EXPERIMENTAL STUDIES OF LOW-FREQUENCY ACOUSTIC FIELDS IN A SHALLOW SEA

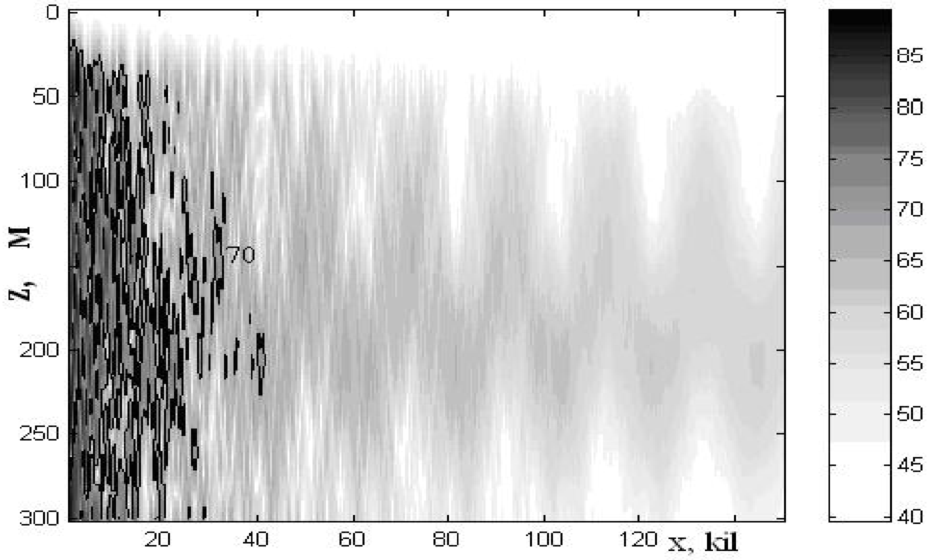
ALEXANDER G. LUCHININ

Institute of Applied Physics, Russian Academy of Science
46 Ulyanov Street, Nizhny Novgorod 603950, Russia
luch@hydro.appl.sci-nnov.ru

The results of the studies of excitation and propagation of low-frequency acoustic fields in a shallow sea, which have been carried out at the IAP RAS for several years, are discussed. A novel equipment complex designed specially for these experiments and intended for the selective excitation and reception of waveguide modes is described. Examples of measurements of various characteristics of low-order mode acoustic signals are given, which demonstrate high efficiency of the applied equipment and measurement technique.

INTRODUCTION

The study of the features of low-frequency sound propagation in a shallow sea is not, actually, a new problem. Numerous papers are devoted to it, dealing with theoretical, experimental, and field research results. In this context we shall refer to book [1] and the references in it. At the same time, a variety of the conditions of low-frequency sound propagation for long distances requires a detailed allowance for all significant factors affecting the characteristics of hydroacoustic systems of different assignment. Therefore, the contributions of these factors to the formation of space-time characteristics of acoustic fields and the possibilities of controlling these characteristics should be studied separately. Specifically, the majority of problems of applied acoustics require minimizing the influences of the bottom and the rough surface. Trivial considerations of this problem reveal the necessity of using vertically developed emitting and receiving antennas, which enable one to emit and receive modes minimally interacting with the bottom and the surface. Advantages of this type of antennas are illustrated in fig. 1 displaying the calculation of the field structure in a waveguide excited by a single radiator and an antenna with the amplitude-phase distribution, whose structure coincides with the first mode of the waveguide. Though the ideas concerning the application of such antennas were formulated rather long ago, the number of papers devoted to experimental results is not large. Below I will give a brief description of the equipment developed at the Institute of Applied Physics of RAS and a survey of some results obtained with the aid of this equipment in field researches fulfilled in the Baltic and Barents Seas in 2001-2005. Part of these results is given in original publications [2-7] and in the present paper for completeness of the presentation.



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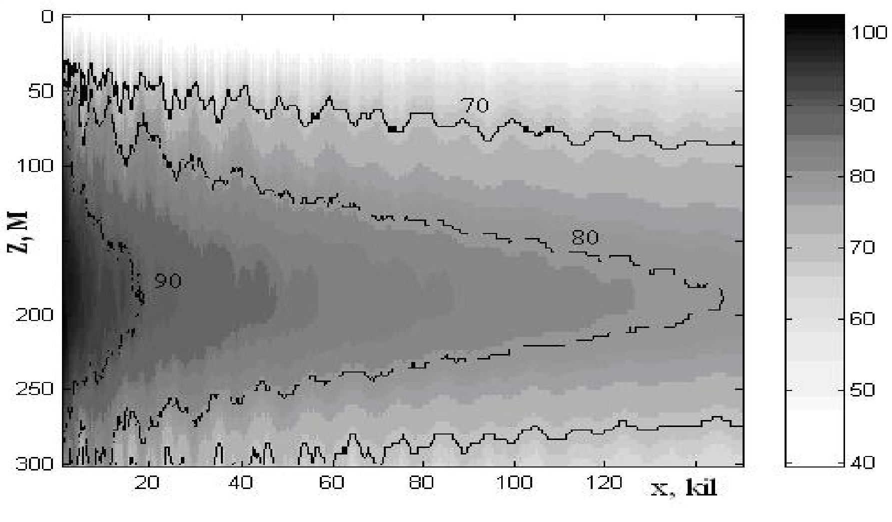

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Fig.1. Low-frequency acoustic field structure (model calculation): (a) – excitation by a single emitter, (b) – excitation by an antenna array consisting of 64 vertically distributed emitters (the radiation frequency is 200 Hz, the total power of the source in both cases is 320 W, and the brightness scale corresponds to the level in dB relatively to 1 μPa)

1. RADIATING COMPLEX

The experimental radiating complex is a vertical chain of 16 half-wavelength spaced (for the central frequency) radiators. Each radiator has its own power supply and control module arranged in a special box close to the emitter. The design and the control algorithms were to satisfy the following requirements: the radiation level sufficient for the research purposes and high efficiency in the assigned frequency band; the possibility of installation at the assigned sea depth without any special sinking-lifting devices (with the use of standard shipboard-type facilities, including small-displacement boats); the possibility of forming the prescribed amplitude-phase distribution over the emitting aperture for signals with specified frequency and temporal characteristics. The developed and manufactured radiating equipment has the following operational characteristics. The emitted acoustic power of a single element is ~ 70 W in the frequency range 234 – 254 Hz. The distance between the elements is 3 m; the number of the radiating elements is 16. The installation depth varied and could achieve 100 m (this limitation is not a principal one; it was determined by the length of the control and power cables, and by the peculiarities of the hydrostatic pressure compensation system needed for the applied type of radiating elements). A general view of the outboard part of the radiating complex is shown in fig. 2.

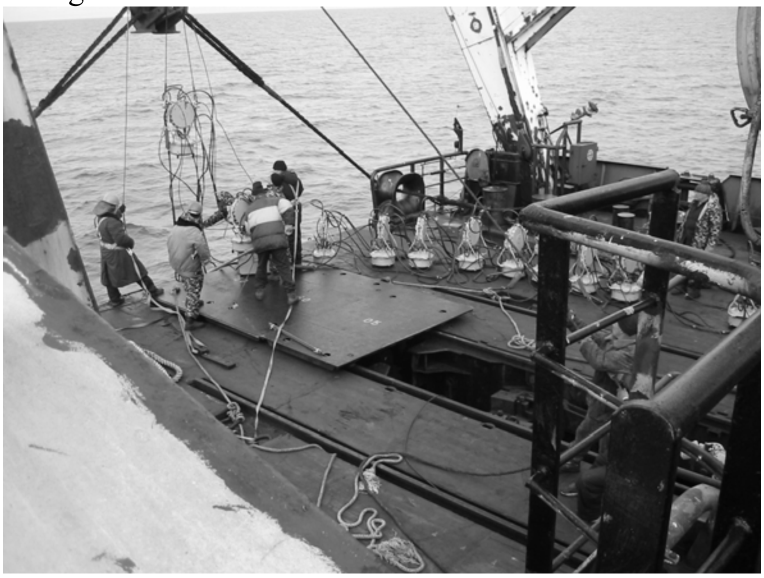

Fig.2. The radiating complex installation

An important feature of the radiating antenna assembled of resonant type radiators is the strong interaction between them, which actually complicates the antenna control and the formation of the necessary amplitude-phase distribution in the e aperture. This interaction level is shown in fig. 3b; the figure exhibits amplitudes and phases of emitter diaphragm vibrations (proportional to the produced pressure) for the excitation of a single central element in the aperture; the rest of the elements are excited due to the reciprocal action through the medium. Figures 3c and 3 d deal with analogous distributions in the radiating aperture, which correspond to the structures of the first and the second modes of the waveguide.

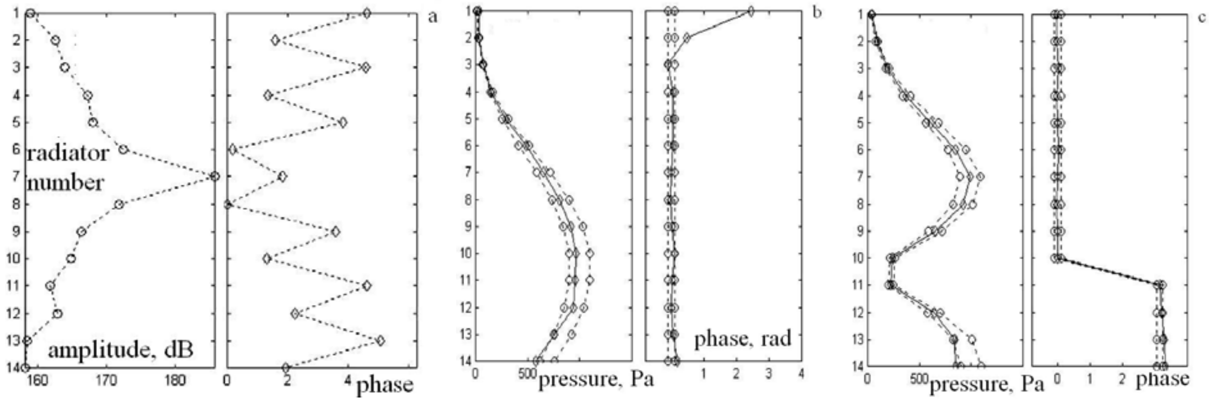

Fig.3. Amplitudes (on the left) and phases (on the right) of pressure in the receivers built in the radiators, when only one radiator No.7 operated, (a) phase and amplitude distributions along the radiating array, when the first (b) and the second (c) modes were excited. The depth is 60 m

The possibility to form such distributions is guaranteed by a preliminary calibration of separate radiators in “free space” and by a number of iteration procedures carried out by the controlling computer. Thus, an effective agreement between the excited acoustic field and different-type waveguides could be provided.

2. RECEVING COMPLEXES

To carry out the research program, alongside with the emitting complex we have designed an independent receiving complex based on the digital hydrophones developed at the IAP RAS [6]. The necessity to apply the digital hydrophones is obvious and caused by several reasons. First of all, this is due to the fact that the execution of the program operations with signals (filtering, heterodyning, detecting, acquisition of a special-shape signal, excess of the threshold, etc.) unloads the data flow transmitted by the sensor by several orders and eliminates the noise influence. The distribution of the computation resources increases the reliability of the system as a whole; reprogramming of the operation mode and diagnostics are carried out without disassembling; the set of sensors forming the antenna is arranged in an ordinary double-wire line without bundled shielded cables or expensive plug connections. In this case digital transmission eliminates interferences, guarantees the required dynamic range, unifies communication cables and the interface, and makes the system easily upgraded in amount of channels. This technology permitted developing two receiving complexes capable of independent operation for up to 5 days (this limitation is caused by the power elements and the storage capacity). There were 32 3-m spaced hydrophones in the antennas of each complex. The dynamic range of the receiving complexes is more than 90 dB. A complex is supplied with high-frequency transmitters with independent bottom installation. They can be used to eliminate the influence of poorly controlled deviations of the antenna from vertical under the action of currents on measurement results. A general view of the digital antenna and the scheme of the receiving complex installation are shown in fig. 4.

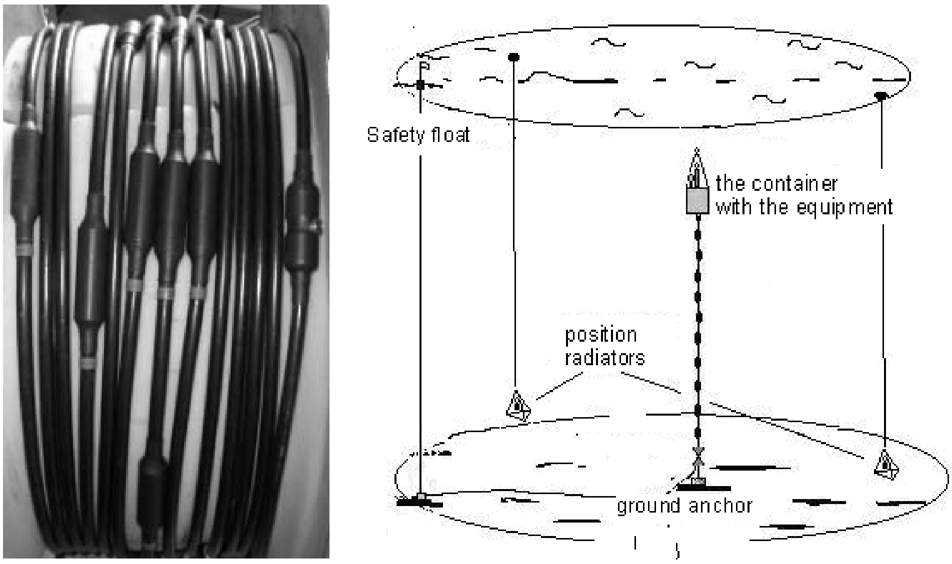

Fig.4. The receiving antenna based on digital hydrophones and the scheme of its installation

3. SOME OBTAINED RESULTS

High efficiency of the application of vertically developed emitting and receiving systems was vividly demonstrated by comparing the total powers of the acoustic fields “pumped” into the waveguide excited by a single emitter and by the entire antenna. Figure 5 shows the dependence of the level of the signals captured by the whole receiving system on the distance between the points of radiation and reception of a single radiator and the antenna with an amplitude-phase distribution uniform over its aperture. The same figure displays, in the brightness form, a typical record of the vertical section of the acoustic field received at a distance of 4 km and excited by a single monopole and the antenna.

One of the most important parts of the experimental program is the study of the features of surface and bottom reverberation in a shallow sea. Mode selection of reverberation signals was of special interest. The spectral distribution of the signal received at a distance of 4 km, when the waveguide was excited by the antenna and the monopole, is shown in fig. 6. The minor lobes of the spectra are due to surface scattering. One can see that the spectrum of the signal received from the monopole (excited by a monochromatic signal) is essentially richer, which is, evidently, caused by the presence of high-number surface-scattered modes in the excited field; such modes are practically absent when the waveguide is excited by the antenna.

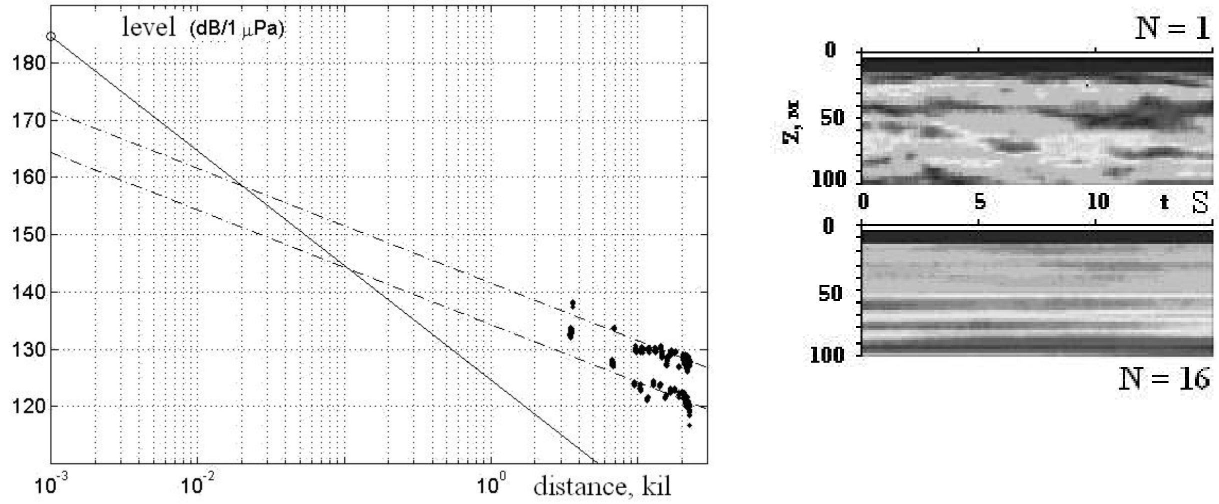

Fig.5. The signal level versus the distance for the emitting antenna (top) and the monopole (bottom); solid line shows the spherical law of signal level decay; the level difference in measurements is of the order of 7 dB. The real power of antenna radiation can be obtained by adding 10lg N to the given data (N=16 is the number of emitters in the antenna)

As for bottom reverberation, its measurements carried out at pulse ($\Delta\tau$ = 10 s) signal excitation enable us to draw the following conclusions. The level of bottom reverberation weakly depends on the type of the source. At the same time it is invariable with respect to the energy "pumped" into the waveguide. The laws of reverberation decay at various distances between the source and the receiver satisfy the power law. The mode analysis of reverberation signals has shown that the decay rate (index of power) increases with the mode number growth; this seems to be quite natural, because the higher the mode number, the stronger the interaction of the mode with the bottom and the more rapid the mode decay. Typical records of probing and reverberation signals of a single operating emitter (left part of the figure) and the antenna are presented in fig. 7. Figure 8 shows the dependence of the index of power on the mode number. Analogous dependences obtained by numerical simulation for several types of bottom sediments are given in the same figure.

Studies of the field characteristics at large distances from the source are also of great interest. Unfortunately, because of some circumstances, those measurements were made only with a single hydrophone lying at the bottom. Nevertheless, they are rather important, since they permit, in principle, extrapolating the field characteristics to other horizons. A record of a pulse carried out at a distance of 150 km from the radiating antenna is given in fig. 9 as an example.

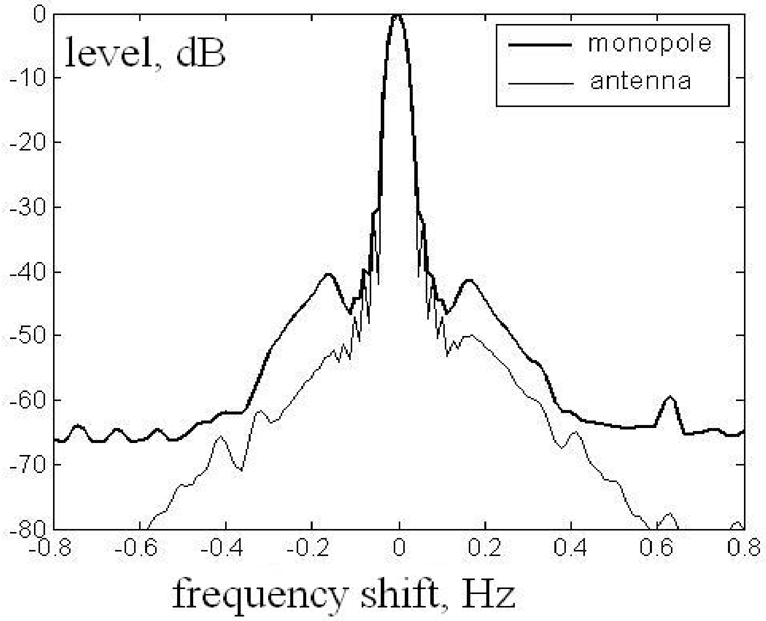

Fig.6. A comparison of spectral densities of powers of the signals received at a distance of 10 km from the source and averaged over the receiving antenna, when an tone signal was emitted by the monopole (thick line) and by the vertical antenna (thin line) normalized to the carrier frequency

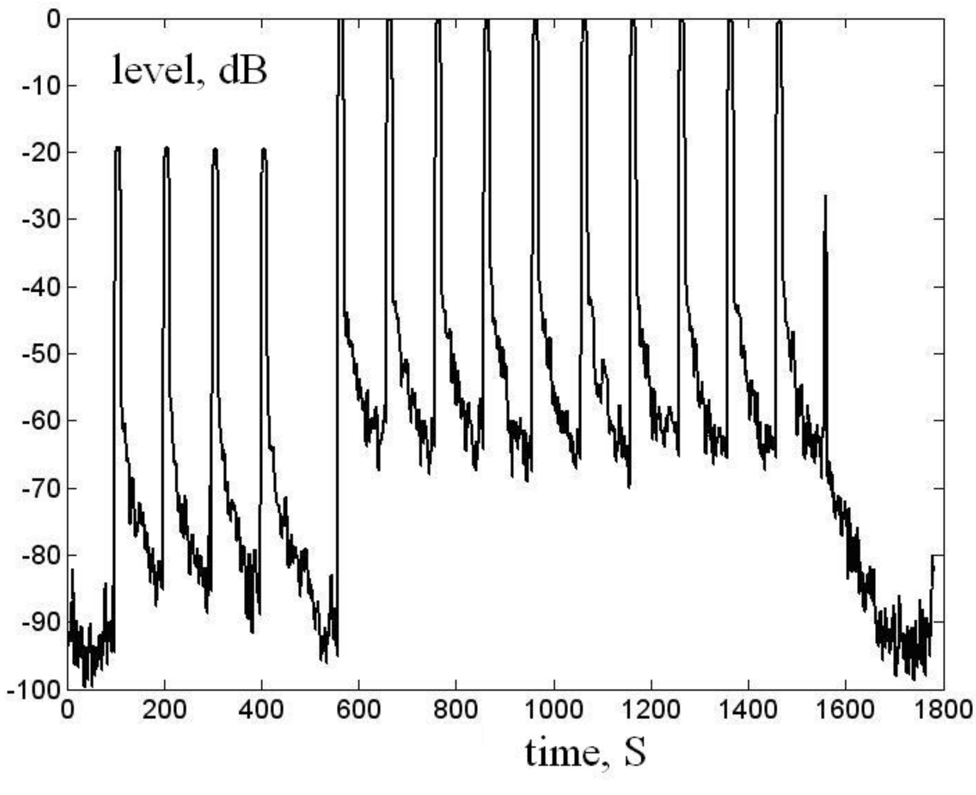

Fig.7. The signal level averaged over all hydrophones of the received antenna and normalized to maximum in a reverberation measurement run

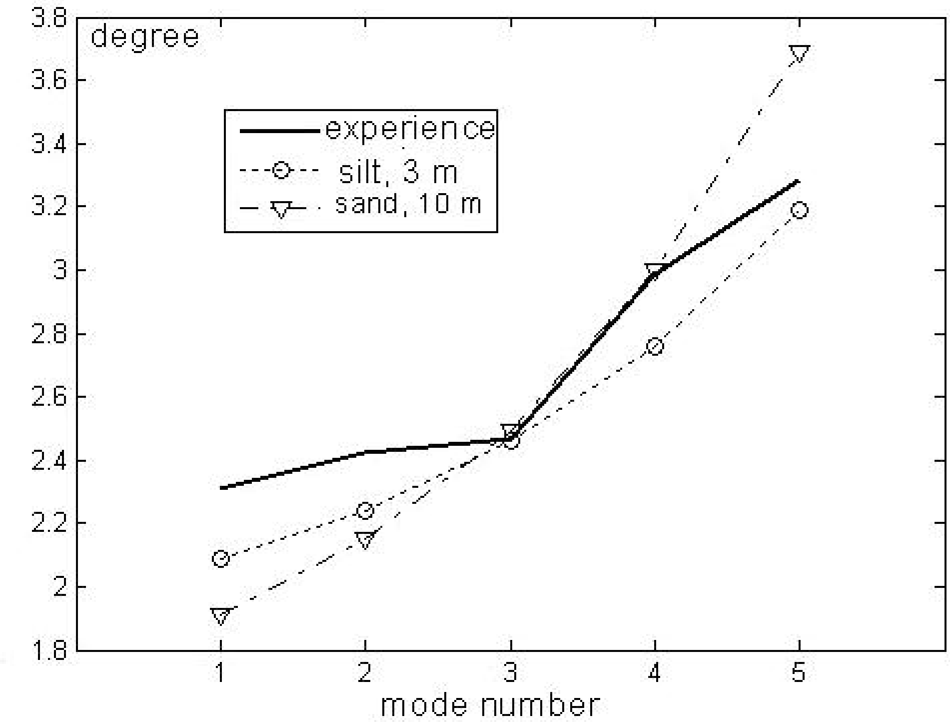

Fig.8. The decay degrees of the reverberation level measured in a field experiment and model calculation

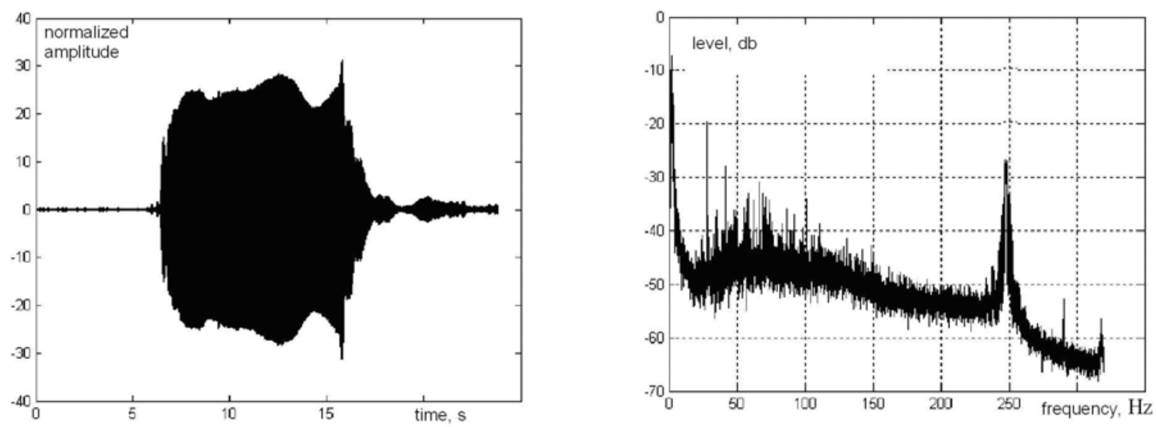

Fig.9. A tone-pulse signal (on the left) and its spectrum (on the right) received by the single bottom hydrophone located at a distance of the order of 150 km from the vertical emitter array

It is seen that the achieved signal/noise ratio is rather large and quite sufficient for the study of finer field characteristics. Weak line width broadening should be also noted. High coherence of different-type signals emitted by the antenna and received by the single hydrophone is also shown in fig. 10 that represents results of convolution of different-type received signals with reference standards (i.e., replicates of the signals “wired” in the radiation control system). Therefore, the obtained results give evidence of wide opportunities provided by vertically developed emitting and receiving antennas both for studies and practical use, when constructing various tomographic systems in a shallow sea [8-10].

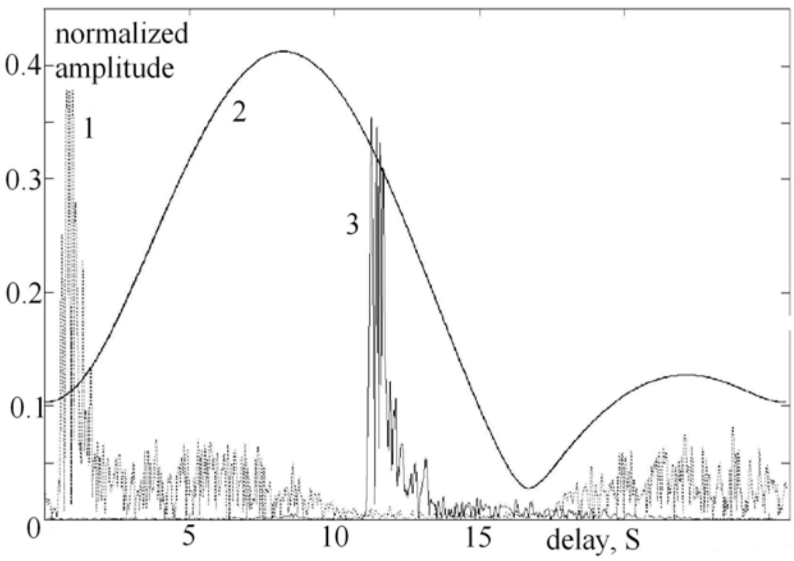

Fig.10. Results of compression of the pulses received from the hydrophone output (1 – phase-manipulated by m-sequence, 2 – tone-impulse signal , 3 – pulses with hyperbolic frequency modulation)

In conclusion we notice that the given examples do not exhaust the list of the performed studies. Since the publication volume is limited, we cannot even briefly touch upon other related problems. That is why we refer to original publications [11] dealing with problems of mode selection based on broadband low-frequency signals. Some problems related to phase conjugation can be also effectively solved employing the developed equipment [12].

The author would like to express his gratitude to the teams of developers, researchers, research vessels, and to his colleagues, whose executive efforts assisted in promoting these studies.

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