the Construction of Acoustical Statistical Models of the Ocean," in "Trudy Pervogo seminara 'Akusticheskiye statisticheskiye modeli okeana'", Moscow, Institute of Acoustics, USSR Academy of Sciences, 1977.

SPATIAL COVARIATION FUNCTION OF A SONIC FIELD

[Article by V. M. Kudryashov pp 64-67]

/Text/ The spatial correlation function of the stochastic part of a sonic field for observation points moving along a line in the azimuthal plane has already been calculated /1/. A new variant of the program is suitable for the case where the line along which the observation points are moving is located along the z axis; that is, along the cross-section of a waveguide. The program is written in FORTRAN for a BESM-6 high-speed computer. The subject of discussion here is a sonic field in a waveguide ($s(\vec{r}) \leqslant z \leqslant H$, $0 \leqslant r < \infty$; $\vec{r} = \{x,y\}$) filled with a liquid medium, the speed of sound C in which depends on the depth z, since the density is constant. The waveguide's upper boundary is acoustically soft or is a solid plate with irregular surfaces (the latter variant will not be discussed here). Let us assume that the irregularities in the boundary are distributed according to the normal law and are statistically uniform, isotropic and sloping, it being the case that $\langle s(\vec{r})\rangle = 0$, $\langle s(\vec{r} + \vec{\rho})s(\vec{r})\rangle = \sigma^2 R(\rho)$, where $\sigma^2 = \langle s^2(\vec{r})\rangle$, $R(0) = 1$. Calculations were made for $R(\rho) = \exp(-\rho^2/\rho_0^2)$. The angled brackets designate an averaging operation with respect to the ensemble of boundaries. The boundary z = H is characterized by a sound reflection factor that is independent of the coordinates. The sound source is a point source emitting a harmonic wave of frequency f. The sound source's coordinates are $r = 0, z = z_0$. Let us represent the sonic potential in the form $\Psi(\vec{r},z)\exp(-i2\pi ft)$, where t = time. Let us look for a solution of the Helmholtz equation for $\Psi(\vec{r},z)$ that satisfies the boundary conditions, the condition on the sound source and the principle of extinguishability at infinity. Let us represent the coherent field in the form of a superposition of normal waves:

$$\langle\Psi(r,z)\rangle = \sum_{m=1}^{\infty}\langle\Psi_m(r,z)\rangle, \qquad (1)$$

where

$$\langle\Psi_m(r,z)\rangle = \langle A_m(r)\rangle\Phi_m(z).$$

For the corresponding normalization of the eigenfunction $\phi_m(z)$,

$$\langle A_m(r)\rangle = i\pi\phi_m(z_0)H_0^{(1)}(\xi_m r),$$

where ξ_m = eigenvalue for the m-th normal wave of the coherent sonic field.

The complete field can be expanded with respect to the coherent field's eigenfunctions and we obtain:

$$\Psi(\vec{r},z) = \sum_{m=1}^{\infty} A_m(\vec{r})\phi_m(z). \qquad (2)$$

The sonic field's normalized covariation function K is determined by the relationship

$$K(\vec{r},\Delta\vec{r},\Delta z) = \langle\Psi(\vec{r}_1,z_1)\Psi^*(\vec{r}_2,z_2)\rangle \Big/ \sqrt{\langle|\Psi(\vec{r}_1,z_1)|^2\rangle\langle|\Psi(\vec{r}_2,z_2)|^2\rangle}. \qquad (3)$$

Here, $\vec{r} = (\vec{r}_1 + \vec{r}_2)/2$, $\Delta\vec{r} = \vec{r}_1 - \vec{r}_2$, $\Delta z = z_1 - z_2$. If $\Psi(\vec{r},z) = \langle\Psi(r,z)\rangle$, then $|K(\vec{r},\Delta\vec{r})| = 1$; that is, $\langle\Psi(r,z)\rangle$ is a coherent field. If there is a stochastic component $\Psi_s(\vec{r},z) = \Psi(\vec{r},z) - \langle\Psi(\vec{r},z)\rangle$ in the waveguide, then $|K(\vec{r},\Delta\vec{r},\Delta z)| < 1$ for $|\Delta\vec{r}| \neq 0$ and $\Delta z \neq 0$; that is, deviation of $|K(\vec{r},\Delta\vec{r},\Delta z)|$ from unity is an indicator of the existence of a stochastic component in the waveguide. Its spatial correlation function is determined by the expression

$$K_s(\vec{r},\Delta\vec{r},\Delta z) = \langle\Psi_s(\vec{r}_1,z_1)\Psi_s^*(\vec{r}_2, z_1)\rangle \Big/ \sqrt{\langle|\Psi_s(\vec{r}_1,z_1)|^2\rangle\langle|\Psi_s^*(\vec{r}_2,z_1)|^2\rangle}. \qquad (4)$$

According to formula (2),

$$\langle\Psi(\vec{r}_1,z_1)\Psi^*(\vec{r}_2,z_2)\rangle = \sum_{m,n=1}^{\infty} \langle A_m(\vec{r}_1)A_n^*(\vec{r}_2)\rangle\phi_m(z_1)\,\phi_n^*(z_1). \qquad (5)$$

Let us assume that the Rayleigh parameter for wave number m is small in comparison with unity. It is then the case that for sloping ($\sigma/\rho_0 \ll 1$) irregularities, multiple rescattering of the waves is substantial only in the range of angles close to a mirror angle. Ignoring back scattering, we have

$$D_m(r,\Delta y) = \bar{D}_m(r) + \sum_\ell \int_0^r D_\ell(\rho,\Delta\rho)\hat{B}_{\ell m}R(\sqrt{|\xi_m/\xi_\ell|}\Delta\rho)e^{-2\mathrm{Im}\xi_m(r-\rho)}, \qquad (6)$$

which is equivalent to the relationship

$$\frac{\partial}{\partial\rho}D_m(\rho,\Delta\rho) = -2\mathrm{Im}\xi_m D_m(\rho,\Delta\rho) + \sum_\ell D_\ell(\rho,\Delta\rho)\hat{B}_{\ell m}R(\sqrt{|\xi_m/\xi_\ell|}\Delta\rho). \qquad (7)$$

Here,

$$\langle A_m(\vec{r}_1)A_m^*(\vec{r}_2)\rangle = D_m(r,\Delta y)(\pi/2)|\mathrm{Re}\xi_m|H_0^{(1)}(\mathrm{Re}\xi_m r_1)H_0^{(1)*}(\mathrm{Re}\xi_m r_2),$$

$$\langle A_m(r_1)\rangle\langle A_m^*(r_2)\rangle = \bar{D}_m(r)(\pi/2)|\mathrm{Re}\ {}_m|H_0^{(1)}(\mathrm{Re}\xi_m r_1)H_0^{(1)*}(\mathrm{Re}\xi_m r_2),$$

$$\hat{B}_{\ell m} = \int_{-\pi}^{\pi} B_{\ell m}d\phi = \frac{\pi}{2}\frac{\sigma^2}{|\xi_m|}\left|\frac{\partial}{\partial z}\phi_\ell(z)\cdot\frac{\partial}{\partial z}\phi_m(z)\right|^2_{z=0} \int_0^\infty R(\rho)I_0(\mathrm{Re}\xi_m\rho)I_0(\mathrm{Re}\xi_\ell\rho)\rho d\rho.$$

The waves forming $\Psi_s(\vec{r},z)$ are not coherent if

$$\langle A_m(\vec{r}_1)A_n^*(\vec{r}_2)\rangle = \langle A_m(\vec{r}_1)\rangle\langle A_n(\vec{r}_2)\rangle \quad (8)$$

for $m \neq n$. In actuality,

$$\langle A_m(\vec{r}_1)A_n^*(\vec{r}_2)\rangle \simeq \langle A_m(r_1)\rangle\langle A_n(r_2)\rangle\exp[\alpha(r)] \quad (9)$$

for $m \neq n$, where

$$\alpha(r) = \frac{\sigma^2}{4|\xi_m\xi_\ell|}\left|\frac{d}{dz}\Phi_\ell(z)\cdot\frac{d}{dz}\Phi_m(z)\right|^2_{z=0}\int_{-\infty}^{\infty}R(\rho)d\rho\int_0^r R\left(\frac{\Delta y}{r}\eta\right)d\eta.$$

The substitution of formula (9) for (8) is permissible if $\rho_0 \ll R_m$, where R_m is the length of the cycle of wave number m.

Formulas (3)-(9) are the basis of the program's algorithm.

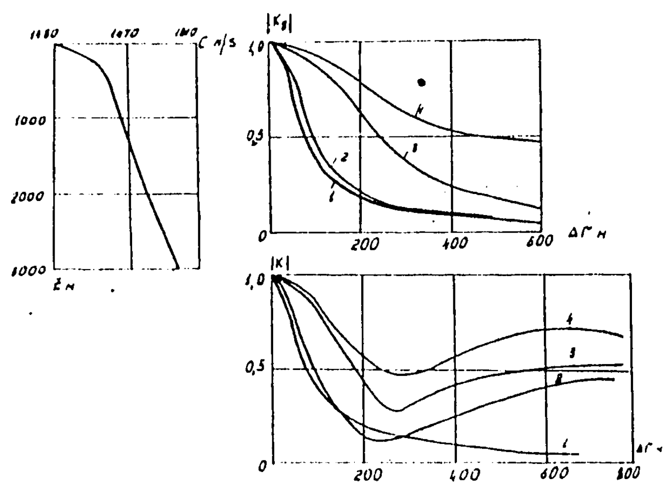


Figure 1.

On the righthand side of Figure 1 is the result of the calculation in the waveguide, for which the profile C(z) is depicted on the left side of Figure 1, with σ = 3 m, ρ_0 = 50 m, H = 4,000 m, z = z_0 = 50 m, f = 90 Hz, r = 301 km.

The dependence of $|K_5|$ (above) and $|K|$ (below) on Δr have been plotted. The numbers 1, 2, 3 and 4 designate the cases 1) Δx = 0, 2) $\Delta x = \Delta y$, 3) $\Delta x = 5\Delta y$, 4) Δy = = 0. It was ascertained that $|K_5(\vec{r},\Delta\vec{r})|$ has two correlation scales in the azimuthal plane: a longitudinal one and a transverse one. The transverse scale is realized in pure form if the observation points are shifted along the coherent field's front. In connection with this, $|K_5|$ decreases monotonically as the observation points disperse and the distance increases. The longitudinal scale appears when when the receiving base line is located along the direction toward the sound source. As a rule, the longitudinal scale is substantially greater than the transverse one, it being the case that as the observation points disperse along the direction toward the sound source, $|K_5|$ and $|K|$ can oscillate.

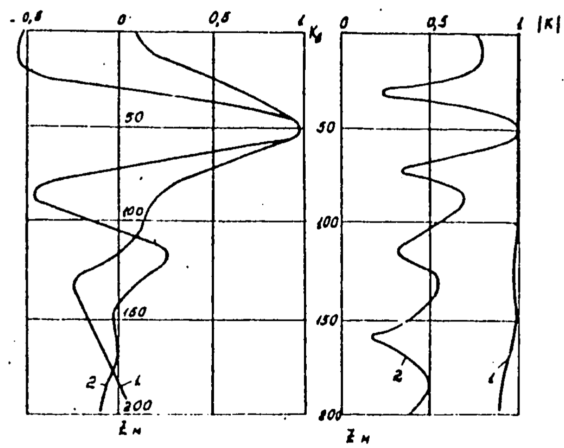


Figure 2.

There is yet a third correlation scale, along the vertical; that is, a field scattered on nonisotropic irregularities is essentially not isotropic. Figure 2 shows the graphs of $|K_5|$ (on the left) and $|K|$ (on the right) when one of the observation points moves downward from the surface. A second observation point is at a depth of 50 m. The numbers 1 and 2 correspond to r = 5 and 501 km. As the distance increases, the vertical correlation scale decreases. The change in the absolute value of the complete field's covariation function as the observation points are dispersed is determined by the change in K_5 and the value of the sonic field's coherence parameter.

BIBLIOGRAPHY

1. Kudryashov, V.M., "On Calculating the Correlation Function of a Stochastic Sonic Field in a Waveguide," in "Trudy Vos'moy Vsesoyuznoy shkoly-seminara po statisticheskoy gidroakustike" /Works of the Eighth All-Union School-Seminar on Statistical Hydroacoustics/, Novosibirsk, 1977, pp 14-15.

ON THE QUESTION OF ANISOTROPY OF THE OCEAN'S NOISE FIELD

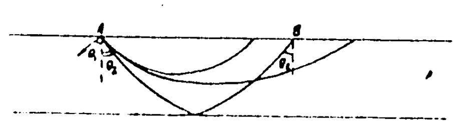
[Article by B. I. Klyachin pp 67-70]

/Text/ In /1,2/ the authors solved the problem of the effect of reflection and refraction on a noise field. It is necessary to supplement this model by discussing scattering on the ocean's surface. Actually, if the surface is disturbed there are noise sources on it and it will scattering any sound waves striking it. Let the noise sources be distributed in the layer near the surface and be isotropic, which corresponds to the proposal of constancy of the hydrometeorological conditions in some extensive body of water. Also, let the distribution of the speed of sound depend only on the ocean's depth, and let its bottom be level. The problem of propagation is examined in a beam approximation. Let I be the density of the sonic energy arriving at a unit area at a unit solid angle. In view of the symmetry of the problem, this value depends only on the angle and the depth. It is clear that the function $I(z,\Theta)$ possesses symmetry relative to the vertical, since different amounts of energy cannot arrive from different directions at angles that are symmetrical relative to the vertical because of the nondifferentiability of the directions to the right and the left relative to the point under discussion.

In /1,2/ it is shown that when such sound field symmetry is present, it is not necessary to allow for divergence of the beam tubes. If $I(\Theta)$ is the intensity of the noise on the ocean's surface when z = 0, then at all other depths it is the case that

$$I(\Theta,z) = I(\Theta')e^{-\beta\Delta\ell}$$

where Θ' = angle of the beam corresponding to Θ at the horizon z = 0; β = energy attenuation factor; $\Delta\ell$ = distance along the beam from horizon z = 0 to horizon z. Let $I(\Theta)$ be the density of the energy of the noise sources located on the surface.



The energy

$$I(\Theta_2)e^{-\beta\ell(\Theta_2)}dwds$$

arrives at angle Θ_2 at point A from point B, which is at a distance of $\ell(\Theta_2)$ (the total length of this beam's cycle). Here we assume that $|V_\delta| = 1$, which simplifies the formula and does not lead to a loss of commonality, while $\ell(\Theta)$ is

$$\ell(\Theta) = 2\int_0^{z_{max}} (\sqrt{1 - \sin^2\Theta c^2(t)/c_0^2})^{-1} dt, \quad (1)$$

where c_0 = speed of sound on the surface; z_{max} = maximum depth to which the given beam sinks.

Let us discuss the energy that has departed from point A at angle Θ_1. This energy is composed of the energy emitted by the "live" sound source at this angle, the reflected energy that arrived at angle Θ_1, and the energy from all angles of approach that was scattered at angle Θ_1:

$$I(\Theta_1) = y(\Theta_1) + |V_n| I(\Theta_1) e^{-\beta\ell(\Theta_1)} + 2\pi \int_0^{\pi/2} m_3(\Theta_1, \Theta_2) I(\Theta_2) e^{-\beta\ell(\Theta_2)} d\Theta_2 \sin\Theta_2, \quad (2)$$

where $|V_n|$ = absolute value of the reflection factor from the surface; m_5 = sound scattering coefficient on the surface, which--according to /3/--equals the ratio of the energy scattered into the solid angle to the energy striking the second solid angle. Let us rewrite (2) in the following manner:

$$\frac{y(\Theta_1)}{1 - |V_n| e^{-\beta\ell}} + \frac{2\pi}{1 - |V_n| e^{-\beta\ell}} - \int_0^{-\pi/2} \sin\Theta_2 m_s I e^{-\beta\ell} d\Theta_2 = I(\Theta_1), \quad (3)$$

that is, we obtain a (Fredgol'm) equation of the second type. In order to solve equation (3), let us make use of the expression for the scattering factor that is obtained /3/ by the method of small perturbations:

$$m_s = (4/\pi)(k\sigma 2)(k\rho_0)^2 \cos^2\Theta_1 \cdot \cos^2\Theta_2, \quad (4)$$

where k = wave number; σ^2, ρ_0 = root-mean-square height of the irregularities and their correlation distance. Substituting (4) into (3), we obtain

$$\frac{y}{1 - |V_n| e^{-\beta\ell}} + \frac{(4/\pi)(k\sigma^2)(k\rho_0)^2 \cos^2\Theta_2}{1 - |V_n| e^{-\beta\ell}} - 2\pi \int_0^{-\pi/2} \sin\Theta_2 \cos^2\Theta_2 I(\Theta_2) e^{-\beta\ell} d\Theta_2 = I(\Theta_2). \quad (5)$$

Let us designate

$$2\pi \int_0^{-\pi/2} \sin\Theta \cos^2\Theta I(\Theta) e^{-\beta\ell} d\Theta = M. \quad (6)$$

It is then the case that

$$I(\Theta) = \frac{y(\Theta) + (4/\pi)(k\sigma)^2 (k\rho_0)^2 \cos^2\Theta \cdot M}{1 - |V_n| e^{-\beta\ell}}. \quad (7)$$

Further, by substituting (7) into (6) we obtain an expression for M in terms of known functions:

$$M = \frac{2\pi \int_0^{-\pi/2} \frac{\sin\Theta \cos^2\Theta \cdot y(\Theta) e^{-\beta\ell}}{1 - |V_n| e^{-\beta\ell}}}{1 - 2\pi \int_0^{-\pi/2} \frac{\sin\Theta \cos^4\Theta \cdot (k\rho_0)^2 (k\sigma)^2/4}{1 - |V_n| e^{-\beta\ell}} d\Theta}, \quad (8)$$

where ℓ is determined by formula (1). Such a simple result is obtained when the variables in the scattering factor are separated. In the more general case it is necessary to look for the solution of equation (3). From (7) it is obvious that for $m_s = 0$, $M = 0$; that is, for total reflection we obtain a formula that is completely equivalent to the results given in /1,2/:

$$I(\Theta) = \frac{y(\Theta)}{1 - |V_n| e^{-\beta\ell}}.$$

This means that allowing for the scattering on the surface, in comparison with the problem that takes only reflection into consideration, means the presence of some additional effective sound sources located at the surface and having an energy flow density of

$$y_{eff} = (4/\pi)(k\sigma)^2(k\rho_0)^2\cos^2\Theta\cdot M.$$

From formula (6) it is obvious that for a scattering factor that is independent of the angle of incidence, 2M means the sonic energy that has arrived at a point on the surface. It is precisely because of this energy that the effective noise sources appear. It is not difficult to see that the effective sources will be greater than the primary ones if the following inequality is fulfilled:

$$\beta\ell_0 < |V_n|(1 - |V_n|).$$

Thus, it is possible to have conditions under which the effective noise sources are significantly--or even much--greater in power than the primary sources. This happens, for example, in the absence of attenuation and as little scattering as possible.

BIBLIOGRAPHY

1. Tulham, R.Y., "Ambient Sea Noise Model," J. ACOUST. SOC. AMER., Vol 36, No 8, 1964, pp 1541-1544.

2. Furduyev, A.V., "Ocean Noises," in "Akustika okeana" /Ocean Acoustics/, Moscow, Izdatel'stvo "Nauka", 1974.

3. Lysanov, Yu.P., "Sound Scattering by Irregular Surfaces," in "Akustika okeana", Moscow, Izdatel'stvo "Nauka", 1974.

A METHOD OF MODELING A ROBOT WITH AN ECHO-LOCATOR

[Article by D. Ye. Okhotsimskiy, A. K. Platonov and V. Ye. Pryanichnikov pp 70-71]

/Text/ The basic purpose of this project is the construction of a high-speed mathematical model of the reflection of waves by a complicated relief, in which the basic physical processes of the formation and reception of the return signals by a robot are taken into consideration.

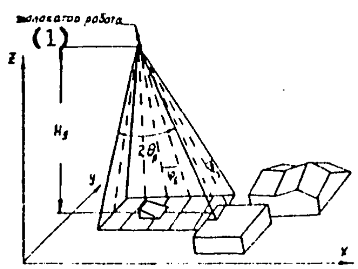


Figure 1. Diagram of echo-location measurements with a moving robot.
Key: 1. Robot's echo-locator

In this work we calculate the characteristics of return signals in the robot movement mode at some height H_s above the reflecting surface's average level $z = F(x,y)$. In connection with this, the emitter's and receiver's radiation patterns are oriented downward and divided into quite small solid angles--the elementary beams $\phi_1 \times \phi_2$ are such that a spherical wave of the appropriate amplitude is propagated inside them (Figure 1). The size of the section of surface irradiated by the elementary beam is substantially smaller th H_s.

Such an orientation of the radiation pattern can be required for the specialized information system of a walking robot that plans the robot's next movements and selects the points where its feet are to be put. Another example is an automatic manipulator operating on a conveyor and identifying different parts.

The robot makes measurements as it moves; therefore, it is necessary to model a large number of acoustic measurements from points that are quite close together. In order to reduce the number of computations it is sufficient to construct the reflected signal for only a few positions of the emitter that we will call the base positions. The intermediate values of the reflected signal are found by linear interpolation, with the addition of a correction factor for noise.

The relief is given by the surface $z = F(x,y)$, the acoustic properties of which are given comparatively simply in the model. In our work we used the robot visualization system and the method of modeling its external environment proposed in /2,3/. We introduced three levels of descriptive detail, each of which has its own horizontal scale of squares in the plan of the relief elements. The flat faces of the relief elements are also squares in the plan or are situated vertically. The relief elements on the different levels are superimposed on each other so that the face of the larger of them is a foundation for a smaller one. On the whole, the surface obtained can be characterized as piecewise linear, piecewise continuous and piecewise translational with respect to X and Y. The description is formulated in a special, rather simple, language. Each face receives its own set of numerical characteristics and coefficients that define its reflection.

A parameter matching algorithm supports the existence of those emitter positions that we call the base ones and in which one surface face F' falls flatly inside each elementary beam. In the base positions the computation of the elementary signals $S_{ij}(t)$ becomes simpler, since this is a problem of determining reflection from a plane. Thus, the computation of the overall signal S(t) comes down to the solution of $N_{W_1} \times N_{W_2}$ problems of calculating elementary return signals. For an arbitrary emitter position, the reflected signal is found by interpolation of the return signals for the adjacent base positions.

The elementary return signals are computed by finite formulas that correspond to integration with respect to infinitely small, diffusely reflecting areas $d\sigma$. The phase interactions of different sections of a face, the location of the front and rear edges of the sonicated area, and the material of which the reflecting face is composed are all allowed for.

BIBLIOGRAPHY

1. Okhotsimskiy, D.Ye., Platonov, A.K., Borovin, G.K., Karpov, I.I., Kiril'chenko, A.A., Kugushev, Ye.I., Lazutin, Yu.M., Pavlovskiy, V.Ye., Pryanichkov, V.Ye., and Yaroshevskiy, V.S., "An Integral Locomotive Robot: a Complex Mechanical System," in "Referaty dokladov Vsesoyuznoy konferentsii po optimal'nomu upravleniyu" /Abstracts of Reports Given at the All-Union Conference on Optimum Control/, Moscow, 1974.

2. Platonov, A.K., and Pryanichkov, V.Ye., "A Method for Describing the External Environment of Robots," in "Trudy I Mezhdunarodnoy konferentsii molodykh uchenykh po problemam diskretnykh sistem v upravlenii" /Works of the First International Conference of Young Scientists on Problems of Discrete Systems in Control Science/, Minsk, 1977, pp 448-460.

3. Pryanichkov, V.Ye., "The Visualization Problem of a Robot Interacting With Its External Environment in a Mathematical Model," in "Trudy Vsesoyuznogo simpoziuma po robotam i manipulyatoram" /Works of the All-Union Symposium on Robots and Manipulators/, Tol'yatti, 1976, Vol 2.

CHARACTERISTIC DIFFERENCES IN ARRIVAL ANGLES AND TIMES OF SIGNALS IN SEPARATE BEAMS UNDER CONDITIONS OF A CLEARLY EXPRESSED ZONAL STRUCTURE OF A SONIC FIELD

[Article by V. P. Akulicheva pp 71-72]

/Text/ As is known, each point in the sonic field of a point source in a layered, nonhomogeneous medium is characterized by rigorously defined angular and temporal structures in the vertical plane.

In order to determine the regularities of these structures, it is necessary to analyze a large mass of their realizations as functions of such parameters as hydrological conditions and source and receiver depths, as well as the distances between them. Let us perform such an analysis for the purpose of evaluating the characteristic differences in signal arrival angles and times for the most common hydrological conditions that characterize a clearly expressed zonal structure of a sonic field.

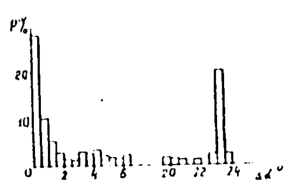


Figure 1.

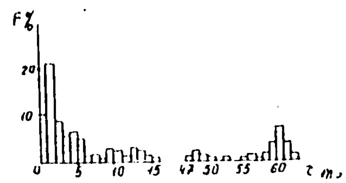


Figure 2.

The angular and temporal structures were calculated on a BESM-6 high-speed computer, using a program developed by A.A. Vagin, assuming unvarying hydrology along the trace and three-ball wave action (moderate seas). Calculations were made for the near zone and the first convergence zone, with a distance spacing of 200 m for a single receiver horizon and 3 source depths. In each angular structure the 3 most intensive beams with a difference of no more than 10 dB were selected for analysis, after which the 3 differences between the angles and times of their arrival were determined. The histograms of the characteristic differences in beam arrival times and angles that were constructed on the basis of these data are shown in Figures 1 and 2. Here the X-axes were used to plot, respectively, the differences in beam arrival angles ($\Delta\alpha$), in degrees, and the differences in the signal arrival times along these beams (τ), in milliseconds, while the frequency of these differences was plotted along the Y-axes.

The results of the analysis showed (Figure 1) that in 25 percent of the cases under discussion, the difference in the arrival angles of the most intensive beams at the reception point is no more than 0.5°, while in 45 percent of the cases it does not exceed 2°. Another interesting fact is that 70 percent of the time this difference is less than 6°, while in 30 percent it lies in the $20\text{-}24^{\circ}$ range.

The difference in arrival times of signals along these elementary beams (Figure 2) is less than 1 ms in 10 percent of the cases and less than 5 ms in 50 percent. The maximum value of τ for the indicated conditions does not exceed 65 ms.

SPATIAL FILTRATION OF A SIGNAL IN A FIELD OF REVERBERATION AND NOISE INTERFERENCE DURING SCATTERED EMISSION AND RECEPTION

[Article by V. V. Krizhanovskiy and S. V. Pasechnyy pp 73-78]

/Text/ Let us analyze the noise stability of a linear, vertically arranged equidistant antenna during detection of a signal against a background of a multicomponent interference field. The antenna belongs to an emitter-receiver system that can be dispersed vertically. The interference field includes the following components: thermal noise brought to the antenna's input /1/, the isotropic noise of the sea /2/, anisotropic dynamic noise from sources just below the surface /2/ and reverberation noise. The latter is caused by single scattering on irregularities in the body of water and on the surface and bottom. Models of the correlation functions of reverberation interference have been based on theoretical models obtained through the use of the method of small perturbations /3,4/. The signal field and the reverberation interference are formed regularly by a homogeneous waveguide that corresponds to the model of a nearby location. The signal is assumed to be a brief one, and the volumetric irregularities are approximated by thin horizontal layers, so that the irradiated scattering volume can be considered to be located in the Fraunhofer zone relative to the emitting-receiving system. Since the structure of the reverberation interference's angular power spectrum depends on time, the waveguide's geometry, the characteristics and location of the scattering sources, the directivity of the radiation, the horizons of the arrangement of the emitter and the receiver in the waveguid, and the reflertive capability of the boundaries, we performed a separate analysis of the effect of these factors on the effectiveness of the spatial filtration of the reverberation interference. In order to define our calculations concretely, it was assumed that the basic volumetric reverberation sources are: a sound-scattering layer of scatterers (ZRS) and the layer of bubbles near the surface. Calculations were made for a 10-element receiving antenna balanced in the direction of the signal's arrival. The waveguide's height i., H = 6,000 m. The emitter and the receiver can be placed on one of three horizons: z = 300, 3,500, 5,500 m. The center of the ZRS layer is on the horizon Z_c = 500 m. The surface was assumed to be absolutely soft. The interference weighting factors were chosen on the basis of a condition of normalization of their total power to unity at moment t = 10 s. The irregularities in the boundaries were characterized by a Gaussian correlation function with a correlation distance ρ = = $\lambda/2\pi$. The coefficient of reflection from the bottom is characterized by a refractive index n = 1 and a soil density μ = 1.5. In all of the figures presented below, the value of the wave distance Δ/λ between antenna elements is plotted along the X-axis, while the interference level is plotted (in decibels) along the Y-axis. The curves describing the changes in the interference level use the following letter designations: ⌣ = components of the reverberation interference from the ZRS layer; cn = from the layer of bubbles; b = from the bottom; s = from the surface. The curves defining the change in the signal-to-noise ratio (in decibels) are labeled c/n.

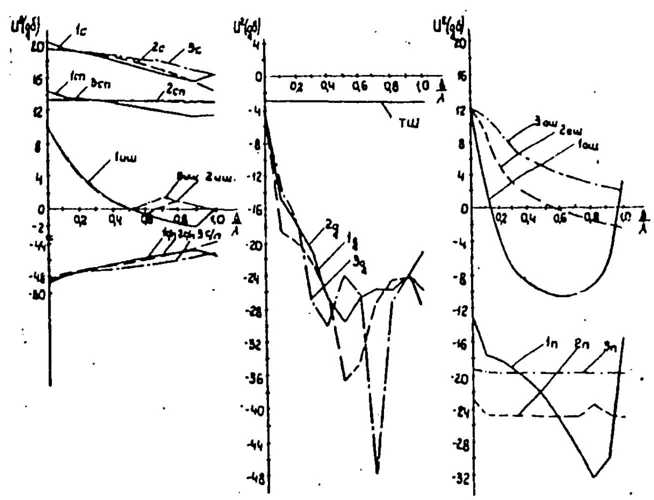


Figure 1.

Figure 1 shows the results of the calculation of the power of the interference at the antenna's outlet for a fixed moment of location time t = 10 s and the 3 receiver location horizons mentioned above, with the emitter horizon being z_u = 300 m. The emitting antenna is a directional one. From the graphs it is obvious that as the receiver gets deeper, there is a substantial deterioration in the filtration of anisotropic interference (by about 18 dB) and the isotropic and reverberation interference from the volumetric scatterers (by about 2-4 dB) and an increase in the surface reverberation level (by about 25 dB). As a result of this, the signal-to-noise ratio decreases. Bottom reverberation is basically received by the side lobes. Calculations show that from the rereflected reverberation components, the basic contribution to the scattered field is made by the components reflected from the surface, which yield an increase in interference power of about 6 dB. The role of the other components is about 0.5-1 dB. An exception is the surface reverberation components, for which the components reflected from the bottom (because of the significant increase in the level of the scattered signals in the vertical directions) are also substantial. In view of its δ-correlativity on the antenna elements, the thermal noise level does not depend on Δ/λ and for the chosen interference ratio has the same form as in Figure 1 in all cases. Analogous results occur for emitter horizons z_u = 3,500 and 5,500 m.

In Figure 2 the broken curves illustrate the effect of increasing the bottom reflection factor (n = 0.8, μ = 2.7) on filtration efficiency. In this case, because

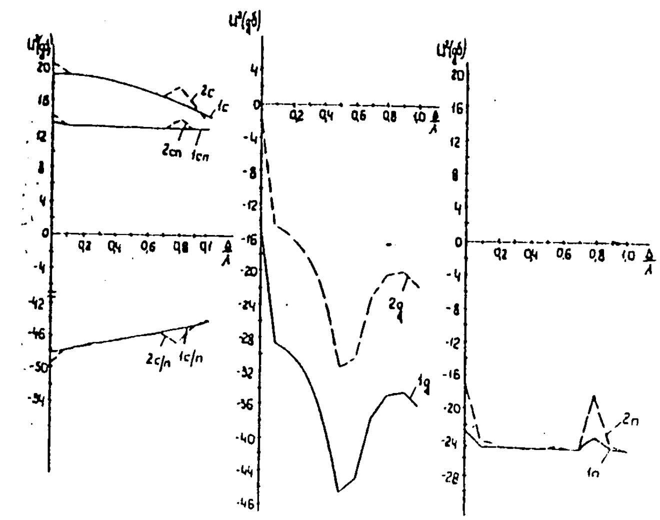


Figure 2.

of the increase in the contribution of the rereflected reverberation components there is an increase in the level of reverberation from the volumetric sources of 1-2 dB and from the surface and bottom sources of 5-6 and 10-15 dB, respectively, in addition to substantial reverberation penetrating through the side lobes (see the appearance of spikes on the curves):

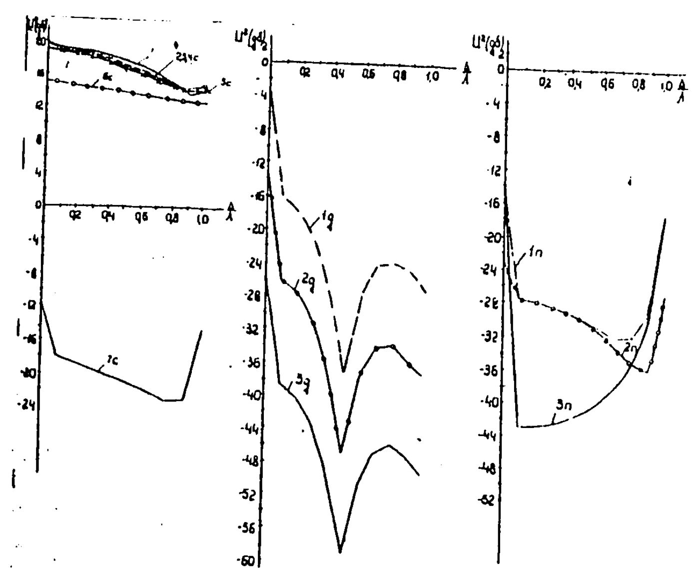


Figure 3.

Figure 3 depicts the results of an investigation of the effect of constricting the emitter's radiation pattern. The emitter has a sector radiation pattern with lobe widths $\Delta\Theta = 120^{\circ}, 60^{\circ}, 30^{\circ}, 15^{\circ}, 6^{\circ}$. The aureole's level was 0.1 of the level of the main lobe's power maximum. The volumetric scatterers were represented by 10 thin layers distributed equidistantly below the surface to a depth of 1,000 m. From Figure 3 it is obvious that for volumetric reverberation (curves 2-5c) as well as surface reverberation (curve 1s), narrowing of the radiation pattern from $\Delta\Theta = 120^{\circ}$ to $\Delta\Theta = 15^{\circ}$ has practically no effect on the reverberation level, while when it is narrowed to 6° (curve 6c) volumetric reverberation is reduced by 3 dB and surface reverberation (curve 2s) by 8 dB. There is a substantial reduction in the level of bottom reverberation (by about 10 dB) when the emitter's pattern is narrowed from $\Delta\Theta = 120^{\circ}$ to $\Delta\Theta = 60^{\circ}$ (curves 1b, 2b). Curve 1c characterizes filtration of the interference from the thin layer with its center at a depth of 500 m and a scattering power equivalent to that of the 10 thin, distributed plates discussed above for $\Delta\Theta = 120^{\circ}$. From a comparison of curves 1c and 2c it is obvious that the difference in spatial filtration for these models is not substantial for t = 10 s, which makes it possible to allow grosser approximations of the areas containing the volumetric irregularities. These same figures show the results of calculations taking into consideration the presence of the expressed scattering indicatrices of the reverberation sources. For the volumetric irregularities (curve 7c), when their correlation distance is increased from $\rho = 0$ to $\rho = 3\lambda/2\pi$, the interference level drops substantially (by about 30 dB). For bottom (curve 3b) and surface (curve 3s) reverberation there is also a reduction in the level of this interference (by about 10-15 dB) when the correlation distance is tripled ($\rho = 3\lambda/2\pi$).

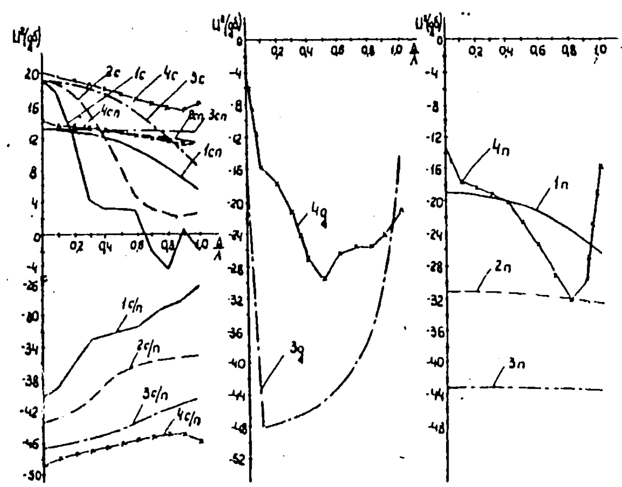


Figure 4.

Figure 4 illustrates the change in the efficiency of spatial interference filtration as time passes. Curves 1-4 correspond to the reception time moments t = 2, 4, 8 and 16 s. From the figure it is obvious that as time passes the effectiveness of the spatial filtration of reverberation interference deteriorates. We should also note the nonmonotonic change in the level of the reverberation components with time that is caused by the increase in the number of elements in these components as time passes, which is manifested particularly strongly for the surface reverberation components (drops in the level of up to 30 dB are possible). As far as anisotropic noise is concerned, its filtration improves with time. Let us mention

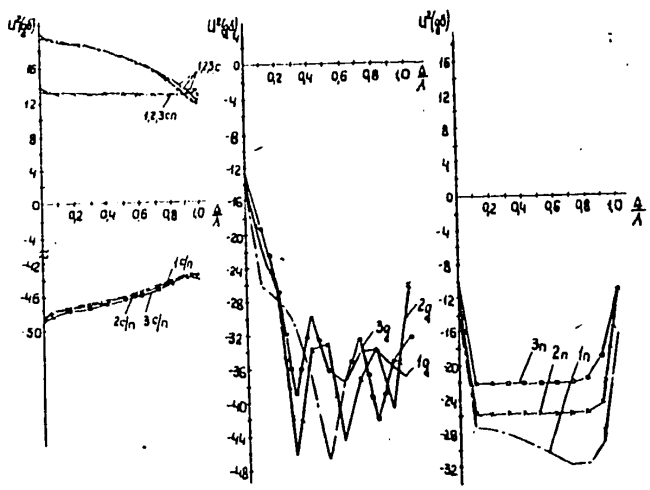


Figure 5.

here that as the waveguide's parameter H decreases, there is an analogous tendency for a change in the nature of the interference filtration with time, but beginning sooner.

Finally, Figure 5 depicts the results of a comparison of the combined surface layer system with the scattered system during the reception of the return signal from a fixed point in space. The emitter's radiation pattern had an aperture $\Delta\Theta = 15^{\circ}$. Curves 1, 2 and 3 reflect the change in the reception conditions when the emitter is submerged to the 3 previously indicated horizons and the reception horizon is fixed at $z_n = 300$ m. From the graphs it is obvious that the system with the deeply submerged emitter gives up almost nothing to a combined emission-reception system near the surface as far as the signal-to-noise ratio criterion is concerned.

From the results that were obtained the following conclusions can be drawn:
when the receiver is sunk deeper there is a substantial deterioration in the filtration of anisotropic interference from surface sources;
for reverberation interference, the components that have been reflected from the surface are substantial;
the surface reverberation level is essentially nonmonotonic with respect to time and increases as the receiver goes deeper;
a change in the bottom parameters within the limits allowable for a model of the "liquid soil" type results in tangible changes in the reverberation field's level and structure;
narrowing of the emitter's radiation pattern within a broad range of angles has little effect on the level and structure of reverberation;
the presence of scattering indicatrices at the reverberation interference sources leads to a substantial reduction in the level of this interference;
as time passes the efficiency of the spatial filtration of reverberation interference drops, while for anisotropic interference it improves;
a system with a deeply submerged emitter is insignificantly worse than a combined system near the surface when receiving a return signal from the same point in space.

BIBLIOGRAPHY

1. Fal'kovich, S.Ye., "Otsenka parametrov signala" /Evaluating Signal Parameters/, Moscow, Izdatel'stvo "Sovetskoye radio", 1970.

2. "Akustika okeana" /Ocean Acousti.../, Moscow, Izdatel'stvo "Nauka", 1974.

3. Bass, F.G., and Fuks, U.M., "Rasseyaniye voln na statisticheski nerovnoy poverkhnosti" /Wave Scattering on a Statistically Irregular Surface/, Moscow, Izdatel'stvo "Nauka", 1972.

4. Krizhanovskiy, V.V., and Pasechnyy, S.V., "Spatiotemporal Correlation of a Reverberation Interference Field," in "Trudy Vos'moy Vsesoyuznoy shkoly-seminara po statisticheskoy gidroakustike" /Works of the Eighth All-Union School-Seminar on Statistical Hydroacoustics/, Novosibirsk, 1977, pp 49-59.

DETECTING NOISE SIGNALS IN A LAYERED, HETEROGENEOUS MEDIUM WITH DISPERSED RECEIVERS

[Article by V. G. Berkuta and V. S. Pasechnyy pp 79-82]

/Text/ Let us discuss the problem of detecting noise signals with a group of receivers dispersed in space so that the interference between the processing areas $\vec{\Omega}_k$ and $\vec{\Omega}_m$ ($\vec{\Omega}_k \cap \vec{\Omega}_m = \phi$) is not correlated. We will assume that a Fraunhofer approximation is realized in each processing area $\vec{\Omega}_k$ ($k = 1,n$) and that the signal's wave front has an arbitrary shape between different areas. It can be shown that the algorithm for the optimum detection of steady-state Gaussian signals against a background of steady-state Gaussian interference, with full correlation of the signals between processing areas, has the form /1/

$$u_0 = \int_{-\infty}^{\infty} \left| K(\omega) \sum_{k=1}^{n} S_k(\omega) e^{-j\omega\tau_k} \int_{\vec{\Omega}_k} U(\omega;\vec{x}) L_k(\omega;\vec{x}) d\vec{x} \right|^2 d\omega, \quad (1)$$

where $L_k(\omega;\vec{x})$ is the solution of the integral equation

$$\int_{\vec{\Omega}_k} \rho(\omega;\vec{x},\vec{x}_1) L_k(\omega;\vec{x}_1) d\vec{x}_1 = e^{-j\omega\vec{d}_k x},$$

$$|K(\omega)|^2 = \frac{g_s(\omega)}{g_N^2(\omega)\left[1 + \frac{g_s(\omega)}{g_N(\omega)} \sum_{k=1}^{n} S_k^2(\omega) d_k(\omega)\right]}, \quad (2)$$

$$d_k(\omega) = \int_{\vec{\Omega}_k} L_k(\omega;\vec{x}) e^{j\omega\vec{d}_k\vec{x}} d\vec{x},$$

$\rho(\omega;\vec{x},\vec{x}_1)$ = spatial correlation function of the interference at frequency ω; $g_s(\omega)$, $g_N(\omega)$ = spectral densities of the signal's and interference's power, respectively; $\vec{d}_k = \vec{x}_5/(|\vec{x}_k|c)$; $\vec{x}_k$ = vector determining the location of the k-th area relative to the source; $\tau_k = |\vec{x}_k|/c$; c = average speed of signal propagation;

$$S_k^2(\omega) = \frac{1}{|x|^2} 10^{-0.1\beta|x_k|} \sum_{r=1}^{m} A_r;$$

$\sum_{r=1}^{m} A_r$ = anomalies of signal propagation in a layered, heterogeneous medium in the beam approximation; β = kilometric attenuation of the signal; m = number of beams reaching the k-th reception area.

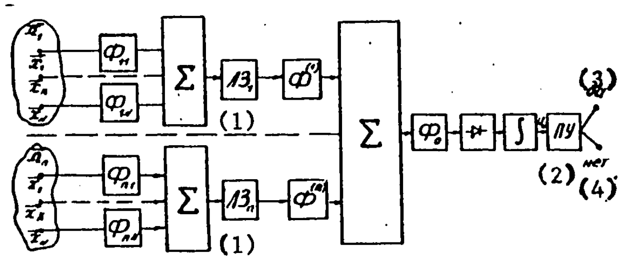


Figure 1. Block diagram of optimum receiver (1): $\Phi_{..}$ = filter with transmission factor $L_k(\omega;x_1)$; LZ_n = lag line for time $t_.$; $\Phi^{(1)}$ = filter with transmission factor $S_k(\omega)$; $\Phi_.$ = filter with transmission factor $k(\omega)$; PU = threshold unit.
Key: 1. LZ 2. PU 3. Yes 4. No
/Subscripts illegible/

Figure 1 is the block diagram of a receiver that realizes algorithm (1). In accordance with this diagram, in each area $\vec{\Omega}_k$ there is optimum spatial processing of a plane wave arriving from direction $\vec{\alpha}_k$. The amplitude-phase distribution of $L_k(\omega;\vec{x})$ in the k-th area is chosen with due consideration for the interference's spatial correlation function and the direction from which the signals arrive. The output voltages of the spatial channels are then delayed, filtered (by the filters with transmission factors $S_k(\omega)$ and, after summation, sent into the optimum temporal processing channel, which is realized according to a "filter-square law detector-integrator" arrangement.

Let us examine the case where the signals are not correlated between the processing areas. It can be shown that the optimum processing algorithm takes on the following form:

$$u_0 = \sum_{k=1}^{n} \int_{-\infty}^{\infty} |K_k(\omega) S_k(\omega) \int_{\vec{\Omega}_k} U(\omega;\vec{x}) L_k(\omega;\vec{x}) d\vec{x}|^2 d\omega, \quad (3)$$

where

$$|K_k(\omega)|^2 = \frac{g_s(\omega)}{g_N^2(\omega)[1 + \frac{g_s(\omega)}{g_N(\omega)} S_k^2(\omega) d_k(\omega)]}$$

Figure 2 is the block diagram of a receiver that realizes algorithm (3). In each area of space $\vec{\Omega}_k$ there is optimum spatial processing of a plane wave arriving from direction $\vec{\alpha}_k$. There then follows filtration (by the filters with the transmission

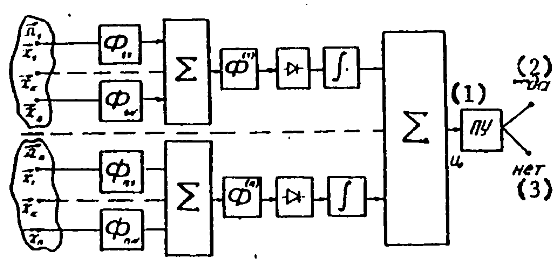


Figure 2. Block diagram of optimum receiver (3): $\Phi_{..}$ = filter with transmission factor $L_k(\omega;\vec{x}_1)$; $\Phi^{(n)}$ = filter with transmission factor $Q_k(\omega)$; PU = threshold unit.
Key: 1. PU 2. Yes 3. No
/subscripts illegible/

factor $Q_k(\omega) = K_k(\omega)S_k(\omega)$, detection and integration of the output effects of the spatial processing channels, after which the temporal processing channels' output voltages are stored.

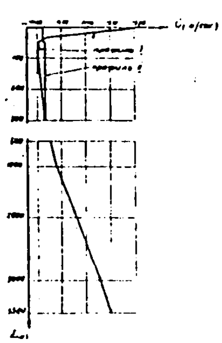


Figure 3.

Let us investigate the noise stability of the receivers synthesized above. As an efficiency criterion we will take the area (volume) of the detection zone, which is the area of space in which the probability D of correction detection in the system is no less than that given for a fixed probability F of a false alarm. Assigning the dependence D = D(x,y,z) on the spatial coordinates of a noise signal's source, 30 detection zones were calculated for the system, each of which consists of 2 spatially dispersed receivers. The 30 calculations were made for the cases of a homogeneous medium and a layered, heterogeneous medium characterized by the C-profiles shown in Figure 3. In the calculations the zones were normalized (with respect to the x- and y-axes) relative to the range of operation of a single receiver in a homogeneous medium. The dispersal of the receivers along the y-axis was $0.7z_0$. The probability of the system's correct detection was taken to be 0.9, while the probability of a false alarm was $F = 10^{-4}$.

An analysis of the 30 noise signal sources for the conditions of a homogeneous medium showed that the gain in the 30 areas for completely correlated signals is 2.5 times in comparison with a single receiver. However, receiver (1) is not very stable as far as variations in the input data are concerned, so that when there is discorrelation of the signals, area 30 (which corresponds to this receiver) is reduced by a factor of 1.7.

Receiver (3) does somewhat worse than receiver (1) in area 30 when fully correlated signals are being received, although its 30 are practically invariant to the degree of input signal correlation and exceed the 30 with a single receiver by a factor of 1.8.

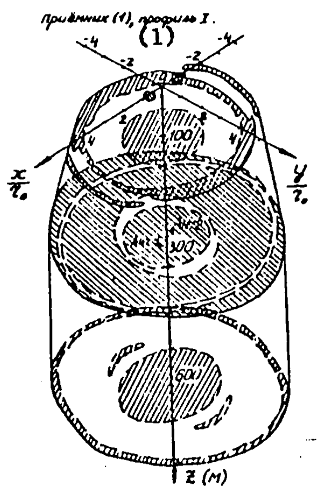


Figure 4.
Key: 1. Receiver (1), profile 1

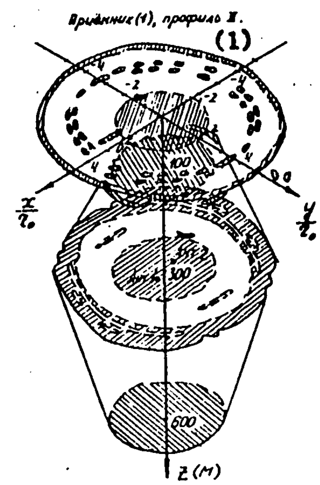


Figure 5.
Key: 1. Receiver (1), profile 2

Calculations of the 30 noise signal sources in a layered, heterogeneous medium showed that the noise stability of receivers (1) and (3) is practically identical. Because of its simpler technical realization, this makes receiver (3) preferable.

The 30 volumes of a noise signal picked up by a dispersed system in a layered, heterogeneous medium exceed those picked up by a single receiver in a homogeneous medium by an average factor of 16, which is basically explained by focusing of the sound. An analysis of the 30 for the sound propagation conditions described by the C-profiles in Figure 3 showed that although the 30 volumes have individual peculiarities, "continuous exposure" is maintained for all the cases under discussion for all practical purposes (Figures 4, 5).

BIBLIOGRAPHY

1. Berkuta, V.G., Krasnyy, L.G., and Pasechnyy, S.V., "Noise-Signal Detection by Spatially Dispersed Receivers," accepted for publication in RADIOTEKHNIKA I ELEKTRONIKA.

2. Berkuta, V.G., and Pasechnyy, S.V., "Signal Processing by a Scattered Group of Receivers." in "Trudy IX Vsesoyuznoy shkoly-seminar po statisticheskoy gidroakustike" /Works of the Ninth All-Union School-Seminar on Statistical Hydroacoustics/, Novosibirsk, 1978.

CONTROLLING THE POSITIONS OF RADIATION PATTERN ZEROES IN ANTENNA ARRAYS WITH DIGITAL SIGNAL PROCESSING

[Article by L. N. Danilevskiy, Yu. A. Domanov, O. V. Korobko and B. I. Tauroginskiy pp 83-85]

/Text/ Let us solve the problem of controlling the positions of radiation pattern (DN) zeroes while simultaneously providing a low side lobe level. We will make use of the amplitude weighting methods proposed in /1/. In order to control DN zeroes let us introduce additional limitations; namely, it is required that the amplitudinal DN be equal to zero at given points. In connection with this, by changing the sector value δ, it is also possible to change the level of the side lobes. For a linear antenna array with N elements, to problem comes down to minimizing the functional

$$Q(a_i) = \int_0^{\pi} P(\alpha)\sin\alpha d\alpha - \int_{\alpha_0-\delta}^{\alpha_0+\delta} P(\alpha)\sin\alpha d\alpha; \quad (1)$$

with the additional limitations $P(\alpha_m) = 0$; $m = 1,\ldots,M$;

$$\sum_{i=1}^{N} a_i = 1, \quad (2)$$

where $P(\alpha)$ = DN of an N-element antenna array that, with respect to power, has the form:

$$P(\alpha) = \sum_{i=1}^{N}\sum_{n=1}^{N} a_i a_n \exp\left[j\frac{2\pi}{\lambda}(x_i - x_n)\cos\alpha - (\tau_i - \tau_n)\right], \quad (3)$$

$$P_1(\alpha_m) = \sum_{i=1}^{N} a_i \exp\left(j\frac{2\pi}{\lambda}\cos\alpha_m - \tau_i\right),\ m = 1,\ldots,M, \quad (4)$$

x_i = coordinates of the array's i-th element; a_i = weighting factors; M = number of controlled DN zeroes; τ_i = discrete phase shift in the elements of the array, which equals:

$$\tau_i = \frac{\Delta\phi}{2}\sum_{s=-(k_1-1)}^{k_1-1} \operatorname{sign}\left(\frac{2\pi}{\lambda}x_i\cos\alpha_0 - s\Delta\phi\right), \quad (5)$$

where

$$k_1 = \text{Ent}\left[\frac{2\pi}{\lambda}\,\frac{(x_N - x_1)\cos\alpha_0}{\Delta\phi}\right],$$

$\Delta\phi$ = phase discreteness value.

Substituting (3) and (4) into (1), we obtain

$$Q(a_i) = \sum_{i=1}^{N} a_i^2 + \sum_{i=1}^{N}\sum_{n=1}^{N} a_i a_n \frac{\sin[(2\pi/\lambda)(x_i - x_n)]\cos(\tau_i - \tau_n)}{(2\pi/\lambda)(x_i - x_n)} - \sum_{i=1}^{N} a_i^2 \sin\alpha_0 \sin\delta -$$

$$\sum_{i=1}^{N}\sum_{n=1}^{N} a_i a_n \left\{\frac{\sin[(2\pi/\lambda)(x_i - x_n)\cos(\alpha_0 + \delta) - (\tau_i - \tau_n)] - \sin[(2\pi/\lambda)(x_i - x_n)\cos(\delta - \alpha_0) - (\tau_i - \tau_n)]}{(2\pi/\lambda)(x_i - x_n)}\right\}. \qquad (6)$$

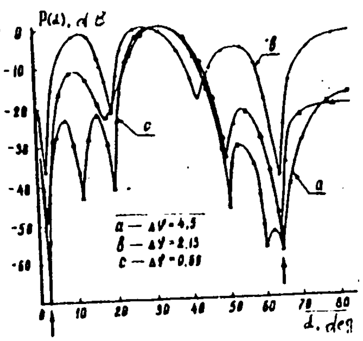


Figure 1.

In order to minimize the functional $Q(a_i)$ with additional limitations (2), we use the method of indeterminate Lagrange multipliers. As a result, we reach a system of equations that are linear with respect to a_i:

$$\frac{\partial Q}{\partial a_i} - \frac{\partial R}{\partial a_i} - \eta_m \frac{\partial P_1(\alpha_m)}{\partial a_i} = 0, \qquad (7)$$

where $R = \sum_{i=1}^{N} a_i - 1$; η, η_m = Lagrange coefficients. Figure 1 depicts DN's with two controlled zero positions that correspond to the weighting factor values that were computed during the solution of system of equations (7) for different phase discreteness values.

When amplitude quantization is taken into consideration, expressions (1)-(2) will be rewritten in the form

$$Q(a_i) = \frac{q^2}{2(2\pi)^2}\sum_{i=1}^{N}\sum_{n=1}^{N} a_i a_n \sum_{m=0}^{\infty}\frac{h_m(i)h_m(n)}{(2m+1)!} \times \left\{\int_0^{\pi}\rho_{in}^{2m+1}(\alpha)\sin\alpha\,d\alpha - \int_{\alpha_0-\delta}^{\alpha_0+\delta}\rho_{in}^{2m+1}(\alpha)\sin\alpha\,d\alpha,\right. \qquad (8)$$

with the additional limitations

$$\sum_{i=1}^{N} a_i = 1;\quad P_1(\alpha_m) = \sum_{i=1}^{N}\frac{q}{2}\left(\sum_{\ell=-(L-1)}^{L-1}\text{sign}\,\{\exp[\tfrac{2\pi}{\lambda}x_1(\cos\alpha_m - \cos\alpha_0)] - \ell q\}\right), \qquad (9)$$

where q = value of the quantization step, while the values of parameters $\rho_{ij}(\alpha)$, $h_m(i)$ and 2L are given in /2/. Substituting (8) and (9) into (7), we obtain a system of equations that are linear with respect to a_i, in which the unknown coefficients depend on the quantization parameters. The problem has been solved for a 12-element, linear, equidistant antenna array, with a different number of

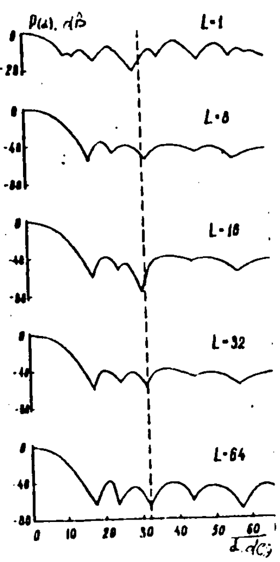


Figure 2.

quantization equations, for the case of control of a single DN zero. Several DN's are represented in Figure 2. It is obvious that for a small number of quantization equations, the exact setting of a DN zero in a given direction is not accomplished. The exact establishment of a DN zero turns out to be possible for L > 32.

Thus, the proposed amplitudinal weighting technique makes it possible to control the positions of zeroes in the DN's of antenna arrays with digital signal processing. In connection with this, there is precise establishment of the establishment of DN zeroes in a given direction for any phase discreteness values, although the level of the DN's side lobes increases substantially as $\Delta\phi$ does. Amplitudinal quantization of the input signals has a more substantial effect on the positions of DN zeroes. The precise establishment of a DN's zero in a given direction is possible for L > > 32.

BIBLIOGRAPHY

1. Wang, H.S.C., J. ACOUST. SOC. AMER., Vol 57, No 5, 1975, pp 1076-1084.

2. Baturitskiy, M.A., Danilevskiy, L.N., Domanov, Yu.A., and Korobko, O.V., RADIOTEKHNIKA I ELEKTRONIKA, No 2, 1978.

CONCENTRATION FACTOR OF A HORIZONTAL, LINEAR ANTENNA DURING MULTIBEAM PROPAGATION OF A NOISE SIGNAL IN THE SEA

[Article by V. I. Bardyshev and V. A. Yeliseyevnin pp 86-88]

/Text/ It is a well-known fact that the phenomenon of multibeamness leads to a decrease in the spatial correlation of a noise signal propagating in the sea when there is longitudinal (in the direction toward the source) dispersion of the hydrophones that pick it up. When working with a horizontal antenna, this results in the expansion of its radiation pattern and the reduction of the concentration factor. Below we present the results of calculations of the effect of the propagation conditions, which are described in /1,2/, on the value of the concentration factor of a horizontal, linear antenna.

A noise signal at audio frequencies, with a relative band width of about 12 percent, was propagated in the sea, under conditions of strongly developed multibeamness, at a distance of up to 29 km. The signal emission and reception points were located close to the underwater sound channel's axis. Signal fluctuation was insignificant, the signal-to-noise ratio was high, and the basic effect on the correlation of the received signal was exerted by its multibeam nature. The low coefficient of beam reflection from the muddy bottom and the presence of a well-developed thermocline resulted in severe attenuation of the bottom and surface reflections and the formation of a sonic field that was basically composed of refracted "water" beams concentrated along the underwater sound channel's axis. Transverse (relative to the direction to the emitter) dispersal of the hydrophones in the horizontal plane had no effect on the cross-correlation of the received signals. For longitudinal dispersal ΔL (along the direction to the emitter) of the hydrophones, the value of the maximum of the spatiotemporal cross-correlation factor R_m was reduced because of the distribution of the signal's energy relative to several correlation maximums corresponding to cross-correlation of signals arriving along different beams with differing propagation times. At distances of 20-29 km, R_m (ΔL) was described quite well by the empirical formula

$$R_m(\Delta L) = \begin{cases} 0.3 + 0.7 \exp -0.06(\Delta L/\lambda - 8), & \Delta L/\lambda > 8, \\ 1, & \Delta L/\lambda \leqslant 8, \end{cases} \quad (1)$$

where λ = the wavelength corresponding to the noise signal's central frequency.

The subject of discussion was a horizontal, linear, discrete, equidistant antenna consisting of N point, nondirectional hydrophones placed at intervals $d = \lambda/2$, where λ = length of the audio wave. The antenna's radiation pattern was rotated in the horizontal plane, through angle β, by a compensator that realized the time lag in the channel of each i-th hydrophone according to the law $\tau_i^k = (i - 1)(d/c)\sin \beta$, where C = the speed of sound. With several simplifying assumptions, the signal's correlation function at the antenna's output can be written in the form

$$B(\tau) = \sum_{i=1}^{N} \sum_{j=1}^{N} R_m(\Delta L_{ij})\langle u(t - \tau_1)u^*(t - \tau_j + \tau)\rangle, \qquad (2)$$

where the angular brackets designate temporal averaging; the asterisk a complexly conjugated expression; $u(t - \tau_1)$ = signal at the output of the i-th hydrophone, shifted by time $\tau_i = \tau_i^\phi - \tau_i^k$; $\tau_i^\phi = (i - 1)(d/c)\sin \alpha$ = time lag of the front of the wave in the channel of the i-th hydrophone, which is rotated toward the antenna at angle α; t = current time; τ = lag time.

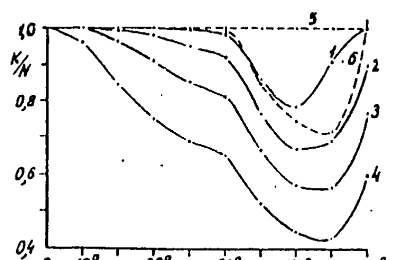
Assuming the emitted noise signal's spectrum to be constant in the frequency band (ω_1,ω_2) and equal to zero outside this band, by making the appropriate transformations it is possible to write the following expression for the antenna's radiation pattern with respect to power:

$$D(\alpha,\beta) = \frac{1}{N^2}[N + 2\sum_{i=1}^{N-1} (N - i)R_m(\Delta L_{ij})\cos V\frac{\sin PV}{PV}], \qquad (3)$$

where $V = 2\pi i(d/\lambda)(\sin \alpha - \sin \beta)$, $P = \Delta\omega/\omega_0$, $\omega_0 = (\omega_2 - \omega_1)/2$, $\Delta\omega = \omega_2 - \omega_1$. The antenna's concentration factor k was defined in terms of its radiation pattern by the well-known formula

$$k = 2[\int_{-\pi/2}^{\pi/2} D(\alpha,\beta)\cos \alpha d\alpha]^{-1}. \qquad (4)$$

During reception of a noise signal, along with the main lobe the antenna's radiation pattern has an "aureole" that reduces the antenna's concentration factor. Discorrelation of the audio signal leads to an additional reduction in the concentration factor.



The figure depicts the results of calculations of the dependence of k/n on the compensation angle β during reception of a noise signal ($\rho = 0.12$) that is discorrelated with respect to space according to expression (1), ɪ ɹr antennas with different numbers of elements (curves 1, 2, 3 and 4 correspond to N = 20, 60, 100 and 120, respectively). For comparison, curve 5 shows the dependence of k/n on β for N = = 100 and a tonal signal, while curve 6 does the same for a noise signal with ρ = 0.12 that is completely correlated throughout the antenna's entire aperture. It can be seen that the reduction in the signal's spatial correlation caused by the multibeam nature of the propagation leads to a 20-30 percent reduction in the concentration factor for compensation angles of 50°-90° for an antenna with an aperture of 50λ.

BIBLIOGRAPHY

1. Bardyshev, V.I., Vasil'yev, N.A., and Gershman, S.G., "Investigation of the Coherency of a Continuous Audio Signal in the Sea," AKUSTICHESKIY ZHURNAL, No 3, 1970.

2. Bardyshev, V.I., and Gershman, S.G., "On the Horizontal Correlation of a Noise Signal," in "Tezisy dokladov vos'moy Vsesoyuznoy Akustisheckoy konferentsii" /Summaries of Reports Given at the Eighth All-Union Acoustics Conference/, Moscow, 1973.

PASSIVE AND ACTIVE INVERSE SYNTHESIS OF THE APERTURE IN DISPERSED SYSTEMS

[Article by V. V. Karavayev and V. V. Sazonov pp 88-90]

/Text/ The research on active synthesis of an aperture that is available in the literature is limited to the case where the locations of the receiver and the transmitter coincide. For passive systems, the problem was solved in the first approximation according to the ratio of the system's base (the distance between the positions) to the distance involved. Both of these problems were discussed in /1/. The second-order effects relative to the indicated ratio were taken into consideration only in /2/, where only several special cases of the problem's geometry were examined.

In applied problems, on the other hand, a hydroacoustically observable moving object can turn out to be at distances comparable with the base of a dispersed system (active or passive). This report is devoted to an analysis of this phenomenon, which is a case that has not previously been discussed in the literature. We will show that in the active case, two-position synthesis has a number of fundamental special features in comparison with the traditional one-position variety.

The maximum resolution of systems is described by an ambiguity function. As was shown in /1/, it is given by the expression

$$I(\vec{\Delta}) = \frac{1}{N}\left|\int \exp\{i[\phi(t,0) - \phi(t,\vec{\Delta})]\}dt\right|^2, \quad (1)$$

where N = normalizing multiplier, selected so that I(0) = 1; integration is carried out with respect to observation time; $\phi(t,\vec{\Delta})$ = phase of the received oscillation, which depends on the moment of observation t (because of the movement of the source or base) and the displacement of this source relative to some selected point 0. In active systems, $\phi(t,\vec{\Delta})$ must be understood as the phase of the reflected signal in the receiver (we are not discussing effects related to modulation of the transmitter, since they do not effect the synthesis process). In a passive system, however, $\phi(t,\vec{\Delta})$ is the phase difference between the first and second receivers on which the noise emissions of a random, delta-correlated source act.

If we designate as $\vec{R}_1$ the radius vector of the indicated zero point that leads from the transmitter (the first receiving position of a passive system), as $\vec{R}_2$ the radius vector of that same point that leads from the receiver (the second receiving point in a passive system), as $\vec{L}(t)$ the vector from point 0 that describes the source's motion, and as $\vec{N}$ the unit vector perpendicular to the plane formed by vectors $\vec{R}_1$ and $\vec{R}_2$, in the Fresnel approximation for the source's movement relative to point 0 we find

$$\phi(t,0) - \phi(t,\vec{\Delta}) = \frac{\omega}{c}\,\vec{L}(t)\hat{M}\vec{\Delta}, \tag{2}$$

where $\hat{M}$ = an operator that in dyad notation has the form

$$\hat{M} = \frac{1}{R_1}|\vec{\nu}_1><\vec{\nu}_1| \pm \frac{1}{R_2}|\vec{\nu}_2><\vec{\nu}_2| + \left(\frac{1}{R_1} \pm \frac{1}{R_2}\right)|\vec{N}><\vec{N}|, \tag{3}$$

it being the case that $\vec{\nu}_1 = \frac{1}{R_1}[\vec{N}\vec{R}_1]$, $\vec{\nu}_2 = \frac{1}{R_2}[\vec{N}\vec{R}_2]$. The "+" sign applies to active synthesis, the "-" sign to passive.

For a short synthesis time, the source's motion relative to the receiving-transmitting system (or this system's motion relative to the source) can be regarded as rectilinear and uniform. This simplifies the formulas substantially, and for the ambiguity function we find

$$I(\vec{\Delta}) = \sin^2 L\Delta\frac{\omega}{2c}\rho \,|\, (L\Delta\frac{\omega}{2c}\rho)^2,$$

where $\rho = \vec{\delta}\hat{M}\vec{\ell}$; $\vec{\delta}$ = unit vector in the direction of resolution $\vec{\Delta}$; Δ = the modulus of vector $\vec{\Delta}$; $\vec{\ell}$ = unit vector in the direction of the source's motion; L = the path covered by the source during the observation time (the length of the synthesized aperture).

From formula (3) it follows that if the direction of synthesis is perpendicular to $\vec{R}_1$ and $\vec{R}_2$, resolution is achieved in the same direction. In connection with this, the value of ρ is $(\frac{1}{R_1} \pm \frac{1}{R_2})$.

In other cases this is not so and, generally speaking, resolution is achieved in a direction different from that of the source's motion. This effect is described by the nondiagonal part of operator $\hat{M}$, which is

$$\hat{\mathcal{M}} = \frac{1}{R_1}|\vec{\nu}_1><\vec{\nu}_1| \pm \frac{1}{R_2}|\vec{\nu}_2><\vec{\nu}_2|.$$

The natural system of coordinates for the problem under discussion is elliptical. Let vector $\vec{\ell}$ be directed along the tangent to the ellipse at point 0. In connection with this, it can be written in the form

$$\vec{\ell} = (\vec{\nu}_1 + \vec{\nu}_2)/2(1 + \cos\Theta), \quad \cos\Theta = (\vec{\nu}_1\vec{\nu}_2).$$

In connection with this, $\vec{M\ell} = \frac{1}{2}(\frac{\vec{\nu}_1}{R_1} \pm \frac{\vec{\nu}_2}{R_2})$. The length of this vector determines the resolution value; it equals

$$\frac{1}{2}\sqrt{\frac{1}{R_1^2} + \frac{1}{R_2^2} \mp \frac{2\cos\Theta}{R_1 R_2}}.$$

If the velocity vector is directed along the normal to the ellipse (along the normal to the conjugated hyperbola), resolution is achieved along the vector

$$\tilde{M}\vec{\ell} = (\frac{\vec{\nu}_1}{R_2} \mp \frac{\vec{\nu}_2}{R_2}),$$

the length of which is $(\frac{1}{R_1^2} + \frac{1}{R_2^2} \mp \frac{2\cos\Theta}{R_1 R_2})^{1/2}/2$.

The elliptical system of coordinates is not the main one for operator $\tilde{M}$, so its axis does not coincide with the directions of maximum resolution. It is easy to show that the maximum of the bilinear form $\rho = \vec{\delta}\hat{M}\vec{\ell}$ is achieved if both $\vec{\ell}$ and $\vec{\delta}$ are latent vectors of operator $\tilde{M}$. Uncomplicated computations demonstrate that with vectors $\vec{n}_1$ and $\vec{n}_2$, this operator's latent vectors form angles α_1 and α_2, the cosines of which are found in the relationship

$$\frac{\cos\alpha_1}{\cos\alpha_2} = -\frac{(1 \mp \gamma)\sqrt{(1 \pm \gamma)^2 + 4\sin^2\Theta}}{2\gamma\cos\Theta},$$

($\gamma = R_1/R_2$, while Θ is the angle between $\vec{R}_1$ and $\vec{R}_2$). In the formula, the signs "$\pm$" in front of the radical apply to the first and second latent vectors, while the signs in the expression "1 ∓ " apply to the active (the first) and passive (the second) synthesis modes. The value of the resolution that is achieved is determined by the eigenvalues of operator $\tilde{M}$. They are different for the two latent vectors and equal

$$\lambda_{1,2} = \frac{1}{2}[(\frac{1}{R_1} \pm \frac{1}{R_2}) \pm \sqrt{(\frac{1}{R_1} \pm \frac{1}{R_2})^2 \mp \frac{4\sin^2\Theta}{R_1 R_2}}].$$

BIBLIOGRAPHY

1. Karavayev, V.V., and Sazonov, V.V., "Osnovy teorii sintezirovannykh antenn" /Principles of the Theory of Synthesized Antennas/, Moscow, Izdatel'stvo "Sovetskoye radio", 1974.

2. Mel'nik, Yu.A., IZVESTIYA VUZOV, RADIOFIZIKA, No 9, 1972, pp 1376-1379.

RELATIONSHIP BETWEEN RESULTS OF OPTIMAL AND NONOPTIMAL PROCESSING OF BROAD-BAND SIGNALS RECEIVED BY A SCANNING ANTENNA

[Article by B. M. Salin pp 90-92]

/Text/ This work is a continuation of /1/, in which we discussed several methods for processing broad-band noise signals received by an angularly scanning linear antenna operating in the passive mode. We discussed an antenna with a radiation pattern $\Gamma(\omega,\phi)$ that depends on the received signal's frequency ω. With several assumptions about the statistical properties of the signal, noise and antenna's scanning rate v, the optimum (according to the criterion of a maximum signal-to-noise ratio) algorithm is one that carries out cross-correlation processing of the sliding spectrum of the output of an antenna with a function in the form /1/:

$$K(\omega,t,\phi) = |\Gamma(\omega;vt - \phi)|^2 \cdot S_s(\omega)/S_n^2(\omega,t) \text{ (plan 1)},$$

where S_s and S_n are the spectral densities of the signal's and noise's power, respectively. In /1/ it was also shown that for the case of spatially istropic noise, optimal processing can be successfully replaced, with a small decline in the signal-to-noise ratio, with standard signal processing with plan 2, which is a filter, a square-law detector and an integrator, it being the case that the loss is determined by the expression /1/

$$\hat{Q}/Q = \mu_1'(\int\int|\tilde{\Gamma}|^4 d\omega d\phi)^{-1/2}, \quad (1)$$

where $\hat{Q}$ and Q are the signal-to-noise ratio at the output of the processing unit realizing plans 2 and 1, respectively, and

$$|\tilde{\Gamma}|^2 = |\Gamma(\omega,\phi)\ ^2 \cdot S_s(\omega)/S_n(\omega),$$

μ_1^2 = greatest eigenvalue of the integral operator with the series

$$\int|\tilde{\Gamma}(\omega,\phi_1)|^2|\tilde{\Gamma}(\omega,\phi_2)\ ^2 d\omega.$$

The purpose of the present article is to evaluate the minimum values of (1) for various combinations of $|\Gamma|^2$, S_s and S_n and to determine the areas of utility of the optimum and quasioptimum (plan 2) processing algorithms.

In order to find the eigenfunctions and eigenvalues of $|\tilde{\Gamma}|^2$ in analytical form, two radiation pattern types were used:

$$\text{I. } |\tilde{\Gamma}|^2 = \sum_{i=1}^{N} A_i e^{-a_i^2\phi} \cdot \chi_i(\omega); \qquad (2)$$

$$\text{II. } |\tilde{\Gamma}|^2 = \sum_{i=1}^{N} A_i \cdot \chi_i(\phi)\chi_i(\omega), \qquad (3)$$

where

$$\chi_i(\omega) = \begin{matrix} 0 \\ 1, \ \Delta\omega i < \omega < \Delta\omega(i+1); \end{matrix} \quad \chi_i(\phi) = \begin{matrix} 0 \\ 1, \ |\phi| = 1(1+\alpha i). \end{matrix}$$

The dependence of the radiation pattern's width on the frequency was selected in the form $a_i^2 = 1 + \alpha(i - 1)$, with the actual case corresponding to the value $\alpha \simeq 1$. As calculations have shown, the minimum values of μ_1^2 are achieved for the following forms of noise and signal spectra: $A_j^2 = a_i\sqrt{2}/\Delta\omega\sqrt{\pi}$ (the first case) and $A_i = (1 + \alpha i)/\Delta\omega$. Table 1 shows the values of loss $\hat{Q}/Q$ that are obtained when using the given values of $\tilde{\Gamma}(\omega,\phi)$, as a function of parameter α and the number of splitting elements N.

Table 1.

Form of $\|\tilde{\Gamma}\|^2$		I	I	II	II	II
α	N	10	30	3	10	50
2/N - 1		0.97	0.98			
9/N - 1		0.93	0.94	0.82	0.85	0.86
49/N - 1		0.89	0.91	0.77	0.82	0.84

By summing up the data in the table, it is possible to draw the conclusion that for the case of steady-state noise at the antenna's output that does not depend on the direction of the antenna's central beam, processing with the filter-square law detector-integrator setup is not more than 2-3 dB less than optimal when the parameters of the filter and the integrating element are chosen correctly.

BIBLIOGRAPHY

1. Antonets, M.A., and Salin, B.M., "On the Question of Selecting the Optimum Parameters of the Integrating Unit When Processing Broad-Band Signals Received by a Scanning Antenna," TRUDY SG-9, Novosibirsk, 1977.

ON ADAPTIVE OPTIMIZATION OF THE DETECTION ALGORITHM IN A SPATIOTEMPORAL INFORMATION PROCESSING SYSTEM

[Article by V. G. Gusev and Ye. V. Cherenkova pp 92-94]

/Text/ The problem of adaptive optimization of spatiotemporal processing systems is an area of research about which much has been written /1/, although--in our opinion--two propositions in the basic works /2,3/ are in need of refinement and development.

1. It is important to have a solution for the problem of synthesis without an indicated limitation, so that the transfer function of a multidimensional continuous filter will then be that theoretical standard /4/ that is necessary for the practical selection of the indicated parameters of the corresponding multidimensional discrete filter that is actually realized by the digital method. In order to solve this problem, let us examine an antenna array with M elements, at the input of which is given a multidimensional random process $X(t) = S(t) + N(t) + P(t)$, the components of which (the signal, isotropic noise and local interference, respectively) are random processes with given spectral density matrices $G_S(j\omega)$, $G_N(j\omega)$ and $G_P(j\omega)$. All of them are Hermitian matrices, it being the case that

$$G_S(j\omega) = g_S(\omega)\bar{L}_S(j\omega)L_S^T(j\omega);\ G_P(j\omega) = g_P(\omega)\bar{L}_P(j\omega)L_P^T(j\omega), \qquad (1)$$

where $g_S(\omega)$ = power spectrum of the signal, while the m-th element of vector $L_S(j\omega)$ is $\exp(-j\omega\tau_m)$; τ_m = time lag between the m-th element of the array and the corresponding point on the signal wave's plane front; for local interference the variables $g_P(\omega)$, $L_P(j\omega)$, $\exp(-j\omega\Theta_m)$ and Θ_m have analogous meanings. The signs "-" and "T" mean conjugation and transposition.

The information processing system under discussion (Figure 1) is a multidimensional spatiotemporal filter. The filters' transfer functions $H_m(j\omega)(m = 1,\ldots,M)$ must be defined so as to maximize the ratio of the increase in the mathematical expectation of the variable z at the low-frequency filter's output (caused by the signal) to the effective value of the fluctuations in this same variable that appear when it is acted upon by all three processes. This ratio can then be represented in the

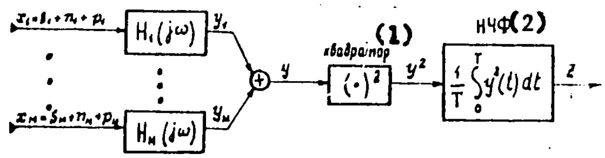


Figure 1.

Key: 1. Square-law generator
2. Low-frequency filter

form

$$Q = (\frac{T}{4\pi})^{-1/2} \int_{-\infty}^{\infty} \bar{H}^T(j\omega)G_S(j\omega)H(j\omega)d\omega\{\int_{-\infty}^{\infty} [\bar{H}^T(j\omega)G_X(j\omega)H(j\omega)\}^2 d\omega]^{-1/2}, \quad (2)$$

where $G_X = G_S + G_N + G_P$: H = vector with the component H_m. Relationship (2) is a functional of the vector function $H(j\omega)$. Having expressed the quadratic forms in (2) in terms of spurs of matrices, it is not difficult to obtain the solution to the corresponding variational problem, as a result of which we find the optimum transfer function of a continuous, multidimensional filter:

$$H(j\omega) = \sqrt{g_S(\omega)}G^{-1}_X(j\omega)\bar{L}_S(j\omega). \quad (3)$$

2. When realizing filters $H_m(j\omega)$ based on multibranch delay lines by the discrete method [2], their transfer functions take on the form

$$H^*_m(j\omega) = \sum_{\ell=0}^{L} h_m(\ell\Delta)e^{-j\omega\Delta\ell}, \quad (4)$$

where the number of time delays L corresponds to the order of the discrete, non-recursive filter, while the unit lag Δ is the quantification interval. For fixed parameters L and Δ, the weighting factors $h_m(\ell\Delta)$ are determined on the basis of the minimum of the integral quadratic error of the approximation of the optimum function $H_m(j\omega)$ with the help of $H^*_m(j\omega)$ (5). We then find that

$$h_m(\ell\Delta) = \frac{\Delta}{\pi} \int_0^{\Delta/\pi} A_m(\omega)\cos\ [\Phi_m(\omega) + \omega\Delta\ell]d\omega, \quad (5)$$

where $A_m(\omega) = \mathrm{mod}\ H_m(j\omega)$; $\Phi_m = \arg H_m(j\omega)$. Assuming that the spectra of the input effects are limited by frequency ω_6, the quantification interval is $\Delta < \pi/\omega_6$ and relationship (2) for the case of a discrete, multidimensional filter acquires the form

$$Q^* = (\frac{T}{4\pi})^{1/2} \int_{-\pi/\Delta}^{\pi/\Delta} \bar{H}^{*T}(j\omega)G_S(j\omega)H^*(j\omega)d\omega\{\int_{-\pi/\Delta}^{\pi/\Delta} [\bar{H}^{*T}(j\omega)G_X(j\omega)H^*(j\omega)]^2 d\omega\}^{-1/2}. \quad (6)$$

An approximate realization of vector function $H(j\omega)$ with the help of $H^*(j\omega)$ results in $Q^* < Q$, it being the case that the larger L and the smaller Δ are, the smaller the losses. Starting from the permissible losses, it is possible to make a substantiated selection of the indicated parameters by analyzing the entire set of interference-signal situations.

3. Let us now modify the adaptive optimization procedure proposed in /3/ for (Vinerovskaya) filtration, as applicable to the detection problem. In this work, the variance of the signal filtration error at the output of the summator in the system in Figure 1 is minimized; that is, error $\varepsilon(t) = y(t) - s(t)$. Let us designate the optimum transfer vector function in this case as $W(j\omega)$. It is not difficult to show that the spectrum of error $\varepsilon(t)$'s power is

$$g_\varepsilon(\omega) = \bar{W}^T(j\omega)G_X(j\omega)W(j\omega) - 2g_S(\omega)\mathrm{Re}\,[W^T(j\omega)L_S(j\omega)] + g_S(\omega). \tag{7}$$

From this it is obvious that error variance $\sigma_\varepsilon^2 = \frac{1}{2\pi}\int_{-\infty}^{\infty} g_r(\omega)d\omega$ is a functional of the quadratic type of vector function $W(j\omega)$. Having solved the corresponding variational problem, we find the multidimensional filter's optimum transfer function

$$W(j\omega) = g_S(\omega)G_X^{-1}(j\omega)\bar{L}_S(j\omega). \tag{8}$$

From a comparison of expressions (3) and (9) /sic/ it is obvious that

$$H(j\omega) = \sqrt{g_S(\omega)}W(j\omega), \tag{9}$$

that is, the indicated vector functions coincide with each other with an accuracy up to that of the scalar multiplier. As a result there appears the practical possibility of a spatiotemporal processing system that maximizes relationship (2) by using as the adaptive procedure an algorithm that minimizes variance σ_ε^2. This fact is extremely important, since σ_ε^2 is a quadratic functional, the minimization of which is accomplished on the basis of a convenient iterative procedure /3/. Direct adaptive maximization of criterion (2) is difficult because of its nonlinearity (type of relationship).

4. What has been done above enables us to say that a spatiotemporal processing system that solves the problem of detection under conditions of local interference has a form similar to that of the system in Figure 1, where the multidimensional filter's transfer function is determined by equality (9), while after the summator there is a filter with the transfer function $(\sqrt{g_S(\omega)})^{-1}$. Discrete realization of the transfer function $W(j\omega)$ results in expressions similar to (5):

$$W_m^*(j\omega) = \sum_{\ell=0}^{L} w_m(\ell\Delta)e^{-j\omega\Delta\ell}, \tag{10}$$

it being the case that the adaptive procedure given in /3/ can be used to determine factors $w_m(\ell\Delta)$. Parameters L and Δ must be selected beforehand on the basis of the permissible losses of noise stability Q^* (7) in relation to Q (2).

BIBLIOGRAPHY

1. Belonozhko, G.N., and Ol'shevskiy, V.V., "Review of Adaptation Methods in Problems of Statistical Hydroacoustics," in "Trudy VI shkoly-seminara po statisticheskoy gidroakustike" /Works of the Sixth School-Seminar on Statistical Hydroacoustics/, Novosibirsk, 1975.

2. Undrou, B., et al., "Adaptivnyye antennyye sistemy" /Adaptive Antenna Systems/, TIIER /expansion unknown/, No 12, 1967.

3. Griffits, L., "A Simple Adaptive Algorithm for Processing Antenna Array Signals in Real Time," TIIER, No 10, 1969.

4. Gusev, V.G., "Metody issledovaniya tochnosti tsifrovykh avtomaticheskikh sistem" /Methods for Investigating the Accuracy of Digital Automatic Systems/, Izdatel'stvo "Nauka", 1973.

ON THE STRUCTURE OF AN ADAPTIVE GONIOMETER

[Article by Yu. K. Vyboldin and L. A. Reshetov pp 95-96]

/Text/ Let us synthesize a multidimensional discriminating device. At the antenna's input let there be an additive mixture of signal and Gaussian steady-state noise fields with a zero average and a known covariance matrix. By analyzing the frequency area, with accuracy up to that of a constant factor we can write the logarithm of the functional of the probability relationship as

$$Q[\vec{X}(\omega),\vec{\alpha}] = \frac{1}{2\pi}\int_{-\infty}^{\infty}[\vec{X}(\omega) - \vec{W}(\omega,\vec{\alpha})]^{*}N^{-1}(\omega)[X(\omega) - W(\omega,\vec{\alpha})]dw, \quad (1)$$

where the asterisk designates a Hermitian-conjugated matrix; $\vec{X}(\omega)$, $\vec{W}(\omega)$ = Fourier transform of the realization and the form of the input signal, respectively; $\vec{N}^{-1}(\omega)$ = inverse matrix of the noise's spectral matrix. If the model of signal $\vec{S}(\omega,\vec{\alpha})$ can be represented as the result of matrix transformation $\vec{S}(\omega,\vec{\alpha}) = \vec{U}(\omega,\vec{\alpha})\vec{\beta}(\omega)$, the evaluation of the least square of the vector $\vec{\beta}(\omega)$ of the emitted signal's shape that minimizes the functional Q has the form /1/

$$\vec{\beta}(\omega) = \vec{P}^{-1}(\omega)\vec{C}(\omega), \quad (2)$$

$\vec{P}(\omega) = \vec{U}^{*}(\omega)\vec{N}^{-1}(\omega)\vec{U}(\omega)$, $\vec{C}(\omega) = \vec{U}^{*}(\omega)\vec{N}^{-1}(\omega)\vec{X}(\omega)$ and, consequently, the estimate of the signal at the antenna is

$$\vec{H}(\omega) = \hat{\vec{S}}(\omega) = \vec{U}(\omega)\vec{\beta}(\omega). \quad (3)$$

For the case of measurement of the angular coordinates of many sources of signals of unknown shape, the expression for the optimum statistics can be written /2/ as

$$\lambda[\vec{X}(\omega),\vec{\alpha}] = \frac{1}{2\pi}\int_{-\infty}^{\infty}\vec{C}^{*}(\omega)\vec{P}^{-1}(\omega)\vec{C}(\omega)d\omega. \quad (4)$$

In order to construct a discriminating goniometric system, let us assume that the deviation of the reference value of parameter $\vec{\alpha}_0$ from the true value $\vec{\alpha}_*$ is not great. If we assume that the fluctuational part of functional λ is considerably less than the mathematical expectation of this functional, we can represent λ as a Taylor series in degrees of $\Delta\alpha$. In connection with this,

$$\vec{\alpha} = \vec{\alpha}_0 + \vec{G}^{-1}\vec{H}, \qquad (5)$$

where $\vec{H}$ = column vector of the functional's first derivatives with respect to the parameter being measured; $\vec{G}^{-1}$ = the matrix that is the inverse of the matrix of the second derivatives of λ, with a minus sign.

From (5) it is obvious that the goniometer's structure will be basically determined by elements the elements $\vec{H}$. In order to find them, let us represent $\vec{U}$ in the form of the sum of matrices with zero elements in all columns with the exception of the m-th column, $\vec{U} = \sum_{m=1}^{M} \vec{A}_m$. Let us designate the following matrix as $\vec{R}_m$:

$$R_m = \mathrm{diag}\ \{\frac{\partial}{\partial\alpha_m}[Z_k(\omega,\alpha_m) + j\frac{\omega}{c}\varepsilon_{k0}(\omega,\alpha_m)]\}, \qquad (6)$$

where $Z_k(\omega,\alpha_m)$ = integrated radiation pattern of the k-th element of the antenna on frequency ω, $\varepsilon_{k0}(\omega,\vec{\alpha}_m)$ = spatial lag, in the direction toward the m-th source, between the k-th element and the antenna's phase center on frequency ω; M = total number of emission sources. It is then the case that

$$H = \frac{1}{2\pi}\int_{-\infty}^{\infty} \vec{X}^{*}\vec{N}^{-1}\{\vec{I} - [\vec{U}\vec{P}^{-1}\vec{U}\vec{N}^{-1}]\vec{R}_m\vec{A}_m\vec{P}^{-1}\vec{U}^{*} + \vec{U}\vec{P}^{-1}\vec{A}_m^{*}\vec{R}_m^{*}[\vec{I} - \vec{N}^{-1}\vec{U}\vec{P}^{-1}\vec{U}^{*}]\vec{N}^{-1}\vec{X}d\omega, \qquad (7)$$

where $\vec{I}$ = a unit matrix.

In the case of the reception of a signal from a single source (M = 1) on an antenna consisting of nondirection receivers with unit sensitivity $Z_k(\omega,\alpha) = 1$ and a distance h between elements, from formula (7) we obtain

$$H = \frac{1}{2\pi}\cdot\frac{h\cos\alpha}{CLN_0}\int_{-\infty}^{\infty}\vec{X}^{*}(\omega)\|(k - p)\exp\ [j\frac{\omega}{c}h(k - p)\sin\alpha_0]\|[j\omega\vec{X}(\omega)]d\omega, \qquad (8)$$

where L = total number of receivers in the antenna; k, p = 1,...,L. Analogously, by computing the elements of $\vec{G}^{-1}$ we obtain

$$\langle G\rangle = \frac{1}{2\pi}(\frac{\Delta\omega_e h}{c}\cos\alpha_0)^2 q[\frac{L}{8}(L^2 - 1)], \qquad (9)$$

where $q = \int_{-\infty}^{\infty}|\beta(\omega)|^2\omega^2 d\omega/N_0\Delta\omega_e^2$ = spectral signal-to-noise ratio; $\Delta\omega_e$ = energy band of the signal. From (8) it follows that in order to construct a discriminating goniometric system for a signal of unknown shape, we should set the antenna's radiation pattern in the direction toward the source of the signal and organize cross-correlation processing between the signal at the k-th channel's outlet with the derivative of the signal at the p-th channel's output. Comparing the obtained structure with that of a goniometer used for the processing of signals with known covariance, we see that in our case, at the output of the receiving channels there are no filters that are matched with the signal's energy band.

BIBLIOGRAPHY

1. Schweppe, F.C., IEEE TRANS. INF THEORY, IT-14, 1968, p 3.

2. Agranovskiy, K.Yu., Vyboldin, Yu.K., and Reshetov, L.A., "Vtoraya Dal'nevostochnaya akusticheskaya konferentsiya 'Chelovek i okean'" /Second Far Eastern Acoustics Conference on "Man and the Ocean"/, Vladivostok, 1978.

HOLOGRAPHIC METHODS FOR SPECTRAL ANALYSIS OF RANDOM SONIC FIELDS

[Article by B. I. Mel'treger and Ye. I. Kheyfets pp 97-99]

/Text/ In order to carry out spectral analysis with the help of holographic methods, information about a sonic field is represented in the form of changes in optical thickness or transparency in a hologram. When it is reproduced in coherent light in the rear focal plane of the lens, which is set behind the hologram, there appears a light pattern, the analysis of which makes it possible to evaluate the spectral characteristics of the sonic field. The methods of greatest interest are those in which the hologram represents an instantaneous sampling of the field /1,2/ or temporal changes in the field at the receiving aperture /2,3/. In the first case, the hologram's carrier is a multichannel light modulator controlled by signals from a receiving array. When there is weak modulation of the light field, inertial registration of the distribution of the light's intensity in the Fourier plane (u,w) of the lens makes it possible to evaluate y_1 of the projection $C(\alpha)$ of the field's angular spectrum $C(\vec{\ell})$ for a narrow band of temporal frequencies and to evaluate y_2 of the temporal spectrum for a narrow angular spectrum concentrated near $\gamma = (\vec{\ell},n) \neq 0$, where $\vec{\ell}$ = unit vector of the wave vector, $\vec{n}$ = normal to the receiving array, $\alpha = \sin \gamma$. In the second method signals are recorded in the form of parallel tracks on the hologram carrier (photographic film, for example) that is moved along the direction of the tracks during reproduction. Inertial registration of the light's intensity $I(\rho,\phi)$ makes it possible to evaluate y_3 of the projection $F(\omega,\alpha)$ of the spectral-angular density of the field's dispersion $F(\omega,\vec{\ell})$, where ρ and ϕ are polar coordinates in the (u,w) plane. Besides this, analysis of the light pattern makes it possible to evaluate y_4 of the projection $C(\alpha)$ of the field's angular spectrum $C(\vec{\ell}) = F(\omega,\vec{\ell})d\omega$.

In order to ascertain the quality of these evaluations, assuming that the random sonic field is a steady-state one and subject to the normal distribution law, expressions have been derived for the statistical moments of the first and second orders. If the field is created by noncorrelated sources located in the receiving aperture's far zone, the average (for realizations of the field) light intensity in the reproduced picture is composed of three parts, one of which is caused by the optical carrier alone, while the other two, which are symmetrical relative to point u = 0, w = 0, represent the field's spectrum. Calculations and experimental investigations have shown that the evaluations that are obtained can be regarded as asymptotically unskewed, for all practical purposes. An analysis of the expressions describing the relative dispersion of the fluctuations in the evaluations of y_q, q = 1,...,4, shows that for all the evaluations under discussion the following relationship is fulfilled: $(\langle y_q^2 \rangle - \langle y_q \rangle^2)/\langle y_q \rangle^2_{TL \to \infty} \to 0$, where T is the registration time and L is the aperture size of the receiving array; that is, the evaluations are valid. Thus, holographic methods are an effective means for the parallel spectral analysis of random sonic fields.

BIBLIOGRAPHY

1. Shenderov, Ye.L., "Formation of Sonic Images in a Phase Holographic System," in "Radio- i akusticheskaya golografiya" /Radio- and Acoustic Holography/, Leningrad, Izdatel'stvo "Nauka", 1976.

2. Svet, V.D., "Metody akusticheskoy golografii" /Methods of Acoustic Holography/, Leningrad, Izdatel'stvo "Rumb", 1976.

3. Penn, V.A., and Chovan, V.L., "Utilization of Holographic Methods in Hydrolocation," in "Akusticheskaya golografiya" /Acoustic Holography/, Leningrad, Izdatel'stvo "Sudostroyeniye", 1975.

ON THE EFFECT OF LARGE-SCALE NONUNIFORMITIES IN THE REFRACTIVE INDEX ON SHIFTS IN EVALUATIONS OF OPTIMUM GONIOMETRIC SYSTEMS

[Article by M. I. Levin, L. A. Reshetov and G. Kh. Takidi pp 99-100]

/Text/ In this article, on the basis of the method of small perturbations we evaluate the effect of solitary, spherical heterogeneities on the discrimination characteristic of a maximally probable goniometer, assuming that the emitted field is a steady-state one and Gaussian in nature.

An optimum goniometer must form the following statistic /1/:

$$\hat{\alpha} = \frac{\sum\limits_{n}^{N}\sum\limits_{k}^{N}\iint\limits_{0}^{T}\frac{\partial K_{nk}(t_1,t_2)}{\partial\alpha}x_n(t)x_k(t)dt_1dt_2}{\sum\limits_{n}^{N}\sum\limits_{k}^{N}\iint\limits_{0}^{T}\left[\frac{\partial K_{nk}(t_1,t_2)}{\partial\alpha}\right]^2 dt_1dt_2}, \quad (1)$$

where $x_n(t)$ = output signal of the n-th receiver; $K_{nk}(t_1,t_2)$ = cross-correlation of the signals from the outputs of the n-th and k-th receivers.

Let a plane wave $P_0 = A_0e^{-i(\omega t-kx)}$ fall on a spherical heterogeneity with radius r_0. Let us assume that $\mu = (\Delta c/c_0) \ll n_0 = 1$, where n_0 and μ are the refractive index in the medium and the increase in the index at the limits of the extent of the heterogeneity; $(kr_0^2/r) \ll 1$, where z = distance from a point inside the heterogeneity to the observation point; $\delta \ll (1/kr_0)$, where δ = angle between the x-axis and the direction from the center of the heterogeneity to the observation point.

Then, using the method of small perturbations, we obtain the following expression for the pressure in the far zone:

$$P = A_0e^{-i(\omega t-kx)}[1 - \phi(k,\delta)e^{ik(R-x)}], \quad (2)$$

where R = distance from the heterogeneity's center to the observation point,

$x = R\cos\delta$ and

$$\Phi(k,\delta) = \frac{4k^2\mu r_0^3}{3R}.$$

Let the incident wave have the form $P_0 = \xi(c_0t - x)$, where $\xi(t)$ = a stationary Gaussian process with a zero average, with an amplitude spectrum $A(\omega)$ and a power spectrum $S(\omega)$:

$$S(\omega) = \begin{matrix} S_0, \ \omega_1 < \omega < \omega_2, \\ 0, \ \omega < \omega_1, \ \omega > \omega_2. \end{matrix}$$

For a narrow-band process, the computation of the cross-correlation function at points with coordinates χ_1, $R\sin\delta \pm h/2$, 0, where $R \gg h$, by integrating with respect to frequency the product of the expressions of the type of (2), with due consideration for the equality $\langle A(\omega)A(\omega')\rangle = S(\omega)\delta(\omega - \omega')$, gives

$$\tilde{k}_{1,2}(\tau) = D\{\cos\omega_0\tau - \Phi(k_0\delta)[\cos(\omega_0\tau - \frac{k_0 h\delta}{2} - k_0R\frac{\delta^2}{2}) + \cos(\omega_0\tau - \frac{k_0h\delta}{2} + k_0R\frac{\delta}{2})]\}, \quad (3)$$

where $\omega_0 \quad (\omega_1,\omega_2)$; $k_0 = \omega_0/c_0$; $D = S_0\Delta\omega/\pi^2$; τ = difference in the time reading at the indicated points. Substituting expression (3) into formula (1) for N = 2, and assuming that the receiving field has uniform sensitivity, we obtain

$$\langle\Delta\hat{\alpha}\rangle = \frac{2\Phi(k_0\delta)}{hk_0}\sin\left(\frac{hk_0}{2}\delta\right)\cos\left(\frac{hk_0}{2}\delta + \frac{Rk_0}{2}\delta^2\right). \quad (4)$$

For $\omega = 2\pi\cdot100$ Hz, $r_0 = 50$ m, h = 10 m, $\delta = 5^\circ$, it is possible to compile a table of the dependence of $\langle\Delta\hat{\alpha}\rangle$ on μ and R.

R (km) \ μ	0.5%	1%	3%	5%
0.5	0.8°	1.6°	4.9°	8.2°
1	-0.2°	-0.3°	-0.9°	-1.5°
1.5	-0.4°	-0.8°	-2.5°	-4.2°
2	-0.4°	-0.7°	-2.1°	-3.6°

The formula for calculating the mean-square error of a optimum goniometer /1/ for an observation time T = 1 s and a signal-to-noise ratio q = 10 yields $\langle\Delta\hat{\alpha}\rangle = 0.7^\circ$.

Thus, when planning acoustical systems working with a high signal-to-noise ratio, the essential factor limiting their accuracy in the goniometric mode can prove to be the scattering field on solitary, large-scale heterogeneities in the refractive index.

BIBLIOGRAPHY

1. Agranovskiy, K.Yu., Kartashev, Yu.A., Kudashev, Ye.B., and Reshetov, L.A., "Direction Finding of a Noise Source in a Randomly Heterogeneous Medium" in "Trudy Devyatoy Vsesoyuznoy shkoly-seminara po statisticheskoy gidroakustike" /Works of the Ninth All-Union School-Seminar on Statistical Hydroacoustics/, Novosibirsk, Institute of Mathematics, Siberian Department, USSR Academy of Sciences, 1978.

PROCESSING HYDROACOUSTIC IMAGES ON A REAL-TIME SCALE

[Summary of report by V. N. Mikhaylovskiy, V. V. Gritsyk, B. V. Kisil' and A. Yu. Lutsyk pp 100-102]

/Text/ When processing hydroacoustic images for the purpose of recovery and identification, it is important to solve the problem under conditions of a real-time scale /1/. We will discuss the problem of processing when noise is present. Let a receptor field R of dimensionality n n be given, with f(x,y) the density of the distribution of interference in R. We will use the following definitions: I = $= K_1/n^2$ = intensity of the interference; K_1 = number of single errors in R /2/. We will discuss the value K_t, where t is the quantity of multiple errors /2/. Let ξ = a random value consisting of the appearance of t (a multiple error), while $P(\xi = t) = \phi(I,t)$ = the law governing the distribution of variable ξ for the fixed interference distribution law f(x,y).

In the report the following problems are solved:
an investigation of the dependence of the recovery of an image for a fixed interference distribution law f(x,y) on the intensity I of the interference's action;
an investigation of the recovery of an image for different distribution laws f(x,y) and a given intensity I;
an investigation of the possibility of carrying out the recovery of an image in R with different algorithms, depending on the interference distribution law f(x,y) and the image's structure.

When errors with a multiplicity of up to t, inclusive, are corrected, the image will be recovered with probability

$$P = \sum_{i=1}^{t} P(\xi = i). \tag{1}$$

For a fixed interference distribution law f(x,y) in the receptor field, the average number of t-multiple errors m(I,t) can be determined as a function of the intensity I of the interference's action. The possibility of a recovery algorithm--that is, the capability of reducing the intensity of the interference in the image's receptor field--is determined according to function m(I,t).

Let I be the intensity of the interference's action on the image's receptor field until recovery, and I_1 be the same after recovery.

It is then the case that

$$K = \frac{I - I_1}{I} \quad (2)$$

is the image recover (correction) factor for the ideal case K = 1.

The possibilities of an image recovery algorithm for correction of erros with multiplicity of up to t, inclusive, for interference action intensity I and distribution law f(x,y) are

$$K(I) = (I = \sum_{t=t+1}^{n^2} m(I,t))/I. \quad (3)$$

This is the filter's characteristic as a function of the intensity of the interference's action, given a fixed law for its distribution.

We also presented examples of the recovery of hydroacoustic images under conditions where interference was active for different distribution laws /3/, and demonstrated the possibility of parallel processing in order to recover images under conditions of a real-time scale.

BIBLIOGRAPHY

1. Gritsyk, V.V., Zlatogurskiy, E.R., and Mikhaylovskiy, V.N., "Rasparallelivaniye algoritmov obrabotki informatsii" /Disparallelization of Information Processing Algorithms/, Kiev, Izdatel'stvo "Naukova dumka", 1977.

2. Gritsyk, V.V., "Image Recovery During Image Identification Under Noisy Conditions," in "Otbor i peredacha informatsii" /Information Gathering and Transmission/, Kiev, Izdatel'stvo "Naukova dumka", No 47, 1976.

3. Gritsyk, V.V., Kisil', B.V., and Kolesnikov, A.N., "Modeling Interference in Receptor Fields of Arbitrary Dimensionality on a YeS-1020 Computer: Methods of Disparallelization of Information Processing," in "Doklady i soobshcheniya nauchno-tekhnicheskogo seminara" /Reports and Notices From the Scientific and Technical Seminar/, L'vov, Preprint No 3, 1977.

THE METHOD OF CORRELATED HOLOGRAMS IN ACOUSTIC INVESTIGATIONS OF THE OCEAN

[Article by Ye. F. Orlov pp 102-104]

/Text/ One of the basic question in hydroacoustic metrology is that of comparing experimental data with theoretical calculations.

In this article there is a discussion of the question of the possibility of comparing theoretical calculations with some characteristics of a field that are averaged with respect to space but still reflect the fine interference structure of an acoustic field in a medium. Let us discuss the signal at the output of an acoustic receiver in a medium in the field of a concentrated, broad-band source. The following equation is taken from /2/:

$$g(t,r,z,z_0) = \int_0^{\infty} f(t-\tau)h(\tau,r,z,z_0)d\tau + n(t), \quad (1)$$

where $f(t)$ = the signal at point of emission $(0,z_0)$; $h(\tau,r,z,z_0)$ = response of the medium to pulse excitation during observation at point (r,z); $n(t)$ = additive interference.

In the method we are proposing, measurements are made during continuous movement of the receiver (or emitter). In this case the received signal will be essentially a non-steady-state one because of the change in the medium's transient characteristic as a function of the source's and receiver's coordinates. Let us introduce the instantaneous signal spectrum $g(t)$ into this discussion:

$$G_T(\omega,t) = \int_t^{t+T} g(t)e^{-i\omega t}dt + N(\omega,t), \text{ where } N(\omega,t) = \int_t^{t+T} n(t)e^{-i\omega t}dt. \quad (2)$$

Function $G_T(\omega,t)$ can be subjected to two-dimensional processing by holographic and optical information processing methods, either for the purpose of recovering the original signal after the necessary filtration or for the purpose of measuring certain parameters of the signal's non-steady-state nature. In this respect, we will call the two-dimensional function $G_T(\omega,t)$ the hologram of signal $g(ty|G_T(\omega,t)|)^2$

an intensity hologram, emphasizing by this the essential difference between the instantaneous spectrum and the generally accepted concept of the spectrum of steady-state processes as a function that is the result of statistical averaging [3]. Taking (1) into consideration, the square of the absolute value of the instantaneous spectrum--the intensity hologram--will have the form:

$$|G(\omega,t)|^2 = F^2(\omega,t)H^2(\omega,r(t),z,z_0), \quad (3)$$

where

$$F^2(\omega,t) = \left|\int_t^{t+T} f(t)^{-i\omega t}dt\right|^2,\ H^2(\omega,t) = \left|\int_t^{t+T} h(\tau,r(t),z,z_0)e^{-i\omega\tau}d\tau\right|^2$$

are, respectively, the emitted signal's instantaneous spectrum and the medium's transfer function.

Secondary spectral analysis of the intensity hologram makes it possible to derive the following two-dimensional functions:
the sliding spectrum of the hologram, with averaging with respect to time:

$$B(\Omega,\omega,t) = \int_t^{t+T_B} |G_T(\omega,t)|^2 e^{-i\Omega t}dt, \quad (4)$$

where frequency $\Omega = uv$ is related to the spatial frequency of the changes in the "hologram, $u = 2\pi/\Lambda$ (Λ = the spatial period); v = relative rate of movement of the receiver; T_B = integration interval during secondary analysis = $\Delta r/v$.

Taking (3) into consideration, (4) will be:

$$B(u,\omega,r/v) = \int_{r/v}^{r/v+\Delta r/v} F^2(\omega,t)H^2(\omega,r/v,z,z_0)e^{-iur}\cdot\frac{dr}{v} + \int_t^{t+T_B} N^2(\omega,t)e^{-i\Omega t}dt; \quad (5)$$

the sliding spectrum of the hologram, with averaging with respect to frequency:

$$C(\tau,r/v) = \int_{\omega_1}^{\omega_2} F^2(\omega,t)H^2(\omega,r/v,z,z_0)e^{-i\omega t}d\omega + \int_{\omega_1}^{\omega_2} N^2(\omega,t)e^{-i\omega\tau}d\omega; \quad (6)$$

the two-dimensional spectrum of the intensity hologram:

$$\Phi(u,\tau) = \int_{\omega_1}^{\omega_2}\int_{r/v}^{r/v+\Delta r/v} F^2(\omega,t)H^2(\omega,r/v,z,z_0)e^{-i(ur+\omega\tau)}d\omega\frac{dr}{v} + \int_{\omega_1}^{\omega_2}\int_t^{t+T_B} N^2(\omega,t)e^{-i(\Omega t+\omega\tau)}d\omega dt. \quad (7)$$

As is known [4], an acoustic field in a layered medium, which is a solution of the wave equation, can be represented in the form of the product of a radial function and a function that is a function of z:

$$P(\omega,r,z,z_0) = R(r)Z(z),$$

where R(r) and Z(z) satisfy the wave equations

$$\nabla_r^2 R(r) + \varkappa^2 R(r) = 0; \quad \frac{\partial^2}{\partial z^2} Z(z) + \gamma^2 Z(z) = 0;$$

where $\gamma^2 = \omega^2/c^2 - \varkappa^2 = k^2 - \varkappa^2$, plus the conditions on the boundaries.

Solution Z(z) is presented in the form of a sum of the normal modes $Z(\gamma_m, z) = Z_m(z)$. The eigenvalues γ_m and $\varkappa_n$ are determined by the appropriate characteristic equation /4/.

Representation of the field in a layered medium in the form of the sum of the normal modes makes it possible (for $\varkappa r \gg 1$) to write the medium's transfer function in the form

$$H^2(\omega,r,z,z_0) = \sum_{m,n} (P_m^2(\omega,z,z_0) + P_n^2(\omega,z,z_0) + 2P_m(\omega,z,z_0)P_n(\omega,z,z_0)\cos \Delta\varkappa_{mn}(\omega)r),$$

where

$$\Delta\varkappa_{mn}(\omega) = \varkappa_m(\omega) - \varkappa_n(\omega) = 2\pi/\Lambda_{mn}$$

is the difference between the radial wave numbers of modes numbers m and n. The interference effects are characterized by the term

$$H_1^2(\omega,r,z,z_0) = 2 \sum_{m,n} P_m(\omega,z,z_0)P_n(\omega,z,z_0)\cos \Delta\varkappa_{mn}(\omega)r. \quad (8)$$

The basic parameters of the field's interference structure are the values of the space interference frequencies $\Delta\varkappa_{mn}(\omega)$ and the mode excitation amplitude P_mP_n. The sequential, point-by-point measurement of the spectral amplitude of a monochromatic signal for given values of r, z and z_0, followed by a comparison of the measurement results with theoretical calculations is, as was mentioned earlier, a difficult assignment to perform experimentally. At the same time, calculation of the transfer function at great distances requires a high degree of accuracy in assigning the frequencies $\Delta\varkappa_{mn}(\omega)$ that cannot be achieved because of inaccurate knowledge of the medium's parameters.

The method of correlated holograms makes it possible to compare experimental data with calculations by measuring the differences between the normal waves' spatial frequencies and their dependence on the frequency and comparing them with the theoretical values. The amplitudes of the excited modes P_mP_n and the frequency $\Delta\varkappa_{mn}(\omega)$ can be determined experimentally, as extreme values of the intensity hologram's sliding spectrum $B(u,\omega,z)$ and the values of frequencies u for which these extremes are observed. The two-dimensional picture $B(u,\omega)$ makes it possible to find the dependence of these parameters on the frequency (dispersion characteristics of the waveguide).

The intensity hologram's two-dimensional spectrum makes it possible to measure experimentally the phase shifts of the normal modes, as a function of frequency, with respect to the values of $\Delta\varkappa$ and τ that correspond to the extreme values of the function $\Phi(u,\tau)$ (expression (7)). The intensity hologram's sliding spectrum, with averaging with respect to frequency--$C(\tau,r)$--is a $(\tau - r)$ diagram /1/.

These characteristics of the interference structure of an acoustic field in the ocean are connected, by well-known relationships /1/, to the hydrophysical parameters of the medium, the bottom and the surface, the experimental investigation of which is a matter of great interest.

BIBLIOGRAPHY

1. Brekhovskikh, L.M., editor, "Akustika okeana" /Ocean Acoustics/, Moscow, Izdatel'stvo "Nauka", 1974.

2. Tolstoy, I., and Kley, K.S., "Akustika okeana" /Ocean Acoustics/, Moscow, Izdatel'stvo "Mir", 1969.

3. Kharkevich, A.A., "Spektry i analiz" /Spectra and Analysis/, Izdatel'stvo Fizmatgiz, 1962.

4. Brekhovskikh, L.M., "Volny v sloistykh sredakh" /Waves in Layered Mediums/, Moscow, Izdatel'stvo "Nauka", 1957.

PAL'M'S RANDOM FIELD

[Artible by A. G. Buymov, and M. T. Reshetnikov pp 104-106]

/Text/ In connection with the digital modeling of hydrolocation systems, there arises the problem of the computer simulation of fluctuations of the medium's parameters, such as temperature, impurity concentration and so on /1/. In this article, as one of the possible approaches to the solution of this problem we propose one based on generalization of a model of a telegraph signal /2/ into a three-dimensional case. As with the model in /3/, we also regard recovery flows to be the engendering flows.

Let X_{ijk} be the tensor of the spatial fluctuations of the medium's modeled parameter X; $\Pi_s = P(X_{ijk} = g_s)$ = unidimensional distribution of the fluctuations at point ijk; $\Pi_{st}(u) = P_u(X_{ijk} = g_s, X_{\ell mn} = g_t)$ = the provisional two-dimensional distribution; $\{g_s\}$ = the ordered set of possible values of parameter X; u = a random value that is

$$u = \begin{cases} 0, \text{ if there are no changes in parameter X between points ijk and } \ell mn; \\ 1, \text{ if there are changes,} \end{cases}$$

and is distributed according to the law

$$\begin{aligned} P(u,0) &= V(ijk,\ell mn), \\ P(u = 1) &= 1 - V(ijk,\ell mn). \end{aligned} \tag{1}$$

Henceforth, let us limit ourselves to the case where probability V depends only on the distances $\tau_1 = \Pi - i$, $_2 = m - j$, $_3 = n - k$; that is,

$$V = V(ijk,\ell mn) = V(\tau_1,\tau_2,\tau_3).$$

Further, let

$$\Pi_{st}(u) = \begin{matrix} \Pi_s\delta_{st}, \text{ if } u = 0, \\ \Pi_s\Pi_t, \text{ if } u = 1; \end{matrix}$$

that is, if parameter X changes between ijk and ℓmn, the values $X_{ijk} = g_s$ and $X_{\ell mn} = g_t$ are selected from $\{g_s\}$ independently. In connection with this, the unconditional two-dimensional distribution of the fluctuations is

$$\Pi_{st} = \Pi_s(\Pi_t + (\delta_{st} - \Pi_t)V). \quad (2)$$

In order to obtain realizations of the random field of parameter X it is possible to use (for example) this method: a three-dimensional, rectangular, nonequidistant array with random distances between the generatrices is generated in space. It is generated by three recovery flows. The values of parameter X in each of the rectangular parallelepipeds that are obtained are constant and are selected from the same general set, regardless of the values of parameter X in the other parallelepipeds. If the flows are independent, probability V in (2) is factored: $V(\tau_1,\tau_2,\tau_3) = V_1(\tau_1)V_2(\tau_2)V_3(\tau_3)$. Probabilities $V(\tau)$, functions $F(\tau)$ and densities $W(\tau)$ of the distribution of the recovery flows' interpulse distances are related by (Pal'm's) formulas /2-4/:

$$V(\tau) = 1 - \int_0^\tau [1 - F(z)]dz / \int_0^\tau [1 - F(z)]dz, \quad (3)$$

$$F(\tau) = 1 + \lambda^{-1}\dot{V}(\tau),\ W(\tau) = \lambda^{-1}\ddot{V}(\tau),\ \lambda = -\dot{V}(0).$$

On the basis of the properties of the probabilities, their distributions and formulas (3), it is possible to conclude that the recovery flows' probabilities $V(\tau)$ satisfy the conditions

$$1 \leqslant V(\tau) \geqslant 0;\ \dot{V}(\tau) \leqslant 0;\ \ddot{V}(\tau) \geqslant 0; \quad (4)$$

that is, they form a class of nonnegative, nonincreasing convex functions. Formulas (2)-(4) are a probability description of the model of the random field, which in the future we will call "Pal'm's field."

By computing the first and second moments of distribution (2), we can show that the normalized correlation function of the field's fluctuations does not depend on its unidimensional distribution and coincides completely with probability V, as introduced by formula (1). This result, together with formula (2), makes it possible to mention that in Pal'm's field, independence and noncorrelatability of the fluctuations are equivalent.

The figure /not reproduced/ shows a cross-section of one of the realizations of the field for the case of Gaussian fluctuations with an exponential correlation function. The image was obtained on a 1020 computer, using a program published in /3/.

BIBLIOGRAPHY

1. Ol'shevskiy, V.V., "Statisticheskiye metody v gidrolokatsii" /Statistical Methods in Hydrolocation/, Leningrad, Izdatel'stvo "Sudostroyeniye", 1973.

2. Tikhonov, A.I., and Mironov, M.A., "Markovskiye protsessy" /Markov Processes/, Moscow, Izdatel'stvo "Sovetskoye radio", 1977.

3. Buymov, A.G., and Reshetnikov, M.T., "Model of an Image in a Two-Dimensional Recovery Flow," in "Korrelyatsionno-ekstremal'nyye sistemy obrabotki informatsii i

upravleniya" /Extreme Correlation Information Processing and Control Systems/, Tomsk, Izdatel'stvo TGU /Tomsk State University/, 2nd edition, 1977.

4. Gnedenko, B.V., and Kovalenko, I.N., "Vvedeniye v teoriyu massovogo obsluzhivaniya" /Introduction to the Theory of Queueing/, Moscow, Izdatel'stvo "Nauka", 1966.

COMBINING THE PRINCIPLES OF INVARIANCE AND NONDISPLACEABILITY WITH OTHER SOLVING RULE SYNTHESIS METHODS UNDER CONDITIONS OF PRIOR INDETERMINACY

[Article by Yu. Ye. Sidorov pp 106-114]

/Text/ 1. Introduction. In solving a number of problems in classifying and evaluating signal parameters in order to produce optimum solving rules, the combined use of the principles of invariance /1/ or nondisplaceability /1,2/ and other optimum procedures for testing statistical hypotheses proves to be both necessary and possible. In a number of cases, such a combination makes it possible not only to find the optimum solution of a problem, but also to obtain solving devices with additional properties that are desirable and practically important when working under conditions of prior indeterminacy.

2. The Principle of Invariance for Sequential Signal Parameter Classification and Evaluation Models. The use of the invariance principle in combination with the sufficiency principle is advisable when synthesizing sequential solving rules for classifying and evaluating parameters in connection with prior parametric indeterminacy. In a sequential model, let the statistical structure $\{(X^{(n)},A^{(n)},P^{(n)});$ $n = 1,2,...\}$ be determined, where $X^{(n)}$ is the Euclidean space of the observations of random values $(x_1,...,x_n)$ at the n-th step; $A^{(n)}$ is the (Borelevskoye) δ-field in $X^{(n)}$; $P^{(n)}$ is the family of probability measures in $(X^{(n)}A^{(n)})$, $n = 1,2,...$, it being the case that sequential inclusion of the δ-fields $A^{(1)} \subset A^{(2)} \subset ...$ takes place. As is known, a sequential procedure assigns a set of stoppage rules $\{\Phi_n(x_1,...,x_n);\ n = 1,2,...\}$ that are $A^{(n)}$-measureable statistics. In accordance with the rule $\Phi_n(x_1,...,x_n)$, the set $(x_1,...,x_n)$ is given some integral value in such a manner that if $\Phi_n(x_1,...,x_n) = n$, after the n-th observation a decision is made about halting the observations. Otherwise, an additional observation x_{n+1} is made.

As a rule, the family of distributions $P^{(n)} = \{P_{\Theta,\vartheta}(x),\ (\Theta,\vartheta) \in \Omega,\ x \in X\}$ depends on parameters Θ and ϑ (which are possibly vector parameters), which belong to the parametric space $\Omega = \Omega_H \cup \Omega_K$. In this case, the problem of classification (or evaluation) is equivalent to the problem of sequential testing of hypotheses:

$H:(\Theta,\vartheta) \in \Omega_H$ (for example, $\Theta = \Theta_0$); $K:(\Theta,\vartheta) \in \Omega_K$ ($\Theta \neq \Theta_0$; for example, $\Theta = \Theta_1$), (1)

while parameter ϑ is indeterminate and interfering. In view of the presence of , hypotheses H and K are complicated, which does not make it possible to use the sequential criterion of ratios of probabilities [1].

Let the problem of testing hypotheses (1) in a sequential model be invariant relative to the groups of mutually unambiguous transformations $\bar{g}X = X$, $\bar{g}A = A$ and $gP = P$, $g \in G$, $\bar{g} \in \bar{G}$, and let each $\bar{g} \in \bar{G}$ generate at the n-th step the transformation $\bar{g}^{(n)}$ on $X^{(n)}$. If $\bar{g}$ transforms observations $X = (x_1,\ldots,x_n)$ component by component, then at the n-th step, $\bar{g}^{(n)}(x_1,\ldots,x_n) = (\bar{g}_1 x_1,\ldots,\bar{g}_n x_n)$. Let us assume that $\bar{G}^{(n)}$ is a group of transformations generated in $X^{(n)}$ at the n-th step; it is then possible to find the statistic $U^{(n)}(x)$ that is the maximum invariant (MI) relative to group $\bar{G}^{(n)}$ of transformations in space $X^{(n)}$, on which should be based all the invariant, sequential solving rules (at the n-th step).

Let us assume that function $U^{(n)}$ has the distribution f(U,V) and that the transformations $\bar{G}^{(n)}$ of the sampling space $X = (x_1,\ldots,x_n)$ initiate the corresponding transformations $G^{(n)}$ in the parametric space Ω, relative to which the MI is the function V. It is then the case that, according to theorem 3 in Chapter 6 of [1], the distribution f(U;V) depends only on MI V and, instead of testing the complicated hypotheses (1), it is sufficient to test the simple hypotheses

$$H:V = V_0;\ K:V = V_1. \qquad (2)$$

According to A. (Val'd's) rule [1] and a statement in [4], sequential hypothesis testing rule (2) consists of comparing at the n-th step the probability relationships $L^{(n)} = L^{(n)}(U^{(n)}) = f(U^{(n)};V_1)/f(U^{(n)};V_0)$ with the two thresholds $C_0 = \beta/(1-\alpha)$ and $C_1 = (1-\beta)/\alpha$, where α and β are the probabilities of Type I and Type II errors. In connection with this, we adopt the hypothesis H if

$$\frac{\beta}{1-\alpha} < L^{(n)} < \frac{1-\beta}{\alpha} \text{ and } L^{(n)} \leqslant \frac{\beta}{1-\alpha} < 1; \qquad (3)$$

adopt the hypothesis K if

$$\frac{\beta}{1-\alpha} < L^{(n)} < \frac{1-\beta}{\alpha} \text{ and } L^{(n)} \geqslant \frac{1-\beta}{\alpha} > 1, \qquad (4)$$

and continue the observations if

$$\frac{\beta}{1-\alpha} < L^{(n)} < \frac{1-\beta}{\alpha}. \qquad (5)$$

Thus, the fact that in the application of the invariance principle to a sequential decision-making scheme the decisive statistics at the n-th step must be based on the MI $U^{(n)}$ makes it possible to construct a classification or evaluation procedure quite simply.

If we further abridge the original data by application of the sufficiency principle (for example, carry out a reduction for each MI $U^{(n)}$ at the n-th step, $n > 1$), it is possible to simplify the solution procedure even more. In this case, observation continuation condition (5) is written equivalently in terms of unidimensional MI $U^{(n)}(x)$ in the form /4/:

$$U_0^{(n)} < U^{(n)}(x) < U_1^{(n)}, \tag{6}$$

where the threshold numbers $U_0^{(n)}$ and $U_1^{(n)}$ are determined from the equations

$$L^{(n)} = C_i,\ i = 0,1.$$

3. The Invariance Principle and the Probability Ratio Method. In a number of invariance problems the solving rules can be based on the probability ratio statistic, which is a nontrivial invariance statistic /1,5/. Such solving rules have a stable structure and stable qualitative characteristics under real underwater observation conditions.

In hypothesis testing problem (1), let the parametric subsets Ω_H and Ω_K be invariant relative to the group of transformations G and countable, while Ω_K is separable. The following statement is then correct: the probability ratio (OP)

$$W(x) = \sup_{\Omega_K} P_\Theta(x) / \sup_{\Omega_H} P_\Theta(x) \tag{7}$$

is invariant (almost invariant) relative to the group $\bar{G}$ of transformations of the sampling space /1/ ($P_\Theta(x) = dP_\Theta(x)/d\mu$; μ = some measure). The OP statistic W(x) has a number of valuable properties that make its use for the solution of several parameter classification and evaluation problems advisable.

In the first place, statistic W(x)--as is the case with statistic MI--reduces the original observation space. In the second place, although statistics MI and OP are not equivalent (for example, statistic W(x) is unidimensional, while MI can also be multidimensional), in a number of invariance problems where MI is unidimensional, after the statistic W(x) is determined it turns out that it is the MI relative to G and, therefore, all the invariance solving rules are expressed in terms of it. In the class of these rules it is possible to find rules with optimum properties: most powerful, locally or uniformly most powerful (RNM). In the third place, in order to test a general linear hypothesis (hypothesis testing problem (1) can be reduced to such), a rule based on the OP statistic is an invariant RNM (RNMI) /5, page 345/. In the fourth place, if statistic W(x) is the MI relative to some group of transformations G_s and is a function of the invariantly sufficient statistic S, then, being invariantly sufficient /3, theorem 2.7.1/, it determines the optimum invariant rule for testing hypothesis (1). Finally, in the fifth place, in some (rare) cases the statistic W(x) determines an RNMI rule that will also be an undisplaced RNM (RNMN). This can occur when W(x) and the family of distributions $P = \{P_{\Theta\vartheta}(x), (\Theta,\vartheta) \in \Omega, x \in X\}$ of the observed sample are subject to the conditions of theorem 1 /1, Chapter 5/ and theorem 6 /1, Chapter 6/.

4. Invariance and Minimax. Let the statistical structure (X,A,P) be defined and let the distributions P_Θ, $\Theta \in \Omega$, be dominated by a σ-finite measure in (X,A). In order to test the complicated hypotheses $H: \Theta \in \Omega_H$ and $K: \Theta \in \Omega_K$ for the unknown

parameter Θ, along with the invariance principle there exists another optimum procedure that minimizes the risk function's maximum and is called the minimax procedure /1/. The use of this procedure is reasonable, since it insures a minimum of the heaviest (on the average) losses when a false solution is found. It is particularly valuable in the presence of any assumptions about the expected values of (but that are not sufficiently reliable for the use of the (Bayyesovskaya) procedure), when it is advisable to use this (even if it be only a small amount) prior information, having protected oneself (in case of its inaccuracy) from catastrophic losses. In order to do this, it is possible to assign an upper limit to the risk function $R(\Theta,\phi)$ and discuss only those procedures ϕ for which $R(\Theta,\phi) \leqslant R^*$ for all Θ, it being the case that here constant R must be greater than the minimax procedure's maximum risk (otherwise, a procedure satisfying this inequality will not be found).

In order to test hypotheses H and K for any mutually nonintersecting subsets Ω_H and Ω_K, here there also exists solving rule ϕ with significance level α that maximizes the minimum power (probability of correct solution) on Ω_K; that is, it maximizes

$$B = \inf_{\Omega_K} E_\Theta \phi(x) \tag{8}$$

in the class of all solving rules of level α that are based on X (E_Θ = averaging sign). If densities $P_\Theta(x) = dP_\Theta(x)/d\mu$ are measurable (according to some σ-finite measure) relative to $(A \times B)$ and $(A \times B')$, where B and B' are given σ-fields in Ω_H and Ω_K, there exists /1, Chapter 8, theorem 1/ a unique maximin and most powerful rule $\phi_{\lambda\lambda'}$ of level α in order to test hypothesis $H{:}\Theta \in \Omega_H$ (λ and λ' are the pair of any distributions in B and B' that are the least favorable in the sense that for any other pair (ν,ν'), the power $B_{\nu,\nu'} \geqslant B_{\lambda,\lambda'}$).

The basic difficulty in solving specific problems is finding the pair (λ,λ') of least favorable distributions. In some cases this search is made easier by the use of invariance considerations, namely: if group $\bar{G}$ of transformations of sampling space X induces a corresponding group G in the parametric space Ω, leaving the subsets Ω_H and Ω_K invariant, the problem of testing hypotheses H and K is symmetrical relative to those Θ that can be translated relative to each other by transformations from group G. If in this case λ and λ' are not also symmetrical relative to G, they make the problem of synthesis easier and, therefore, will not be the least favorable ones.

However, it is more natural that when the problem of testing hypotheses H and K is invariant relative to some group of transformations, the pair (λ,λ') of least favorable distributions is also invariant and that there generally exists an invariant maximin rule. In an important class of problems the existence of such a rule (Ψ) satisfying the condition

$$\inf_G E_{g\Theta}\phi(X) \leqslant E_\Theta \Psi(X) \leqslant \sup_G E_{g\Theta}\phi(X) \tag{9}$$

for all $\Theta \in \Omega$ and $g \in G$ is postulated in /1, Chapter 8, lemma 2/. If group $G = \{g_1,\ldots,g_m\}$ is finite and $\Psi(X) = \frac{1}{m}\sum_{\ell=1}^{m} \phi(\bar{g}_\ell,x)$, then Ψ will be a critical function that is invariant relative to G and satisfies condition (9), since $E_\Theta\phi(\bar{g}X) = E_{g\Theta}\phi(X)$, and $E_\Theta\Psi(X)$ is the average of several values, the minimum and maximum of which coincide with the first and second terms in (9), respectively.

Providing that RNMI rules exist, the successful utilization of the maximin approach to obtain optimum solving rules is possible most parameter classification and evaluation problems. As has already been mentioned, all invariant solving rules are expressed in terms of the MI. The changeover to this statistic provides a substantial reduction in the original data, including the reduction of the maximin problem. This can be demonstrated in the following manner, using (Khant-Steyn's) theorem and theorem 2, Chapter 6, in [1].

Let a group of transformations G, relative to which the problem of testing hypotheses H and K is invariant, be generated by two subgroups D and E in the sense that it is the smallest group containing D and E (group G then contains the set of products $e_m d_m, \ldots, e_1 d_1$, $m = 1,2,\ldots$, $d_i \in D$, $e_i \in E$, $i = \overline{1,m}$). Let us also assume that $y = S(x)$ = the MI relative to group D. For each $e \in E$ the following condition is fulfilled: the equality $S(x_1) = S(x_2)$ entails $S(ex_1) = S(ex_2)$, and that $z = t(y)$ = the MI relative to group E^*, which consists of those elements e^* such that $e^*y =$ $= S(ex)$ when $y = S(x)$. Also, let groups D and E^* satisfy the conditions of Khant-Steyn's theorem [1], which proves the existence of an almost invariant critical function $\Psi(X)$ that satisfies condition (9). There then exists a maximin rule depending on the MI $y = S(x)$ and a maximin rule depending on the MI $z = t(y)$ [1].

Thus, reduction of the maximin problem is accomplished sequentially, step by step, by finding the maximum invariants relative to the subgroups of the group of transformations G.

Changing over to the maximally invariant statistic, it is possible to make a further attempt to find the RNMI rule. If the assumptions of the Khant-Steyn theorem are fulfilled for some group of transformations $\bar{G}$, then for any problem that is invariant relative to $\bar{G}$ and permits an RNMI rule, this rule maximizes the minimum of the power (is a maximin) in the class of all invariant rules. This conclusion can be drawn from condition (9) by the way indicated in the proof of lemma 2 in Chapter 8 of [1]. On the other hand, if it is established that in any specific problem the rule that is RNMI relative to G does not maximize the power's minimum, the prerequisites of Khant-Steyn's theorem cannot be fulfilled. However, this in no way means that in another problem (with another distribution $P_\Theta(x)$) that is invariant relative to the same group $\bar{G}$, the RNMI rule will not maximize the power's minimum, because this depends not only on the group of transformations, but also on the family of distributions $P = \{P_\Theta(x), \Theta \in \Omega, x \in X\}$.

5. The Nondisplaceability and Minimax Principles. As we have seen, the single-alternative problem of classifying and evaluating signal parameters when there is parametric prior indeterminacy comes down to testing hypotheses $H{:}\Theta \in \Omega_H$ and $K{:}\Theta \in \Omega_K$ about the unknown parameter Θ continuously with respect to Θ for each A of the distribution $P_\Theta(A) = \int_A P_\Theta(x)d\mu(x)$, where A = any set from sampling space X; $\mu =$ = some σ-finite measure on (X,A), while the nonintersecting subsets Ω_H and Ω_K, as before, meet the condition $\Omega_H \cup \Omega_K = \Omega$. In single-alternative classification and evaluation problems, the loss function $L(\Theta,d_i)$, $i = H,K$, is usually constant in sets Ω_H and Ω_K, so let $L(\Theta,d_i) = a_i$ for $\Theta \in \Omega_j (j \neq i)$ and $L(\Theta,d_i) = 0$ for $\Theta \in \Omega_i$.

Corroborations. If there exists a minimax rule for testing hypotheses H and K, it must be nondisplaceable; each nondisplaceable rule for testing these hypotheses, providing that there is at least one common point Θ_0 on the boundary of subsets Ω_H

and Ω_K, is minimax /1/. Let us show the correctness of these statements, because in /1/ they are presented without proofs.

In the case of the first statement, the condition of nondisplaceability when testing hypotheses H and K is equivalent to the inequality

$$\sup R_\phi(\Theta) \leqslant \frac{a_H a_K}{a_H + a_K}, \qquad (10)$$

which is derived from expression (3) in /7/, allowing for expression (1) in that work for the average risk function $R(\Theta,\phi)$ (compare (10) with the condition $R(\Theta,\phi) \leqslant R^*$ in Paragraph 4). Actually,

$$R(\Theta,\phi) = E_\Theta L[\Theta_1,\phi(x)] = \begin{cases} a_N P_\Theta\{\phi(x) = d_H\} \text{ for } \Theta_1 \in \Omega_K, \\ a_K P_\Theta\{\phi(x) = d_K\} \text{ for } \Theta_1 \in \Omega_H, \end{cases} \qquad (11)$$

so that expression (3) in /7/ reduces to the inequalities

$$a_H P_\Theta\{\phi(x) = d_H\} \geqslant a_K P_\Theta\{\phi(x) = d_K\} \text{ for } \Theta \in \Omega_H \qquad (12)$$

and

$$a_K P_\Theta\{\phi(x) = d_K\} \geqslant a_H P_\Theta\{\phi(x) = d_H\} \text{ for } \Theta \in \Omega_K \qquad (13)$$

Since $P_\Theta\{\phi(x) = d_H\} + P_\Theta\{\phi(x) = d_K\} = 1$ for Θ Ω_H (Ω_K), nondisplaceability condition (3) of the rule $\phi(x)$, as written in /7/ is converted into the inequality

$$\left.\begin{aligned} P_\Theta\{\phi(x) = d_H\} &\geqslant \frac{a_K}{a_H + a_K} \\ P_\Theta\{\phi(x) = d_K\} &\leqslant \frac{a_H}{a_H + a_K} \end{aligned}\right\} \text{ for } \Theta \in \Omega_H; \qquad (14)$$

$$\left.\begin{aligned} P_\Theta\{\phi(x) = d_H\} &\leqslant \frac{a_K}{a_H + a_K} \\ P_\Theta\{\phi(x) = d_K\} &\geqslant \frac{a_H}{a_H + a_K} \end{aligned}\right\} \text{ for } \Theta \in \Omega_K. \qquad (15)$$

Inequality (10) is fulfilled for any minimax solution-selection rule, which is obvious from a comparison with rule $\phi(x) = d_H$ or $\phi(x) = d_K$, which make decisions d_H or d_K with probabilities $a_K/(a_H + a_K)$ and $a_H/(a_H + a_K)$ according to expressions (14) and (15).

In the case of the second statement, in view of the continuity of the risk function $R_\phi(\Theta)$, for any nondisplaced rule the value of this function on the boundary between Ω_H and Ω_K is

$$R_\phi(\Theta_0) = a_H a_K/(a_H + a_K). \qquad (16)$$

Therefore,

$$\sup R_\phi(\Theta) = a_H a_K/(a_H + a_K), \qquad (17)$$

which satisfies condition (10). Consequently, any nondisplaced rule for testing hypotheses H and K is a minimax one.

6. Examples. As is known, problems in detecting and evaluating the parameters of hydrolocation signals can be solved with the help of different methods (criteria). Therefore, the question of an objective comparison of the effectiveness of different methods is an urgent one. One of the variants of this comparison can be the following. Let there be two methods for solving such problems (we will assume that they are detection problems): A and B. Let there be n tests of these methods; if an object exists (does not exist) and with the help of any method a decision can be made about its presence (absence), the test is considered to be successful and its outcome is provisionally assigned the symbol "1"; otherwise, the test is considered to be unsuccessful and its outcome is assigned the symbol "0". These outcomes can be regarded as independent random variables x_{Ai} and x_{Bi}, which take on the values "1" and "0," $i = \overline{1,n}$. Let $X_i = 1$ for $x_{Ai} > x_{Bi}$ and $X_i = 0$ for $x_{Ai} < x_{Bi}$. Let us designate $p_i = P\{X_i = 1\}$ and discuss the problem of testing hypothesis $H:p > 1/2$ (methods A and B are equivalent) relative to the alternative $K:p_i > 1/2$ for all i (method A is better than method B).

The problem of testing these hypotheses remains invariant relative to the group of n permutations of the values $X_1,\ldots,X_n$, and the MI relative to this group is the function $X = \sum_{i=1}^{n} X_i$. There exists /1/ an RNMI rule for testing these hypotheses that rejects H if $\sum_{i=1}^{n} X_i > C$, where C is the threshold determined according to the given significance level . At the same time, lemma 2 /1, Chapter 8/ is applicable to this problem. It shows that condition (9) is correct for our RNMI rule and that it has a desirable maximin property ($\max \inf_{\Omega_K} E_p\phi(x)$) in the class of all invariant rules.

Let us mention here that the problem of constructing a rule for determining the coordinates of an object, which was solved in /8/, was also reduced to testing hypotheses analogous to those written above, so that the rule for testing these hypotheses (formula (1) and (2) in /8/) is also a maximin RNMI.

7. Conclusion. The suggestions that have been made about combining the principles of invariance and nondisplaceability with other synthesis methods in order to solve hydrolocation signal parameter classification and evaluation problems are feasible, since their realization makes it possible to obtain solution schemes with additional desirable properties that make them even more desirable and effective when working under real conditions. Let us mention that combining the invariance and minimax principles sometimes results in optimization of the solving rules even if there is nonparametric prior indeterminacy. For example, it is possible to construct uniformly maximin most powerful rules for classifying and evaluating signal parameters. However, the main uses of the minimax principle (or its inverse form--maximin) will be found in problems with parametric prior indeterminacy.

BIBLIOGRAPHY

1. Leman, E., "Proverka statisticheskikh gipotez" /Texting Statistical Hypotheses/, Moscow, Izdatel'stvo "Nauka", 1964.

2. Linnik, Yu.V., "Statisticheskiye zadachi s meshayushchimi parametrami" /Statistical Problems With Interfering Parameters/, Moscow, Izdatel'stvo "Nauka", 1966.

3. Zaks, Sh., "Teoriya statisticheskikh vyvodov" /Theory of Statistical Conclusions/, Moscow, Izdatel'stvo "Mir", 1975.

4. Prokof'yev, V.N., "Using the Invariance Principle in the Sequential Detection and Discrimination of Signals," RADIOTEKHNIKA I ELEKTRONIKA, No 5, 1976, pp 1027-1033.

5. Kendall, M., and St'yuart, A., "Statisticheskiye vyvody i svyazi" /Statistical Conclusions and Connections/, Moscow, Izdatel'stvo "Nauka", 1973.

6. Prokof'yev, V.N., "Invariant Signal Detection Rules Based on the Maximum Probability Statistic," RADIOTEKHNIKA I ELEKTRONIKA, No 12, 1975, pp 2459-2466.

7. Sidorov, Yu.Ye., "The Principles of Nondisplaceability and Similarity in Problems of Classifying and Evaluating Parameters With Prior Indeterminacy," in "Trudy Devyatoy Vsesoyuznoy shkoly-seminara po statisticheskoy gidroakustike" /Works of the Ninth All-Union School-Seminar on Statistical Hydroacoustics/, Novosibirsk, Institute of Mathematics, Siberian Department, USSR Academy of Sciences, 1978.

8. Sidorov, Yu.Ye., "An Invariant Rule for Determining the Coordinates of Targets," RADIOTEKHNIKA I ELEKTRONIKA, No 8, 1976, pp 1759-1762.

BASIC CONCEPTS OF THE STABILITY OF STATISTICAL PROCEDURES

[Article by F. P. Tarasenko and V. P. Shulenin pp 114-119]

/Text/ 1. Introduction

The successful utilization of statistical procedures in hydrolocation problems is made difficult by the lack of an adequate statistical model of the processes being observed. We will use the term "statistical model" to mean some set of assumptions relative to the joint distribution of the sampling observations. The classical methods that were developed within the framework of parametric statistics, proved to be very sensitive to deviations from an adopted model /1,2/. For the solution of practical problems, only in rare cases is a parametric model adequate and, because of their great sensitivity to deviations from a model, the classical methods turn out to be not very effective. Searches for other methods that would be sufficiently effective with less limited models or less sensitive to deviations from the model, led to the development of nonparametric procedures /3,4/ and stable statistical procedures /1,2,5/. Bickel and Lehman /6/ present a useful classification of statistical models. Different authors interpret the term "stable" (robust) differently. Perhaps the most common and, at the same time, diffuse definition is given by (Kendall) and (St'yuart) /7/: "A statistical procedure that is insensitive to deviations from the assumptions on which it is based is called stable." This definition can be given more concretely if the type of statistical procedure is indicated, the possible deviations from the model are defined more precisely, and a definite meaning is given to the term "insensitive." Thus, when discussing stable procedures it is necessary to answer the following questions (see Bickel /8/:

1. Stability of what? It is necessary to define precisely the type of statistical procedure.

2. Stability in relation to what? In order to answer this question it is necessary to characterize the ideal statistical model and introduce some supermodel that includes the possible deviations from the ideal model.

3. Stability in what sense? In order to answer this question the quality criteria that are used and the goal we hope to achieve should be defined specifically.

Generally speaking, the stability of statistical procedures can be defined in terms of resistance to the most variegated violations of the statistical model's assumptions. Let us examine the most important deviations from a model. For a parametric model, the conditions of a specific experiment make it possible, to a great degree, to guarantee assumptions (1) and (2) and, therefore, deviations from the parametric form of distribution are of the greatest practical interest. In such situations we will talk about resistance to a change in distribution, and henceforth our basic attention will be devoted to this type of stability.

2. A Qualitative Approach to the Stability of Statistical Procedures

Let the sequence $x_1,\ldots,x_n$ of independent and identically distributed random variables with distribution function (FR) $F(x)$ be given. Let $T(x_1,\ldots,x_n)$ = some statistic (this can be either an evaluation of a parameter or a criterion statistic). The qualitative approach to the stability of $T(x_1,\ldots,x_n)$ relative to a change in F relies on the following intuitive requirement [9]:

Quite small changes in $F = L(x)$ must correspond to arbitrarily small changes in the distribution law $L(T(x_1,\ldots,x_n))$ of statistic T. This requirement can be formulated more accurately as follows: for appropriately selected metrics d in the FR's space S and an ideal model F_0 S, let us define supermodel S_r in the form $S\eta = \{F{:}d(F_0,F) \leqslant \eta\}$, in connection with which it is required that for any $\varepsilon > 0$ there existed that $\delta > 0$ and n_0, such that for all $n > n_0$,

$$d(F_0,F) < \delta \rightarrow d(L_{F_0}(T),L_F(T)) < \varepsilon. \tag{1}$$

As Hampel mentioned [9], requirement (1) is nonconstructive and therefore changes to an asymptotically equivalent nonstochastic variant--the requirement of continuity in the space of functionals of the FR. Let us mention here that many well-known evaluations, including that of maximum probability, and many test statistics can be considered to be evaluations of the appropriate functionals [2,12]. Let $T(x_1,\ldots,x_n) = T(F_n(x))$, where $F_n(x)$ is an empirical FR, be an evaluation of the functional $T(F)$. It is then the case, as Hampel demonstrated [9], that (1) is equivalent to the following requirement:

$$d(F_1,F_2) < \delta \rightarrow |T(F_1) - T(F_2)| < \varepsilon,\ S_\eta \in F_1,F_2. \tag{2}$$

Condition (2) makes it possible, in the space of functionals $T(F)$, to limit the possibilities of the selection of the functional appropriate for the given problem for the purpose of obtaining a stable (in the sense of (1)) evaluation $T(F)$. Using the concept of continuity and absolute continuity, in [9] the author presents a whole series of different definitions of qualitative stability.

3. A Quantitative Approach to Defining Stability

Let the statistic $T(x_1,\ldots,x_n)$ be given and the ideal model $F_0 \in S$ and some supermodel $S_\eta = \bigcup_{F_0 \in S} \{F{:}d(F_0,F) < \eta\}$ be defined. The quantitative approach to the stability of statistical procedures reflects the goal that we wish to achieve with respect to the criterion of the quality of statistic T. Of course, the goals can be extremely variegated, which gives rise to a whole series of definitions [2,10].

Let us define the functional of the quality of statistic T for FR F in terms of Q(T).

Definition 1. The real function $_T(F)$, which represents the FR's space in R^1 and is defined in the form

$$\Gamma_T(F) = \sup \{Q_F(T), F \in S_\eta\} - \inf \{Q_F(T), F \in S_\eta\},$$

is called Q, or the stability of statistic T relative to the enlargement of S to S_η.

Definition 2. Statistic T_1 is more stable than statistic T_2 if for each $F \in S_\eta$: $\Gamma_{T_1}(F) \leq \Gamma_{T_2}(F)$.

Definition 3. Statistic T is uniformly more stable in the class of statistics m if $\Gamma_T(F) \leq \Gamma_{T'}(F)$ for all $F \in S_\eta$ and all $T' \in m$.

Definition 4. Statistic T is absolutely stable if $\Gamma_T(F) = 0$ for each $F \in S_\eta$.

Let us now examine the given class of statistics $T(\Psi; x_1, \ldots, x_n)$, the specific structure of which is determined by some function $\Psi \in M$ and let us be interested in achieving the minimum of $Q_F(T)$. The minimax approach then leads to the following definition /2/:

Definition 5. $\Gamma_T^*(F)$, defined in the form

$$\Gamma_T^*(F) = \min_{\Psi \in M} \max_{F \in S_\eta} Q_F(T(\Psi, x_1, \ldots, x_n)),$$

is called minimax Q, or the stability of statstic T in class m relative to the supermodel S_η.

4. Characteristics of the Stability of Evaluations

Let it be necessary to evaluate some parameter Θ, given in the form of a functional $T(F)$; $F_0, F \in S_\eta$. The choice of the appropriate functional is made on the basis of the definitions of qualitative stability. We will look for the evaluation of the parameter in the form $T(F_n)$. For many known evaluations the following asymptotic representation is correct /2/:

$$T(F_n) = T(F) + \int \Omega(x; F, T) dF_n(x) + O_p(n^{-1/2}), \quad (3)$$

where $\Omega(x;F,T)$ is the effect function introduced by Hampel, which is defined in the form

$$\Omega(x; F, T) = \lim_{\varepsilon \to 0} (T(F_{x,\varepsilon}) - T(F))/\varepsilon,$$

where

$$F_{x,\varepsilon}(y) = (1 - \varepsilon)F(y) + \varepsilon c(y - x), \; c(\vartheta) = \{1 : \vartheta \geq 0, 0 : \vartheta < 0\}.$$

Effect function $\Omega(x;F,T)$ is the most important local characteristic of the stability of evaluation T and characterizes the effect of an individual observation on the value of the evaluation. In connection with this, it is used intensively during the study of the effect of "overshoots" and "malfunctions" on statistical procedures. Besides this, from (3) it follows that $\sqrt{n}(T(F_n) - T(F))/\sigma_F(T)$ has an asymptotically standard normal distribution, with $\sigma_F^2(T) = \int \Omega^2(x;T,F)dF$. For this class of evaluations the natural quality criterion $Q_F(T)$ is dispersion $\sigma_F^2(T)$, and all the definitions in Paragraph 3 can be formulated by using $\sigma_F^2(T)$. Some numerical characteristics of the stability of evaluations can be determined directly, in terms of the effect function /9/:

1. Sensitivity of evaluations T to gross errors ("malfunctions") is defined in the form $\gamma_F(T) = \sup_x |\Omega(x;F,T)|$.

2. Sensitivity to grouping and rounding off is defined with the help of Lipshits's constant $\lambda_F(T) = \sup_{x \neq y} \{|\Omega(x;F,T) - \Omega(y;F,T)|/|x - y|\}$.

The global characteristic of the stability of an evaluation is the "stability limit" (breakdown point), which characterizes the maximum possible deviation from the ideal model (in the sense of some distance, such as (Levi's)) at which the bias of the evaluation still remains limited. Let the deviation from the ideal model F_0 be given with the help of Levi's metrics:

$$d_L(F_0,F) = \inf \{\varepsilon : F(x - \varepsilon) - \varepsilon \leqslant F_0(x) \leqslant F(x + \varepsilon) + \varepsilon\}$$

and

$$B(\varepsilon) = \sup \{T(F) : d_L(F_0,F) \leqslant \varepsilon\}.$$

Stability limit ε^* is then defined in the form $\varepsilon^* = \sup \{\varepsilon : B(\varepsilon) < \infty\}$.

5. Example

It is necessary to evaluate parameter Θ according to the results of measurements

$$y_i = \Theta + \xi_i, \quad i = 1,\ldots,n, \tag{4}$$

where ξ_i are independent and identically distributed erros in measurements (interference) with FR $F(x)$. It is a well-known fact that if $F(x) = \Phi(x/\sigma)$, with being the standard normal distribution, the optimum evaluation is the sampling mean.

Let a measuring device with probability $1 - \varepsilon$ operate in its basic mode, in connection with which the measurement errors have FR $\Phi(x/\sigma)$ and with a low probability in the "malfunction" mode, in connection with which the FR is $\Phi(x/\sigma_1)$, $\sigma_1 > \sigma_0$. It is then the case that $n\sigma^2(\bar{x}) = (1 - \varepsilon)\sigma_0^2 + \varepsilon\sigma_1^2$. For $\sigma_0 = 1$, $\varepsilon = 0.1$ and $\sigma_1 = 3$ we have $\sigma^2(\bar{x}) = 1.8$, while for $\sigma_1 = 5$ we have $\sigma^2(\bar{x}) = 3.4$. Thus, the sampling mean's dispersion increases rapidly as σ_1 does and, moreover, it can even equal infinity /5/.

In order to illustrate several of the concepts that have been introduced, let us discuss the functional $T_\alpha(F)$, given inexplicitly in the form

$$\int_{F^{-1}(\alpha)}^{F^{-1}(1-\alpha)} F(2T_\alpha(F) - x)dF(x) = \frac{1 - 2\alpha}{2}, \quad 0 \leqslant \alpha < 1/2.$$

We will look for the evaluation of parameter Θ from (4) in the form $T_\alpha(F)$. It is not difficult to satisfy ourselves that the evaluation (we will label it H/L_α) has the form

$$H/L_\alpha = \text{med}\,\{M_{ij}, (i,j) \in S_{k+1,n-k}\},\ k = [\alpha n],$$

where $M_{ij} = (x_{(i)} + x_{(j)})/2$; $S_{k+1,n-k}$ = the set of pairs of indices (i,j) such that $k + 1 \leqslant i \leqslant j \leqslant n - k$; "med" means median. The characteristics of the H/L_α evaluation are derived in /11/.

The effect function of evaluation H/L_α has the form

$$\Omega(x;F,H/L_\alpha) = A(\alpha,F)\cdot\begin{cases}(1 - 2\alpha)\,\text{sgn}\,x, & |x| > F^{-1}(1 - \alpha)\\ 2F(x) - 1, & |x| < F^{-1}(1 - \alpha).\end{cases}$$

The sensitivity to gross errors is $\gamma_F(H/L_\alpha) = (1 - 2\alpha)A(dF)$.

The sensitivity to grouping and rounding off if

$$\lambda_F(H/L_\alpha) = 2A(\alpha,F)\cdot f(x_m),$$

where x_m = the mode of the density $f(x)$, $A(\alpha,F) = 1/2 \int_\alpha^{1-\alpha} f(F^{-1}(t))dt$.

Sensitivity limit ε^* of evaluation H/L_α is

$$\varepsilon^* = \begin{cases}1 - 1/2(2(1 - 4\alpha^2))^{1/2}, & \alpha < 1/6,\\ 4^{-1}(1 + 2\alpha), & \alpha > 1/6.\end{cases}$$

For the purpose of comparison, the characteristics of several evaluations for a normal distribution are presented in the table below.

Evaluation	σ^2_Φ	γ_Φ	λ_Φ	ε^*
$\bar{x}$	1.000	∞	1.00	0.00
med	1.571	1.25	∞	0.50
H/L	1.047	1.77	1.41	0.29
$H/L_{0.1}$	1.092	1.52	1.52	0.31
$H/L_{0.2}$	1.170	1.40	1.86	0.35

Thus, the evaluations' characteristics are substantially different and the choice of the appropriate evaluation must be determined by the goal we wish to achieve.

BIBLIOGRAPHY

1. Tukey, T.W., "A Survey of Sampling From Contaminated Distributions," in "Contributions to Probability and Statistics," Stanford University Press, 1960, pp 448-486.

2. Huber, P.J., "Robust Statistics: a Review," ANN. MATH. STAT., Vol 43, 1972, pp 1041-1067.

3. Fraser, D.A.S., "Nonparametric Methods in Statistics," W., N.V., 1957.

4. Gayek, Ya., and Shidak, Z., "Teoriya rangovykh kriteriyev," /Theory of Rank Criteria/, Izdatel'stvo "Nauka", 1971.

5. Yershov, A.L., "Stable Methods for Evaluating Parameters," AVTOMATIKA I TELEMEKHANIKA, No 8, 1978, pp 66-100.

6. Bickel, P.J., and Lehman, E.L., "Descriptive Statistics for Nonparametric Models: I. Introduction," ANN. STAT., Vol 3, 1975, pp 1038-1044.

7. Kendall, M.Dzh., and St'yuart, A., "Statisticheskiye vyvody i svyazi" /Statistical Conclusions and Connections/, Izdatel'stvo "Nauka", 1973.

8. Bickel, P.J., SCAND. J. STATIST. THEORY AND APPL., Vol 3, No 4, 1976, pp 145-168.

9. Hampel, F.R., Ph.D dissertation, University of California (Berkeley), 1968.

10. Zielinski, R., BULL. DE L'ACADEMIE POLONAISE DES SCIENCES. SERIE DES SCIENCES MATH., ASTR. ET PHYS., Vol 25, No 12, 1977, pp 1281-1286.

11. Shulenin, V.P., "On the Stability of the Hodges-Leman Class of Evaluations," in "VII Vsesoyuznaya konferentsiya po teorii kodirovaniya i peredachi informatsii" /Seventh All-Union Conference on the Theory of Information Encoding and Transmission/, Moscow-Vil'nyus, Part 6, 1978, pp 147-151.

12. Dmitriyev, Yu.G., Koshkin, G.M., Simakhin, V.A., Tarasenko, F.P., and Shulenin, V.P., "Neparametricheskoe otsenivaniye funktsionalov po statsionarnym vyborkam" /Nonparametric Evaluation of Functionals According to Fixed Samples/, Izdatel'stvo Tomskogo universiteta, 1974.

ADAPTIVE PROCESSING OF TWO-COMPONENT NOISE SIGNALS

[Article by V. P. Peshkov pp 119-121]

/Text/ Let us discuss the problem of detecting an additive mixture $S(t) = S_1(t) + S_2(t)$ of narrow-band $S_1(t) = A(t)\cos[\omega_0 t + \Psi(t)]$ and broad-band $S_2(t)$ Gaussian signals against a background of Gaussian interference $N(t)$ under conditions of prior indeterminacy (the central frequency and band $\Delta\omega$ of signal $S_1(t)$ are unknown, as are the correlation functions $K_{S_2}(t,t_1)$ and $K_N(t,t_1)$.

According to results published in /1,2/, the optimum receiver for a two-component signal is a two-channel one.

The Broad-Band Channel. The adaptive detector of the signal's broad-band component is realized on the basis of narrow-band spectral analysis (on the basis of a BPF /expansion unknown/, for example) with subsequent weighted storage that allows for the spectral properties of the signals and the interference /2/. In connection with this, detection is accomplished in two stages.

During the first stage, nonoptimum temporal processing with a preselector in the form of an ideal band-pass filter takes place for the purpose of determining the reference channels. In order to do this, the results of the processing in each spatial channel are retained for several review cycles. The matrix of numbers $M = N \times m$ that is obtained is used to determine the threshold by successive determination of the signal channels and the elimination of them from the procedure of computing the threshold in the next iteration. The procedure is repeated until newly segregated signal channels are not observed after a normal iteration.

In the second stage there is an evaluation of the spectral densities $g_N(\omega)$ and $g_{SN}(\omega)$, the transmission factor /2/ is formed, and there is adaptive processing in each spatial channel, using the iterative procedure for computing the thresholds.

The results of modeling showed that a given algorithm makes it possible, after several iterations, to eliminate almost completely the effect of the signal channels on the magnitude of the threshold, achieve a given false alarm probability, and detect a signal with a high degree of reliability.

The Narrow-Band Channel. The above-mentioned iterative procedure for determining the threshold can also be used in the channel for the detection of narrow-band signals, in connection with which: spectral analysis of the input sample is performed according to the BPF's algorithm; from the mass of numbers that is obtained, sliding is used to form groups of numbers (with $2\ell + 1$ numbers per group), in each of which there is a minimum number; from the mass of numbers that is obtained, an evaluation of the interference spectrum is formed by smoothing it with respect to $2p + 1$ numbers; obeleniye /translation unknown/ of the input signal's spectrum is carried out by dividing it by the obtained evaluation of the input spectrum; the recurrent threshold computation procedure that was explained above is applied, with segregation and elimination of the signal channels, and the excesses above the threshold are found.

The results of modeling of this algorithm showed that the error in evaluating the spectral density of the signal's narrow-band component does not exceed 1 dB, even in the most unfavorable situation, when there are also narrow-band components in the neighboring frequency channels.

In order to accomplish adaptation with respect to the band, it is necessary to combine all the adjacent elementary components that exceeded the threshold. An investigation of the algorithm that accomplishes the band adaptation showed that it is necessary to introduce two thresholds into the system: one threshold is used to evaluate the signal's band (gate), while the other, which provides a given false alarm probability, finds the excesses inside the gate that are then combined by cumulative or weighted storage. The determination of the gate can be by optimum or cumulative storage of the results of spectral analysis for several cycles. The modeling results showed that band adaptation increases resistance to interference and eliminates ambiguity in determining the number of discrete signal components during detection.

BIBLIOGRAPHY

1. Peshkov, V.P., "Band Optimization," in "Tezisy dokladov na Respublikanskoy nauchno-tekhnicheskoy konferentsii 'Problemy peredachi informatsii provodnymi kanalami svyazi'" /Summaries of Reports Given at the Republic Scientific and Technical Conference on "Problems of Information Transmission Over Wire Communication Links"/, Kiev, 1975.

2. Krasnyy, L.G., and Peshkov, V.P., "Adaptive Detection of Noise Signals," in "Trudy VIII Vsesoyuznoy shkoly-seminara po statisticheskoy gidroakustike" /Works of the Eighth All-Union School-Seminar on Statistical Hydroacoustics/, Novosibirsk, Institute of Mathematics, Siberian Department, USSR Academy of Sciences, 1977.

EFFECT OF CONCENTRATED REFLECTORS ON THE EFFECTIVENESS OF HYDROACOUSTIC INFORMATION PROCESSING

[Article by A. P. Trifonov and Yu. S. Radchenko pp 121-123]

/Text/ For a hydroacoustic information transmission channel, it is typical that reception of the useful signal's field $S_0(t,\vec{x};\vec{\ell}_0)$ takes place against a background not only of fluctuation noises, but also of interfering signals reflected from the bottom, the surface and intervening objects. Let us given the name "quasi-determined interference" to the group of n interfering signals $\{S_k(t,\vec{x};\vec{\ell}_k)$ $(k = \overline{1,n})$ with unknown parameters $\vec{\ell}_k = \{\ell_{k1},\ldots,\ell_{k\mu}\} \in \vec{L}$ that are present in the observed data with probabilities p_k.

Into receiving aperture D over time [0,T], let there enter a mixture $y(t,\vec{x})$ of the useful signal's field $S_0(t,\vec{x};\vec{\ell}_\alpha)$ (which depends on the vector of the parameters $\vec{\ell}_0 = \{\ell_{01},\ldots,\ell_{0\mu}\} \in \vec{L}$), the quasidetermined interference and Gaussian noise; the signal at the output of the receiver's linear part then has the form

$$M(\vec{\ell}) = \int_0^T \int_D y(t,\vec{x})B(t,\vec{x})dtd\vec{x} = z^2\{\lambda_0 S(\vec{\ell},\vec{\ell}_0) + \sum_{k=1}^{n} \frac{\lambda_k}{z_k} S_k(\vec{\ell},\vec{\ell}_k)\} + zN(\vec{\ell}), \qquad (1)$$

where $B(t,\vec{x})$ defines the structure of the receiving system /1/; z = useful signal-to-noise ratio; z_k = ratio of the useful signal's amplitude to the amplitude of the k-th interfering signal; $\{S_i(\vec{\ell},\vec{\ell}_i)\}$ $(i = \overline{0,n})$ = normalized signal functions (generalized indeterminacy functions) of the useful and interfering signals /2/. The term λ_0 equals either 0 or 1, with probability $p_k:\lambda_k = 1$ and with probability $q_k = 1 - p_k:\lambda_k = 0$.

Assuming that the receiving system is optimum only in the presence of a useful signal and noise at the input, let us find its characteristics when it is affected by quasidetermined interference. If the parameters of the useful and interfering signals are not known, one method for overcoming the prior indeterminacy is the maximum likelihood method (MMP). In accordance with the MMP, the detection algorithm has the form $M(\vec{\ell}_m) = \max M(\vec{\ell}) \gtrless h$, where h = the threshold. As an estimate of parameter $\vec{\ell}_0$ we will use $\vec{\ell}_m$, which is the location of the absolute maximum of $M(\vec{\ell})$ in area $\vec{L}$. In order to calculate the characteristics of the maximum likelihood receiver (PMP), it is necessary to know the distribution function of the absolute maximums of the field $M(\vec{\ell})$ in area $\vec{L}$. There is no precise solution to this problem, so let us use an approximate (asymptotically accurate) approximation of this distribution function. The approximation can be written as

$$F(h) = P[\max M(\vec{\ell}) < h] \simeq F_N(h) \prod_{k=0}^{n} F_k(h), \tag{2}$$

where, according to [2],

$$F_N(h) = \begin{cases} \exp[-\frac{\xi h^{\mu-1}}{(2\pi)^{\frac{\mu+1}{2}}} \exp(-\frac{h^2}{2})], & h \geqslant \sqrt{\mu - 1} \\ 0, & h < \sqrt{\mu - 1} \end{cases} \tag{3}$$

and for high signal-to-noise ratios z, $F_k(h)$ has the form

$$F_k(h) = q_k + p_k \Phi(h - z/z_k). \tag{4}$$

Here, $p_0 = 0$, $q_0 = 1$ if $\lambda_0 = 0$ and $z_0 = 1$, $p_0 = 1$, $q_0 = 0$ if $\lambda_0 = 1$. When deriving (2), (3) and (4), we used a method with division of the area into signal subareas $\{\vec{L}_k\}$ $(k = \overline{0,n})$ in the vicinity of points $\{\vec{\ell}_k\}$ and the noise subarea $\vec{L}_N$ that is supplementary to them. In the case where $S_0(t,\vec{x};\vec{\ell}_0)$ and $\{S_k(t,\vec{x};\vec{\ell}_k)\}$ are narrow-band wave fields with a random phase,

$$F(h) - F_N(h) \prod_{k=0}^{n} \{1 - p_k Q(z/z_k, h)\}. \tag{5}$$

In (5), Q(u,v) = a (Markum) function.

The probability α of a false alarm and β of signal transmission into the PMP can be written, using (2), (3) and (5), as

$$\alpha = P[\max M(\vec{\ell}) > h | \lambda_0 = 0] = 1 - F_N(h) \prod_{k=1}^{n} \{1 - p_k Q(z/z_k, h)\},$$
$$\beta = P[\max M(\vec{\ell}) < h | \lambda_0 = 1] = F_N(h) \prod_{k=0}^{n} \{1 - p_k Q(z/z_k, h)\}. \tag{6}$$

In (6), $p_0 = 1$, $z_0 = 1$. The results of the calculation of the characteristics of detection of an object at an unknown range according to formulas (6) for n = 1, in accordance with the criterion of an ideal observer, are presented in Figure 1. The solid curves are calculated for an optimum threshold h, which was selected with due consideration for the possible presence of interference. The broken curves are calculated for the threshold h = z/2, which is asymptotically optimum when detect- a signal against a background of noise.

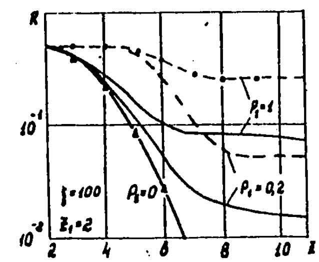


Figure 1. Total probability of detection error.

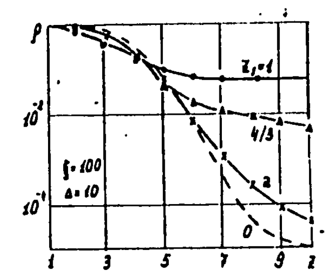


Figure 2. Provisional scattering of range estimate.

Let us characterize the reliability of the evaluation by probabilities $p^{(k)} = P[\vec{\ell}_m \in \vec{L}_k]$ $(k = \overline{0,n})$. Using (2), (3) and (5), $p^{(k)}$ can be written as

$$p^{(k)} = \int_{-\infty}^{\infty} \{F_N(h) \prod_{i=0}^{n} F_i(h)\} dF_k(h) = \int_{-\infty}^{\infty} F_N(h) h \exp\left[-\frac{h^2 + (z/z_k)^2}{2}\right] I_0\left(\frac{hz}{z_k}\right) \prod_{i=0}^{n} \{1 - p_i Q(z/z_i, h)\} dh. \quad (7)$$

If the accuracy of the evaluation is characterized by the scattering matrix (of the second starting moments of the errors) $\hat{V}(\vec{\ell}_0) = \langle(\vec{\ell}_m - \vec{\ell}_0) + (\vec{\ell}_m - \vec{\ell}_0)\rangle$, we obtain

$$\hat{V}(\vec{\ell}_0) = \sum_{k=0}^{n} p^{(k)}[\hat{a}_k + \hat{D}_k] + (1 - \sum_{k=0}^{n} p^{(k)})\hat{V}_N(\vec{\ell}_0). \quad (8)$$

Here, $\hat{a}_k = (\vec{\ell}_k - \vec{\ell}_0) + (\vec{\ell}_k - \vec{\ell}_0)$, $\hat{D}_k = (z_k/z)^2 \hat{S}_k^{-1} \hat{S}_0 \hat{S}_k^{-1}$, where $\hat{S}_k = \| [\partial^2 S_k(\vec{\ell}, \vec{\ell}_k)/\partial \ell_i \partial \ell_j] \vec{\ell}_k \|$. The systematic and fluctuational errors in the evaluation are determined in the subareas $\{\vec{L}_k\}$, while $V_N(\vec{\ell}_0) = \|\ell_{0i}\ell_{0j} + L_i^2 \delta_{ij}/12\|$ = matrix of anomalous errors related to taking a noise spike for a signal. The results of the calculation of the distance to an object, using formula (7) and (8) for $n = 1$, $\mu = 2$ are presented in Figure 2. Here, $\rho = 12V/L^2$, $\Delta = \ell_1 - \ell_0$. The signal functions $\{S_i(\ell, \ell_i)\}$ $(i = 0,1)$ were assumed to be bell shaped and of unit duration.

Theoretical relationships (6), (7) and (8) are asymptotically precise for $h \gg 1$, $\xi \gg 1$, $z \gg 1$. In order to establish the limits of their applicability, the detection and evaluation algorithms (according to the MMP) were modeled on a computer. The results are plotted in Figures 1 and 2.

BIBLIOGRAPHY

1. Gatkin, N.G., "Algorithms for the Optimum Spatiotemporal Processing of Random Fields," in "Trudy IV Vsesoyuznoy shkoly-seminara po statisticheskoy gidroakustike" /Works of the Fourth All-Union School Seminar on Statistical Hydroacoustics/, Kiev, 1972.

2. Kulikov, Ye.N., Radchenko, Yu.S., and Trifonov, A.P., "Characteristics of a Maximum Likelihood Receiver in the Presence of Quasidetermined Interference," IZVESTIYA VUZOV. RADIOELEKTRONIKA, Vol 9, 1978, pp 3-9.

ON THE QUALITY OF SOME EVALUATIONS OF MAXIMUM LIKELIHOOD

[Article by V. V. Borodin pp 123-125]

/Text/ The maximum likelihood principle is frequently used in problems involving the evaluation of random or unknown quantities.

It is frequently necessary to evaluate parameters on which the mean of the normal distribution depends in a complex, nonlinear fashion. In this article we investigate the quality of the maximum likelihood evaluation (OMP) in such a case.

Let there be a random vector quantity $\vec{y} = \{y_1, y_2, y_3\}$, distributed according to the normal law, with a unit covariance matrix and an average value $\vec{y}(\vec{x})$ that depends functionally on the two-dimensional vector $\vec{x}$, with

$$F(\vec{y}|\vec{x}) = \frac{\exp\{-(1/2)\|\vec{y} - \vec{y}(\vec{x})\|^2}{(2\pi)^{3/2}}. \quad (1)$$

Also, let:

1. the condition of separability be fulfilled for vector $\vec{y}(\vec{x})$; that is, $\vec{y}(\vec{x}_1) \neq \neq \vec{y}(\vec{x}_2)$ for all $\vec{x}_1 \neq \vec{x}_2 \in D$, where D = the area of change in vector $\vec{x}$;
2. function $\vec{y}(\vec{x})$ be continuously and twice differentiable;
3. Gramme's matrix $\Gamma_{ij}(\vec{x}) = \langle\partial_i\vec{y}(\vec{x}), \partial_j\vec{y}(\vec{x})$ be not degenerate for all $\vec{x}$ D. In connection with these assumptions, the probability density of the evaluation of $\vec{x}$--providing that the true value of $\vec{x}$ is $\vec{x}_0$--has the form

$$F(\vec{x}|\vec{x}_0) = \frac{\exp\{-(1/2)\|\vec{y}(\vec{x}) - \vec{y}(\vec{x}_0)\|^2 P(x)\}}{2\pi} \sqrt{\det \Gamma_{ij}(\vec{x})} \cdot$$

$$\cdot \int\limits_{I(x)}^{2} \prod_{s=1}^{2} (1 - t\varkappa_s(\vec{x})) \frac{e^{-(1/2)(t-t_0(\vec{x}))^2}}{\sqrt{2\pi}}\, dt. \quad (2)$$

The variables introduced here have the following meanings. Functions $\vec{y}(\vec{x})$ determine the two-dimensional surface R_2 in the sampling space Y. Operator $P(\vec{x})$ is the operator of the orthogonal projection onto the plane tangent to R_2 at point $\vec{y}(\vec{x})$. Variables $\varkappa_1(\vec{x})$ and $\varkappa_2(\vec{x})$ are the main Gaussian curvatures of surface R_2 at point $\vec{y}(\vec{x})$; $\vec{n}(\vec{x})$ is the unit vector of the normal to surface R_2 at this point; $t_0(\vec{x}) = \langle\vec{n}(\vec{x}),\vec{y}(\vec{x}_0) - \vec{y}(\vec{x})\rangle$. Interval $I(\vec{x})$ for which the integration is performed is determined in the following manner.

Let

$$\lambda_{1,2}(x) = \underset{\vec{x}'\in D}{\inf\atop\sup} \left\{\frac{2\langle\vec{n}(\vec{x}),\vec{y}(\vec{x}') - \vec{y}(\vec{x})\rangle}{\|y(x') - y(x)\|^2}\right\},$$

so that three different cases are possible: $\lambda_1 < \lambda_2 < 0$, $I(\vec{x}) = (\lambda_1^{-1}(\vec{x}),\infty)$; $\lambda_1 < 0 < \lambda_2$, $I(\vec{x}) = (\lambda_1^{-1}(\vec{x}),\lambda_2^{-1}(\vec{x}))$; $0 < \lambda_1 < \lambda_2$, $I(\vec{x}) = (-\infty,\lambda_2^{-1}(\vec{x}))$.

If vector $\vec{y}$ has n components, $\vec{y} = \{y_1,\ldots,y_n\}$, while the vector $\vec{x}$ being evaluated has (n - 1) components, $\vec{x} = \{x_1,\ldots,x_{n-1}\}$, and Conditions 1, 2 and 3 are applied to the vector as was done above, in this case the the probability density of the OMP--providing that the true value of $\vec{x}$ is $\vec{x}_0$, has the form

$$F(\vec{x}|\vec{x}_0) = \frac{\exp\{-(1/2)\|\vec{y}(\vec{x}) - \vec{y}(\vec{x}_0)\|^2 P(\vec{x})\}}{(2\pi)^{k/2}}\sqrt{\det\Gamma_{ij}(\vec{x})}\cdot \int_{I(x)} \prod_{s=1}^{n-1}(1 - t\varkappa_s(x))\frac{e^{-(1/2)(t-t_0(\vec{x}))^2}}{\sqrt{2\pi}}dt. \qquad (3)$$

Here $P(\vec{x})$ is the operator of the orthogonal projection onto the hyperplane that is tangent to hypersurface R_{n-1} at point $\vec{y}(\vec{x})$, ${}_s(\vec{x})$; $s = 1,\ldots,n - 1$ = main Gaussian curvatures of hypersurface R_{n-1} at this point. All the other terms have the same meaning as before.

In the general case, when vector $\vec{y}$ has n components, $\vec{y} = \{y_1,\ldots,y_n\}$, while vector $\vec{x}$ has k components, $\vec{x} = \{x_1,\ldots,x_k\}$, $k < n$, the expression for the provisional OMP probability density can be written in the following form:

$$F(\vec{x}|\vec{x}_0) = \frac{\exp\{-(1/2)\|\vec{y}(\vec{x}) - \vec{y}(\vec{x}_0)\|^2 P(\vec{x})\}}{(2\pi)^{k/2}}\sqrt{\det\Gamma_{ij}(\vec{x})} \int_{\Omega(x)} \frac{\det D_{ij}(\vec{y}|\vec{x})e^{-(1/2)\|\vec{y} - \vec{y}(\vec{x}_0) - \vec{y}(\vec{x})Q(\vec{x})\|^2}}{\det\Gamma_{ij}(\vec{x})(2\pi)^{(n-k)/2}Dy}. \qquad (4)$$

Here, $P(\vec{x})$ is the operator of the orthogonal projection on the plane tangent to surface R_k at point $\vec{y}(\vec{x})$; $Q(\vec{x}) = E - P(\vec{x})$; E = unit operator. Matrix $D_{ij}(\vec{y}|\vec{x})$ is given by the expression

$$D_{ij}(\vec{y}|\vec{x}) = \Gamma_{ij}(\vec{x}) - \langle\partial^2_{ij}\vec{y}(\vec{x}),y\rangle,$$

while area $\Omega(\vec{x})$, with respect to which the integration is carried out, lies wholly in the subspace of (n - k) measurements that is orthogonal to plane R_k at point $\vec{y}(\vec{x})$ and is determined by the following expression:

$$\Omega(\vec{x}):\{\vec{y} = Q(\vec{x})\vec{y}\Big|\sup_{\vec{x}'\in D}\frac{2\langle\vec{y},\vec{y}(\vec{x}') - \vec{y}(\vec{x})\rangle}{\|\vec{y}(\vec{x}') - \vec{y}(\vec{x})\|^2} < 1\}.$$

BIBLIOGRAPHY

1. Zaks, Sh., "Teoriya statisticheskikh vyvodov" /Theory of Statistical Conclusions/, Moscow, Izdatel'stvo "Mir", 1975.

GAUSSIAN SIGNAL DETECTION WITH A LONG OBSERVATION TIME

[Article by K. B. Krukovskiy-Sinevich pp 125-126]

/Text/ In a number of cases a return signal can be regarded as the reaction to the sounding message of a linear filter with a randomly changing transient characteristic of the form

$$h(t) = a(t)H(t), \qquad (1)$$

where a(t) and H(t) are random and regular functions, respectively. If we assume that $a(t_1)a(t_2) = \delta(t_1 - t_2)$ and examine sounding signals with an ambiguity function characterized by high resolution with respect to distance, from (1) it follows that

$$R(t_1,t_2) = R_0(t_1 - t_2)H(t_1)H(t_2). \qquad (2)$$

The terms in (2) are defined as follows: $R(t_1,t_2)$ = the return signal's correlation function; $R_0(t_1 - t_2)$ = the sounding message's correlation function. In /1/ there is a definition of an optimum (according to (Bayyes's) criterion) receiver for a weak Gaussian signal with a correlation function of type (2) and additive Gaussian interference. For a sufficiently homogeneous (within the observation limits (-T/2,T/2)) function H(t) and $\Delta FT \gg 1$, where ΔF is the effective width of the signal's spectrum, it is logical to use the Gaussian probability distribution law for the process taking place at the output. In this case the computation of the probabilities of false alarms and correct signal detection does not present any difficulties. However, as was pointed out correctly in /1/, the magnitude of the error related to the approximate model of the output process is not always obvious. In order to evaluate these errors, let us examine the following example:

$$H(t) = \begin{cases} H_0, & |t| < T/2, \\ 0, & |t| \geqslant T/2, \end{cases} \qquad (3)$$

$$F_0(\omega) = \begin{cases} E_0/\Delta F, & |\omega - \omega_0| < \pi\Delta F, \\ 0, & |\omega - \omega_0| \geqslant \pi\Delta F, \end{cases} \qquad (4)$$

where $F_0(\omega)$ = energy spectrum of the sounding signal; E_0 = its energy. As is known, the spectra of signals with linear and hyperbolic frequency modulation that are widely used in practice approximate the spectrum of type (4). For the indicated H(t) and $F_0(\omega)$, P_0--the probability of correct detection--is defined for different values of the product ΔFT and a fixed false alarm probability that equals 0.1. The detection characteristics were calculated both for the Gaussian approximation and without allowing for it. These computations showed that for $P_0 \sim 0.9$, the Gaussian approximation results in errors of less than 5 percent.

BIBLIOGRAPHY

1. Van Tris, G., "Teoriya obnaruzheniya otsenok i modulyatsii" /Theory of Detection of Estimates and Modulation/, Izdatel'stvo "Sovetskoye radio", Vol 3, 1977.

ON SELECTING THE INTERFERENCE CLASSIFIER FOR SIGNAL DETECTION SYSTEMS

[Article by A. M. Zil'bershteyn and Yu. S. Natkovich pp 126-127]

/Text/ We are discussing the problem of signal detection under conditions where the interference belongs to a given discrete set (the elements of which are assumed to be relabeled) and can be registered in "pure" form in the initial processing time interval preceding the moment of the signal's possible appearance. For such problems it is possible to use a two-step detection procedure /1/, according to which a sample of the pure interference is used for classification for the purpose of determining its probable number $\gamma \in \Gamma = \{\overline{1,n}\}$, while a "signal" sample is used for signal detection, assuming that the background is interference with the number γ that was selected during the first stage. The system that realizes the two-stage detection procedure contains the interference classifier and "engaged" (depending on its solutions) detectors.

In this article the feasibility of using a system with a classifier is evaluated by comparison with a system for the optimum processing of a signal sample alone (without taking the pure interference sample into consideration).

The basic goal of this investigation is to determine the requirements for a rule for classifying a pure interference sample (for given arbitrary detection rules in the channels), the implementation of which guarantees the advisability of using the two-step procedure.

Let us designate as $\phi_{k1}(y,x)$ the solving rules of a detection system that realizes the two-step procedure and the processing of pure interference sample y and signal sample x.

Let the following be given: conditions of full prior information; a detection rule optimality criterion that is the minimum probability of mistaken solution of $\Phi[\phi] = \sum_{\gamma \in \Gamma} \Phi_\gamma[\phi]$, where

$$\Phi_\gamma[\phi] = q\alpha_\phi(\gamma)\lambda\gamma + p \int_{\gamma\times\Theta} \beta_\phi(\gamma,\Theta)\lambda'(d(\gamma,\Theta)),$$

where ϕ = arbitrary detection solving rule; q, p = probabilities of interference or mixed situations; Θ = set of values of signal parameter Θ; λ_γ, λ' = prior distributions in Γ and $\Gamma \times \Theta$; $\alpha_\phi(\gamma)$, $\beta_\phi(\gamma,\Theta)$ = provisional false alarm and signal passage probabilities. The optimum detection rule for the signal sample alone is the (Bayyes) rule $\phi^*(x)$ (for a simple loss matrix). The use of $\phi_{k1}(y,x)$ in comparison with $\phi^*(x)$ is advisable if

$$\Phi[\phi_{k1}(y,x)] < \Phi[\phi^*(x)]. \qquad (1)$$

Statement 1. In order to fulfill (1) it is sufficient that for any $\gamma \quad \Gamma$,

$$\ell^{d=\gamma}(\gamma) > (1 - \Phi_\gamma[\phi^*(x)])(1 - \Phi_\gamma[\phi_{d=\gamma}(x)])^{-1} \qquad (2)$$

($d \in D = \overline{1,n}$ = solution of the classifier; $\ell^{d=\gamma}(\gamma)$ = provisional probability of the correct solution of the classifier; $\phi_\alpha(x)$ = channel rules).

Now let there be conditions of prior indeterminacy relative to λ_γ, λ', q and p; the optimality criterion is minimax for $\alpha_\phi(\gamma) \leqslant \alpha$, $\gamma \in \Gamma$.

The use of $\phi_{k1}(y,x)$ in comparison with the optimum $\tilde{\phi}(x)$ under such conditions is advisable if

$$\max_{\Gamma\chi\Theta} \beta_{\phi_{k1}(y,x)}(\gamma,\Theta) < \max_{\Gamma\times\Theta} \beta_{\tilde{\phi}(x)}(\gamma,\Theta). \qquad (3)$$

Statement 2. In order to fulfill (3) it is sufficient that for any $\gamma \in \Gamma$,

$$\ell^{d=\gamma}(\gamma) > (1 - \max_{\Gamma\times\Theta} \beta_{\tilde{\phi}(x)}(\gamma,\Theta))(1 - \max_{\Gamma\times\Theta} \beta_{\phi_{d=\gamma}(x)}(\gamma,\Theta))^{-1}. \qquad (4)$$

Classification rules satisfying conditions (2) or (4) can be obtained according to the results published in /2/.

BIBLIOGRAPHY

1. Natkovich, Yu.S., and Zil'bershteyn, A.M., "On One Two-Step Signal Detection Procedure," in "Doklady VII Vsesoyuznoy konferentsii po teorii kodirovaniya i peredachi informatsii" /Reports Given at the Seventh All-Union Conference on the Theory of Information Encoding and Transmission/, Moscow-Vil'nyus, Part 6, 1978, pp 96-101.

2. Fomin, A.S., "Classification of Observations Under Conditions of Indeterminacy," RADIOTEKHNIKA I ELEKTRONIKA, Vol 21, No 7, 1976, pp 1408-1416.

NOISE SIGNAL IDENTIFICATION UNDER CONDITIONS OF INTERFERENCE AND FREQUENCY-INDEPENDENT DISTORTIONS

[Summary of report by V. V. Geppener, V. B. Nazarov and M. A. Senilov pp 127-128]

/Text/ In this work we discuss questions relating to the identification of random noise signals (processes) in the presence of additive interference and frequency-dependent attenuation in the medium. Linear solution functions are derived and the existence of a condition of solving rule invariance to the power of the interference is indicated. With due consideration for the latter statement, the problem of formulating a linear solution function that is invariant to the effect of interference of unknown power is set. Various noise-resistant analogs of parametric and nonparametric solving rules are found.

There is also a discussion of solution rules that are invariant relative to frequency-dependent distortions in the medium. As experiments have shown, the construction on a digital computer of solving rules using invariant descriptions provides higher quality identification in comparison with noninvariant algorithms.

METHODS FOR DISCOVERING THE PROPERTIES OF OBJECTS ON THE BASIS OF THE ANALYSIS OF A SET OF RETURN SIGNALS

[Article by I. O. Arro, T. Yu. Sullakatko and V. R. Kheynrikhsen, pp 128-130]

/Text/ In many branches of science and technology (hydroacoustics, geology, flaw detection and so on) there arises the need to evaluate the parameters of an object that is being investigated. The informative signals are frequently return signals y(t), in which--along with the directly reflected signals $S_0(t)$ that characterize the object's external parameters and the attenuation caused by the medium--there appear components $S_i(t)$ that carry information about the object's internal parameters (configuration, material parameters and so forth) /1/:

$$y(t) = \sum_{i=0}^{n} S_i(t,\vec{x},\vec{\varkappa},\vec{\gamma}) + n(t),\ t \in [0,T], \qquad (1)$$

where n(t) = white noise; $\vec{x}(t)$ = vector of the information parameters; $\vec{\varkappa}(t)$ = vector of the completely known parameters; $\vec{\gamma}(t)$ = vector of the random (interfering) parameters.

Let us assume that the system has only one input and one output; that is, there is only one source of sounding pulses and a single return pulse receiver, although the dynamic and spatial characteristics of the electroacoustic converters must also be taken into consideration. Components $S_i(t)$ can frequently be regarded as linear, invarient (with respect to time) representations of the sounding signal u(t) /3/. In the absence of noise, the total, integrated Fourier spectrum $\dot{S}_y(j\omega)$ from the received signal forms the sum of the spectra of the component pulses:

$$\dot{S}_y(j\omega) = \sum_{i=0}^{N} \dot{S}_i(j\omega),\ \omega \in (-\infty,\infty).$$

The latter are formulated from the object by the sounding signal's spectrum:

$$\dot{S}_i(j\omega) = \dot{S}_v(j\omega)\dot{F}_i(j\omega), \tag{3}$$

where $\dot{F}_i(j\omega)$ = a component transfer function.

All the information about the object is contained in the set of component transfer functions $\{\dot{F}_i(j\omega)\}$. The object's total transfer function is:

$$\sum_{i=0}^{N} \dot{F}_i(j\omega) = \dot{S}_y(j\omega)/\dot{S}_v(j\omega). \tag{4}$$

If $\dot{F}_i(j\omega)$ is known with an accuracy of up to the constant factors of the real and imaginary parts; that is,

$$\dot{F}_i(j\omega) = a_{ci}a_i(\omega) + jb_{si}b_i(\omega), \tag{5}$$

where $a_i(\omega)$, $b_i(\omega)$ = given functions; a_{ci}, b_{si} = unknown variables, the problem can be solved on the basis of the method of least squares as applied to the real and imaginary parts of equation (4). In the general case, $\dot{F}_i(j\omega)$ should first be approximated by a function determined by the least number of parameters for the given approximation accuracy. These parameters' specific values are determined on the basis of the selected quality criterion until equation (4) is satisfied. However, this method is not advisable, because even for simple, realized, physical transfer functions, the number of parameters selected is quite large.

If the sounding signal is a harmonic oscillation of unit amplitude; that is,

$$\dot{S}_v(j\omega) = \delta(\omega - \omega_0), \tag{6}$$

the object's total transfer function is determined by (7):

$$\sum_{i=0}^{N} F_i(j\omega_0) = \dot{S}_y(j\omega_0) = A_{yc} + jA_{ys} = \sum_{i=0}^{N} (A_{ic} + jA_{is}). \tag{7}$$

Equation (7) does not make it possible to determine A_{ic} and A_{is}, since they also acquire new values when the frequency changes. However, some integral estimate can be obtained if the sounding signal is a narrow-band one relative to $\dot{F}_i(j\omega)$, but finite in duration τ_u. The received signal then has the form

$$y(t) = \sum_{i=0}^{N} A_i a(t - \tau_i)\cos\,[\omega_0 t - \phi_i], \tag{8}$$

where $a(t)$ = normalized envelope of the sounding signal; A_i, τ_i = amplitude and time lag of the i-th pulse; ϕ_i = initial phase of the i-th pulse, which can be random. A matter of practical interest is the processing of the low-frequency, integrated envelope in square channels, which is equivalent to the introduction of new coordinates A_{ic} and A_{is}:

$$A_{ic} = A_i\cos\,\phi_i,\; A_{is} = A_i\sin\,\phi_i. \tag{9}$$

The vector of information parameters is transformed accordingly:

$$\vec{x} = \{\vec{A},\vec{\tau},\vec{\phi}\} \to \{\vec{A}_c,\vec{A}_s,\vec{\tau}\}. \tag{10}$$

If we assume that $\vec{\tau}$ is known or enlarge the number of equations to each element of resolution with respect to lag, it is possible to find A_{ic} and A_{is} as the solutions of the following equations:

$$\sum_{i=0}^{N} K_{ij}A_{ic} = B_{jc}, \quad \sum_{i=0}^{N} K_{ij}A_{is} = B_{js}, \quad 0 < j < N, \qquad (11)$$

where

$$K_{ij} = \int_0^T a_j(t - \tau_j)a_i(t - \tau_i)dt, \quad k_{ii} = 1,$$

$$B_{jc} = \int_0^T y(t)2 \cos \omega_0 t a_j(t - \tau_j)dt, \quad B_{js} = \int_0^T y(t)2 \sin \omega_0 t a_j(t - \tau_j)dt.$$

For a long duration of the realization and a short duration of an element of resolution with respect to lag, the number of initial equations is extraordinarily large and it is advisable to solve the problem on the basis of adaptive search algorithms. The zero approximation (initial state) is obtained on the basis of a determination of the extreme values of B_{jc} and B_{js}, where $\tau_j \in [0,T]$ for all elements of resolution with respect to lag.

The test of the evaluative realization's convergence to the original one is made according to the mean-square criterion.

On the basis of what has been said, an adaptive correlation filter for evaluting the amplitudes and lags of the set of interfering radio pulses can be constructed according to the following block diagram:

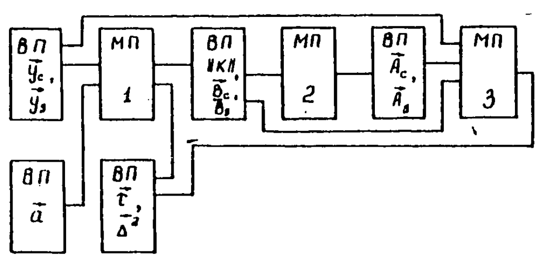


Figure 1. Block diagram of a quadrature measuring device: ВП = = memory unit; МП = microprocessors; 1 = correlator; 2 = solutions of linear equations; 3 = iterative procedure controls.

The properties of objects are determined on the basis of $\vec{A}_s$, $\vec{A}_c$, $\vec{\tau}$ and prior data, during secondary processing.

BIBLIOGRAPHY

1. Metsaveer, Ya.A., and Pikk, Yu., "Return Signal of Finite Pulse From a Cylindrical Shell Filled With a Liquid," IZVESTIYA AN ESSR. FIZIKA I MATEMATIKA, Vol 25, No 3, 1976, pp 260-268.

2. Nigul, U.K., editor, "Ekho-signaly ot uprugikh ob"yektov" /Return Signals From Elastic Objects/, Tallin, Institute of Cybernetics, Estonian SSR Academy of Sciences, Vol 2, 1974, p 346.

3. Kangur, O.E., Kollom, U.A., Ots, A.E., et al., "On an Algorithm for Determining the Parameters of Elastic Shells From Return Signals," in "AN SSSR IX Vsesoyuznaya akusticheskaya konferentsiya" /USSR Academy of Sciences' Ninth All-Union Acoustics Conference/, Moscow, 1977, pp 21-24.

ON AN ALGORITHM FOR THE REMOTE DETERMINATION OF PARAMETERS OF SHELLS

[Article by Ya. A. Metsaveer pp 130-134]

/Text/ In this article we will discuss the determination of the parameters of a single class of objects--thin elastic shells--on the basis of an acoustic return signal.

As the parameters of the return signal, let us use the amplitudes and times of arrival of the first return signals, as well as the shapes of these return signals and the shape of the sounding pulse. This difference in pulse shape is caused by distortions taking place during wave propagation in the shell or its filler and, consequently, is a carrier of information about the object's internal structure. Distortions in the shape of return signals can be divided into "quasi-steady-state" and "prefront." In order to define them, let us represent return signal $p_n(t)$ with the help of a Fourier integral, in the form

$$p_n(t) = \int_{-\infty}^{\infty} f^F(\omega)F_n(\omega)e^{-i\omega t}d\omega = \int_{-\infty}^{\omega_1}(\ )d\omega + \int_{\omega_1}^{\omega_2}(\ )d\omega + \int_{\omega_2}^{\infty}(\ )d\omega, \qquad (1)$$

where $f^F(\omega)$ = spectral density of the sounding pulse; $F_n(\omega)$ = transfer function (spectral characteristic function) on the n-th return signal; ω_1, ω_2 = limits of the frequency band beyond which function $f^F(\omega)$ equals zero, for all practical purposes. "Quasi-steady-state" means those distortions that are described by the integral from ω_1 to ω_2, while "prefront" means those for the description of which the remaining infinite integrals play an essential role.

In order to select the parameters of the quasi-steady-state approximation of the return signal, it is advisable to look for those constants that are invariant relative to the sounding pulse; that is, in terms of which the amplitudes, arrival times and quasi-steady-state distortions of individual return signals are defined for any sounding pulse. In order to find these parameters we should study the behavior of the individual return signals' transfer functions $F_n(\omega)$. As an example, Figure 1 depicts the absolute values of the functions $F_n(\omega)$ of several return signals from a cylindrical aluminum shell of thickness h/R = 0.05 that is filled with water and also immersed in water.

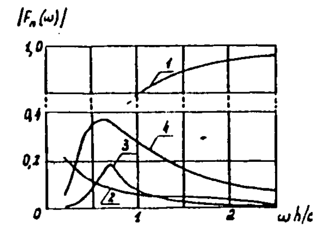


Figure 1: 1. reflected pulse; 2. first emitted pulse of momentless mode; 3. first emitted pulse of flexing mode; 4. first refracted pulse.

From the behavior of transfer functions $F_n(\omega)$ it follows that the latter are quite smooth and can be approximated by functions containing a small number of constant return signal parameters. A quasi-steady-state approximation of the return signal from a thin spherical or cylindrical shell can be represented approximately by the integral

$$p(t) = \int_{\omega_1}^{\omega_2} f^F(\omega)[F_0(\omega,a_{0j}) + \sum_{n=1}^{\infty} F(\omega,a_{nj})]e^{-i\omega t}d , \qquad (2)$$

where F_0, F = approximating functions for the reflected and secondary return signals' transfer functions; a_{nk} (n = 0,1,...) = constant approximations = parameters of the return signal; n = serial number of the return signal; j_0, k_0 = numbers of reflected and secondary return signal parameters. The following relationships can be used as transfer functions:

$$F_0(x,a_{0j}) = B_0(1 + a_{01}x^{-a_{02}})^{-1}\exp\ [i(a_{03} + a_{04}x + a_{05}\text{arctg}\ a_{06}x)],$$
$$F(x,a_{nk}) = B_0x^{a_{n1}}\exp\ \{a_{n2} + a_{n3}x + a_{n4}x^2 + i[a_{n5} + a_{n6}x + a_{n7}\text{arctg}\ (a_{n8} + a_{n9}x)]\}, \qquad (3)$$

where $x = 2\pi fh/c$; f = frequency of the oscillations. Such a representation of the return signal means expansion of the signal into separate return pulses. The information in each pulse is determined by the small numbers j_0 or k_0. It stands to reason that the number of these return signal parameters is significantly greater than the investigated object's (shell's) number of parameters. Therefore, it turns out to be advisable to divide the return signal's parameters into basic and auxiliary ones; the introduction of this concept proves to be necessary only in order to find the return signal's basic parameters. A return signal's basic parameters can be used as the most constant approximations of the transfer functions, as well as some combinations of the latter. For example, in the case of empty, circular, cylindrical shells, by taking $a_{n1} = 0$, n = 0,1,2, in (3), as the return signal's basic parameters we can use the constants a_{04} and a_{n2}, a_{n3} and a_{n4} for n = 1,2, as well as a_{16} where the pulse with index n = 1 corresponds to the first reflected pulse of the momentless mode and the one with index n = 2 corresponds to the first reflected pulse of the flexing mode. If the shell's parameters lie within the limits β = 2.40-3.80; γ = 2.50-9.00; Δ = 0.01-0.05, the basic return signal parameters mentioned above are determined in terms of the latter by the formulas

$$B_0 = (R/L)^{1/2}/2,\ a_{04} = 2(L - R)/h;$$

. . . .

$$
\begin{aligned}
a_{12} &= 1.88 + 1.02\varepsilon - 0.63\beta + 0.28\gamma - 0.21\varepsilon\beta + 0.04\varepsilon\gamma - 0.01\beta\gamma; \\
a_{13} &= 3.32 + 1.96\varepsilon + 1.38\beta - 0.95\gamma + 0.29\varepsilon\beta - 0.08\varepsilon\gamma + 0.01\beta\gamma; \\
a_{14} &= -6.00 - 1.94\varepsilon - 0.21\beta + 0.40\gamma; \\
a_{16} &= [0.93 + \exp(1.86 - 0.60\beta)]/\Delta; \\
a_{22} &= -2.81 - 2.40\varepsilon - 0.14\beta - 1.04\gamma + 0.86\varepsilon\beta + 0.06\varepsilon\gamma + 0.32\beta\gamma; \\
a_{23} &= -4.14 + 1.86\varepsilon + 2.36\beta + 0.83\gamma - 0.47\varepsilon\beta - 0.04\varepsilon\gamma + 0.19\beta\gamma; \\
a_{24} &= 2.52 - 0.12\varepsilon - 1.10\beta - 0.13\gamma,
\end{aligned}
\tag{4}
$$

where $\varepsilon = \ln \Delta$; $\Delta = h/R$; $\beta = [E/(1 - \nu^2)\rho_1]^{1/2}/c$; $\gamma = \rho_1/\rho$; L = distance to the shell's axis; R, h = radius and thickness of the shell; E, ν, ρ_1 = modulus of elasticity, Poisson's ratio and density of the shell's material; ρ, c = density of and speed of sound in the medium surrounding the shell.

The search for the return signal's parameters (approximation constants) according to its realization is the subject of /5/. In order to determine the object's parameters, the transfer functions of the individual return signals that have been found should be identified. This should be considerably simpler if it is known to what class the object being investigated belongs.

In order to establish whether a shell is empty or filled with a liquid, it is sufficient to investigate the amplitude of the first reflected pulse. If the reflected pulse's amplitude is a function of frequency ω, the shell is filled with a liquid; otherwise, it is empty.

For the classes of shells being investigated, having dependences of types (3) and (4) in order to determine a shell's parameters according to the quasi-steady-state approximation of the return signal, it is sufficient to: 1) obtain from a recorded return signal the transfer functions for a small number of first return pulses; 2) establish the class of the shell; 3) identify the obtained transfer functions; 4) find the approximation constants of the transfer functions of the reflected and first emitted pulses in the momentless and flexing modes (of the first refracted pulses, also, in the case of shells filled with a liquid); 5) find the shell's parameters by solving, for example, a system of type (4) in the least squares sense. Let us mention here that the algorithms for determining the parameters of the shell and the filler that were presented here were done so only for the purpose of demonstrating the theoretical possibility of determining all the shell and filler parameters with the exception of the shell's material's Poisson ratio. The latter cannot be determined from the return signal, since a change in it within limits of 0.2-0.3 has no effect on the return signal's parameters for all practical purposes.

In the case of complex shells, the return signal consists of separate return pulses, each of which has its own excitation mechanism, so that the deterministic approach for determining their structure that we have been discussing is not applicable.

BIBLIOGRAPHY

1. Hickling, R., "Analysis of Echoes From a Hollow Metallic Sphere in Water," J. ACOUST. SOC. AMERICA, Vol 36, No 6, 1964, pp 1124-1137.

2. Metsaveer, Ya.A., "On the Scattering of Waves by Elastic, Spherical Shells in an Acoustic Medium" YZVESTIYA AN EST. SSR. FIZIKA I MATEMATIKA, Vol 19, No 4, 1970, pp 415-422.

3. Metsaveer, Ya.A., and Pikk, Yu.P., "Return Signal of a Finite, Spherical Pulse From a Spherical Shell Filled With a Liquid," PRIKLADNAYA MATEMATIKA I MEKHANIKA, Vol 40, No 4, 1976, pp 648-654.

4. Kheyfets, Ye.I., and Shenderov, Ye.L., "Formation of Caustics /probably Acoustics/ During the Interaction of Sound With Shells," AKUSTICHESKIY ZHURNAL, Vol 18, No 3, 1972, pp 456-463.

5. Arro, I., Sullokatko, T., and Khaynrikhsen, V., "Methods for Determining the Properties of Objects on the Basis of an Analysis of a Set of Return Signals," this collection, p 148.

MEASURING THE QUALITY FACTOR OF THE PRIMARY FILTERS OF A HUMAN BEING'S DIRECTIONAL AUDITORY SYSTEM

[Article by L. A. Zhestyannikov, V. A. Zverev and V. A. Chaplygin pp 134-135]

/Text/ A model of the human directional auditory system that was constructed on the basis of an algorithm for aperture synthesis in the frequency area has been used to measure the quality factor of the human directional auditory system's primary filters. It has been demonstrated theoretically that in the adopted model, the intensity of the sound from a sonic source that is perceived by a person, even without allowing for diffraction of the sonic waves around the head, essentially depends on the angular position of the sonic source in the horizontal plane, on the emitted signal's spectrum, and on the primary filters' quality factor. Since the emitted signal's spectrum is a physically measurable value, experimental data on reducing the intensity of the sonic source's emissions that are sensed subjectively by a human being when the source's angular position changes make it possible to determine the primary filters' quality factor. However, a man cannot measure the intensity of a sound-emitting source subjectively, but can only compare the sound from sources that are turned on in sequence or determine the threshold of perception of one signal against a background of another one. Besides this, a strict accounting of the frequency-dependent effects of sonic wave diffraction around the head of a listener is extremely difficult, so a measurement technique was chosen that includes the use of headphones and a delay line that simulates an angular shifting of the source through 35°. As test signals we used two noncoherent noise signals, one being in a broad band up to 18 kHz, while the other was in a 1-kHz band with an average frequency of 1 kHz. The broad-band noise was constantly suppressed, while the narrow-band noise was controlled by a pulse generator during the time intervals when the electronic key was open. The pulses lasted for 1 second, with a pause in between of 10 seconds. The listeners determined the binaural threshold of audibility of the narrow-band noise signal against the background of the broad-band signal in both the presence and absence of a lag in one of the stereo signal channels. The threshold was registered on an automatic recorder. The measured audibility threshold values were used to calculate the primary filters' quality factor, which came to a quality factor value $Q = 4.1 + 0.4$. The measured quality factor value was somewhat less than that obtained by E. Tsviker and R. Fel'dkeller (Q = 6) and approximates the values obtained by measurements made directly at the basilar membrane of a dead body. The value obtained for the quality factor of the primary filters of a human being's directional auditory system is indicative of the absence of accentuation of the frequency characteristics of the filters of a human being's auditory system on the neuron level.

PRINCIPLES OF THE DESIGN OF AN OPERATIONAL SYSTEM FOR PREDICTING THE ACOUSTICAL SITUATION IN THE OCEAN

[Article by V. V. Ol'shevskiy, V. S. Timerkayev and Z. D. Usmanov pp 135-139]

/Text/ The most effective method for investigating the ocean is the acoustical method /1-7/. Therefore, the interest of investigators in creating acoustical-ocean-oceanographic models and developing methods for predicting its characteristics on just this basis is completely natural. Along with this, various aspects of the theory and methods of pattern identification have been developed in recent years, which places in the investigator's hands an effective and constructive tool for the solution of problems of this nature. Let us discuss the basic concepts that are needed in the solution of the problem of acoustico-oceanographic prediction and examine some questions concerning the design of an operational system for the computer realization of prediction algorithms.

1. Basic Concepts. Let us introduce (see, for example, /4-7/) three sets Θ_X, Θ_Y and Θ_Z corresponding to the description of the characteristics of acoustical fields in the ocean, $\vec{X}(\vec{\alpha}) \in \Theta_X$; the acoustical characteristics of the ocean, $\vec{Y}(\vec{\beta}) \in \Theta_Y$, and oceanographic characteristics, $\vec{Z}(\vec{\gamma}) \in \Theta_Z$, where $\vec{X}(\vec{\alpha})$, $\vec{Y}(\vec{\beta})$ and $\vec{Z}(\vec{\gamma})$ are vector functions describing the elements of these sets. Vector function $\vec{X}(\vec{\alpha})$ is understood to mean the set of functions defining the dependences of different parameters of the acoustical fields (levels, correlation functions, probability distributions and so on) on the spatiotemporal coordinates and the frequency; vector function $\vec{Y}(\vec{\beta})$ is understood to mean the set of functions defining the dependences of the ocean's acoustic parameters (reflection, scattering and absorption factors and so on) on the spatiotemporal coordinates and the frequency; vector function $\vec{Z}(\vec{\gamma})$ is understood to mean the set of functions defining the dependences of the oceanographic characteristics (wave action on the surface, the ocean's biological composition, water temperature and salinity, bottom soil composition and so on) on the spatiotemporal coordinates.

Many years of research in oceanography and ocean acoustics [1-7] have been essentially directed at obtaining a mapping of the ocean's hydrophysical characteristics into acoustical ones; that is, in formulating equations of the type

$$\vec{X}(\vec{\alpha}) = P_{XY}\{\vec{Y}(\vec{\beta})\}, \quad (1)$$

$$\vec{Y}(\vec{\beta}) = P_{YZ}\{\vec{Z}(\vec{\gamma})\}, \quad (2)$$

where P_{XY} and P_{YZ} are operators of the indicated mappings, different components of which can be determinant as well as stochastic. Naturally, we can also talk about mappings that are the reverse of (1) and (2):

$$\vec{Z}(\vec{\gamma}) = Q_{ZY}\{\vec{Y}(\vec{\beta})\}, \ \vec{Y}(\vec{\beta}) = Q_{YX}\{\vec{X}(\vec{\alpha})\},$$

where Q_{ZY} and Q_{YX} are operators that are the reverse of P_{YZ} and P_{XY}, respectively.

Let $\hat{\Theta}_x$, $\hat{\Theta}_y$, $\hat{\Theta}_z$, $\hat{P}_{xy}$ and $\hat{P}_{yz}$ be data banks, respectively, of acoustic field characteristics, the ocean's acoustic characteristics, its hydrophysical characteristics, and the operators that define their relationships. It is obvious that $\hat{\Theta}_x \subset \Theta_x$, $\hat{\Theta}_y \subset \Theta_y$, $\hat{\Theta}_z \subset \Theta_z$, $\hat{P}_{xy} \subset P_{xy}$, $\hat{P}_{yz} \subset P_{yz}$, since data banks, in principle, cannot encompass all the possible situations of conditions in the ocean, but can only describe approximations to the general sets of such situations. These data banks contain both experimental data and the results of theoretical investigations in oceanography and hydroacoustics and are the basis for the creation of a system for predicting the acoustic situation in the ocean.

The design of the prediction system must be based on the principles of pattern identification [8-11], since--in our opinion--there exist no alternatives to this approach. Further, it is necessary to introduce a proximity (similarity) measure in the spaces Θ_x, Θ_y and Θ_z:

$$\begin{aligned} \sigma_x(k,\ell) &= \sigma_x[\vec{X}_k(\vec{\alpha}),\vec{X}_\ell(\vec{\alpha})], \\ \sigma_y(k,\ell) &= \sigma_y[\vec{Y}_k(\vec{\beta}),\vec{Y}_\ell(\vec{\beta})], \\ \sigma_x(k,\ell) &= \sigma_z[\vec{Z}_k(\vec{\gamma}),\vec{Z}_\ell(\vec{\gamma})], \end{aligned} \quad (3)$$

where σ_x, σ_y and σ_z must correspond to the existence of a solvable problem that is a question requiring a special discussion in each case; when solving the problem of predicting the acoustic situation, metrics of the Euclidean type can apparently be used.

2. Conceptual Model of Prediction of the Acoustic Situation. The information base of the prediction system is composed of data banks of the acoustic fields' characteristics $\hat{\Theta}_x$, the ocean's acoustic characteristics $\hat{\Theta}_y$, and oceanographic characteristics $\hat{\Theta}_z$. With their help, the operator banks $\hat{P}_{xy}$ and $\hat{P}_{yz}$ are formed and, further, a correspondence among vector functions $\vec{X}(\vec{\alpha})$, $\vec{Y}(\vec{\beta})$ and $\vec{Z}(\vec{\gamma})$, which are the subject of the identification process, is established.

Let us determine the two basic stages in solving the problem of predicting the acoustic situation in the ocean. The first stage is analysis of the information in the data banks and determination of the oceanographic characteristics' classes. The second stage is assignment of the spatiotemporal limitations on the situation being predicted and the actual solution of the prediction problem. From this point of view, let us examine the methodology for solving the formulated problem. Since the final goal is prediction of the acoustic situation, our features should be acoustic ones; that is, we should formulate the space of indicators $\vec{X}(\vec{\alpha})$. In connection with this, the objects to be identified are vector functions $\vec{Z}(\vec{\gamma})$, and the subsequent problem reduces to determining the subsets $\hat{\theta}_z$ of oceanographic characteristics such that

$$\hat{\Theta}_z = \cup \hat{\theta}_z. \quad (4)$$

In this case, naturally, the solution of the taxonomy problem requires the use in the space of acoustic indicators of a proximity measure of the type of (3) and the formulation of condition $\sup_{k,\ell} \sigma_x(k,\ell) < \sigma_{x0}$, where the threshold value σ_{x0} is chosen either on the basis of heuristic considerations using the available hypotheses, or by selection in connection with repeated solution of the taxonomy problem. The second variant for determining subsets (4) is to assign their desirable number, which--again--is formulated heuristically. With this, the problem of analysis is essentially taken care of.

The next (resultant) task is to preduct the acoustic situation. The input data for the prediction are the spatiotemporal limitations ($\vec{R}$, T); that is, in essence an indication of the area of the world ocean ($\vec{R}$) and the time interval (T) to which the prediction must be related. With the help of data bank $\hat{\Theta}_z$, limitations $\vec{R}$ and T determine indicators $\vec{Z}^{(R,T)}(\vec{\gamma})$ and, further, subsets $\cup \vec{\theta}_z^{(\vec{R},T)} \subset \hat{\Theta}_z$ that correspond to these limitations. Starting with the indicators

$$\vec{Z}^{(\vec{R},T)}(\vec{\gamma}) \in \cup \vec{\theta}_z^{(\vec{R},T)},$$

with the help of algorithms of type (1) and (2), the vector functions $\vec{X}^{(\vec{R},T)}(\vec{\alpha})$ of the acoustic situation in the ocean are determined, which process corresponds to solution of the prediction problem. When making the prediction, we can (naturally) take into consideration the probability distributions of the oceanographic characteristics within the limits of subsets (4).

2. Operational System. As follows from the discussion of the procedure for predicting the acoustic situation, its realization on a computer is related to the use of the data banks and packages of applied programs for processing oceanographic and acoustic information. For the effective solution of this problem on a computer, it is necessary to have an operational system /12/ that contains the following basic elements: an input data control system; a processor time regulation subsystem; a subsystem for distributing the memory and information among the different computer channels; a file control subsystem; a data bank and applied program bank control subsystem; an information representation control subsystem; a subsystem for interactive investigator-computer intercourse. Such an operational system must,

naturally, insure effective utilization of the computer, make it easy for the investigator to communicate with the computer and, finally, provide a high-quality solution to the prediction problem.

BIBLIOGRAPHY

1. Ol'shevskiy, V.V., "Statisticheskiye svoystva morskoy reverberatsii" /Statistical Properties of Marine Reverberation/, Moscow, Izdatel'stvo "Nauka", 1965.

2. Ol'shevskiy, V.V., "Statisticheskiye metody v gidrolokatsii" /Statistical Methods in Hydrolocation/, Leningrad, Izdatel'stvo "Sudostroyeniye", 1973.

3. Brekhovskiy, L.M., editor, "Akustika okeana" /Ocean Acoustics/, Moscow, Izdatel'stvo "Nauka", 1974.

4. Grubnik, N.A., and Ol'shevskiy, V.V., "An Acoustic Model of the Ocean," in "Trudy Pervogo seminara 'Akusticheskiye statisticheskiye modeli okeana'" /Works of the First Seminar on Acoustic Statistical Models of the Ocean/, Moscow, Acoustics Institute, USSR Academy of Sciences, 1977, pp 3-11.

5. Middleton, D., "A Statistical Acoustic Model of the Ocean," in "Trudy Pervogo seminara 'Akusticheskiye statisticheskiye modeli okeana'", Moscow, Acoustics Institute, USSR Academy of Sciences, 1977, pp 12-55.

6. Ol'shevskiy, V.V., "Models and Simulated Computer Experiments in Statistical Hydroacoustics," "Trudy Pervogo seminara 'Akusticheskiye statisticheskiye modeli okeana'", Moscow, Acoustics Institute, USSR Academy of Sciences, 1977, pp 70-85.

7. Middleton, D., and Ol'shevskiy, V.V., "Contemporary Problems in Constructing Acoustic Statistical Models of the Ocean," "Trudy Pervogo seminara 'Akusticheskiye statisticheskiye modeli okeana'", Moscow, Acoustics Institute, USSR Academy of Sciences, 1977, pp 86-89.

8. Zagoruyko, N.G., "Metody raspoznavaniya i ikh primeneniya" /Identification Methods and Their Utilization/, Moscow, Izdatel'stvo "Sovetskoye radio", 1972.

9. Zagoruyko, N.G., "Iskusstvennyy intellekt i empiricheskoye predskazaniye" /Artificial Intellect and Empirical Prediction/, Novosibirsk, Novosibirsk State University, 1975.

10. Yelkina, V.N., Zagoruyko, N.G., and Timerkayev, V.S., "The '75' Algorithm for Filling in Blanks in Empirical Tables," in "Vychislitel'nyye sistemy" /Computer Systems/, Novosibirsk, No 61, 1976, pp 3-11.

11. Dyuran, B., and Odell, P., "Klasternyy analiz" /Claster Analysis/, Moscow, Izdatel'stvo "Statistika", 1977.

12. Tsikritzis, D., and Bernstayn, F., "Operatsionnaya sistema" /Operational System/, Moscow, Izdatel'stvo "Mir", 1977.

ON SELECTING THE MINIMUM DISTANCE BETWEEN TWO ANTENNAS WHEN DETERMINING THE CORRELATION FUNCTION'S DEPENDENCE ON THE SPACE ANGLE

[Article by V. V. Buryachenko, V. S. Gorbenko and L. Ya. Taradanov pp 139-141]

/Text/ An acoustic interference field can be represented as a sum of isotropic and nonisotropic components. The interference field's nonisotropic component is characterized by dependence of its probability, spectral, correlational and other characteristics on the space angle, and is of the greatest interest when investigating a noise field.

In this article we determine the minimum allowable distance between two hydroacoustic antennas that eliminates the masking effect of the noise field's isotropic component when measuring the correlation function between the two antennas' outputs. The dependence of the correlation function between the two antennas' outputs on the space angle makes it possible to evaluate the angular heterogeneity of the nonisotropic noise sources.

On the basis of works /1,2/, the correlation function of the output processes of two transparent, discrete antennas is determined in general form by the expression

$$K(t_1,t_2|R_{pq}|) = \left(\frac{1}{2\pi}\right)^2 \sum_{pq}\sum \iiiint_{-\infty}^{\infty} H_p(j\omega_1)H_q^*(j\omega_2)K(t_1 - \tau_p, t_1 - \tau_q; \vec{\tau}_p, \vec{\tau}_q)d\tau_p d\tau_q d\omega_1 d\omega_2, \quad (1)$$

where $\vec{\tau}_p \in P$, $\vec{\tau}_q \in Q$ = radius of the antennas' elements' position vector; P, Q = = sets of elements of the first and second antennas, respectively; $|R_{pq}|$ = distance between the antennas' phase centers; $H_p(j\omega)$, $H_q(j\omega)$ = transfer functions of the antennas' elements (amplitude-phase distribution); $K(t_1,t_2;\vec{\tau}_p,\vec{\tau}_q)$ = spatiotemporal correlation function of the noise field.

For the case of an isotropic noise field, in the absence of angular correlation of the waves and antennas with equiamplitude distributions $H_p(j\omega) = H_q^*(j\omega) = A$, instead of (1) we obtain

$$K(\tau, |R_{pq}|) = 4A^2 \sum_{pq} \sum \int_0^\infty G(\omega) \frac{\sin(\omega/c)r_{pq}}{(\omega/c)r_{pq}} \cos \omega\tau d\delta, \qquad (2)$$

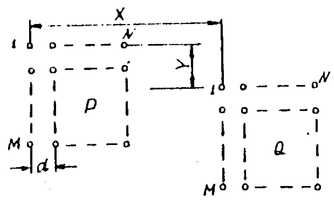
where $G(\omega)$ = frequency spectrum of the noise; $r_{pq} = |\vec{r}_p - \vec{r}_q|$; $\tau = t_1 - t_2$.

In the case of two identical plane antennas with an equidistant arrangement of the elements (see figure below), formula (2) can be converted into a form convenient for computer use:

$$K(\tau;X,Y) = 8\Pi A^2 \int_{f_H}^{f} G(f)\cos 2\pi f\tau \sum_{p=1}^{2N-1} \sum_{q=1}^{2M-1} (N - |N - p|)(M - |M - q|)\frac{\sin x}{x} df, \qquad (3)$$

where

$$x = \frac{2\pi fd}{c} - \sqrt{(N_x - N + p)^2 + (M_y - M + q)^2};$$



M, N = number of antenna elements in a row in the vertical and horizontal directions, respectively; $N_x = X/d$, $M_y = Y/d$ = displacements of the antennas relative to each other in units d, where d = distances between adjacent antenna elements horizontally and vertically; X, Y = horizontal and vertical displacements of the antennas.

Correlation function (3) can be defined in terms of an antenna's radiation pattern. In particular, for Y = 0:

$$K(\tau;X) = 2 \int_{f_H}^{f} G(f)\cos 2\pi f\tau \int_0 \int_0 R^2(\phi,\gamma;f)\cos\left(\frac{2\pi f}{c}X\cos\phi\sin\gamma\right)\sin\gamma d\gamma d\phi df. \qquad (4)$$

/Upper limit of integration for first integral in (3) and all integrals in (4) almost illegible./ For $\tau - X = 0$, from (4) we obtain:

$$K(0;0) = 4\pi \int_{f_H}^{f_3} \frac{G(f)}{K(f)} df, \qquad (5)$$

where k(f) = dependence of the antenna's concentration factor on the frequency.

Let us mention here that computation with formula (3) requires less computer time than when formula (4) is used.

In order to determine the minimum displacement between the antennas, it is necessary to assign some small value to the normalized correlation function for $\tau = 0$:

$$(0;X,Y) = \frac{K(0;X,Y)}{K(0;0,0)} < a, \qquad (6)$$

for example, a = 0.05. By using (3) and (5) and limitation (6), X and Y should be determined with the help of a computer. Then, during the experimental determination of $K(t_1,t_2;\vec{e})$, where $\vec{e}$ = the unit vector of the antennas' angular orientation, the masking effect of the noise field's isotropic component on the result of the measurement of the noise field's nonisotropic component's correlation function at the two antennas' outputs will be eliminated.

BIBLIOGRAPHY

1. Gatkin, N.G., and Gorbenko, V.S., "Some Models of the Correlation Functions of a Random Process's Field," in "Trudy IV Vsesoyuznogo simpoziuma. Metody predstavleniya i apparaturnyy analiz sluchaynykh protsessov i poley" /Works of the Fourth All-Union Symposium on Methods of Representation and Equipment Analysis of Random Processes and Fields/, Leningrad, Izdatel'stvo VNIIEP /All-Union Scientific Research Institute of Electrical Measuring Instruments/.

2. Gorbenko, V.S., Indyk, Yu.Ye., and Matsypura, V.T., "On the Spectral and Correlational Properties of Processes at the Output of a Rotating Antenna," in "Akustika i ul'trazvukovaya tekhnika" /Acoustics and Ultrasonic Technology/, Izdatel'stvo "Tekhnika", No 2, 1976, pp 115-118.

END