Adaptive methods for detecting passive signal from an underwater object

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Abstract: *In order to determine the total spatial and temporal scale of the propagation of anthropogenic sources of noise, it is necessary to identify them, which can be achieved by comparing underwater and sea surface observation data. For this purpose, it is necessary to determine the direction to the noise object in a function of time. In the development of a passive hydro-acoustic system positioned on the seabed for the detection, classification and determination of the direction to an underwater object, an adaptive processor shall be designed, examined and experimented to dynamically determine the weighting factors of a two-element antenna grille according to the criteria of the minimum of the average square error and the maximum of the signal noise ratio.*
Keywords*: ADAPTIVE PROCESSOR, LINEAR ANTENNA ARRA, UNDERWATER MONITORING, NOISE, SPECTROGRAM.*

1. Introduction

The planned measures in the Program of Measures to the Marine Strategy for Environmental Protection in the Sea Waters of the Republic of Bulgaria envisage the monitoring under indicator D11C1.1 in fulfillment of the requirements of the RDMS to be performed on the basis of the analysis of data and information to be collected in the national "noise" register. The register will describe all human activities that generate impulse sounds in the sea area of the Republic of Bulgaria. Data on noise emissions from different types of ships will be collected from ship manufacturers / owners or specialized information systems (eg national AIS system, etc.), as well as from measurements by underwater noise monitoring stations. Data and information on anthropogenic activities will be collected continuously throughout the year and the noise register will be periodically updated. As a result of human activities in the marine environment, various types of fields are excited such as sound, light, electromagnetic, thermal, hydrodynamic, etc. Of all these fields, the sound field is distributed over the longest distances from the source [3,4]. That is why great attention is paid to the assessment of the energy impact of sound waves on marine species. A harmful underwater sound field is one in which exposure causes temporary or permanent damage to the fauna of the marine ecosystem. In theory, when such a field is created as a result of human activity, it is referred to as harmful anthropogenic noise. Anthropogenic noise is recognized as a serious stress factor for most marine mammals, many marine fish, crustaceans and other marine organisms. In addition to legally regulated activities that create anthropogenic noise in marine areas, short-term sound anomalies are possible, such as the sound of leaking gas in the event of a pipeline breach, or an uncharacteristic level of anthropogenic noise in protected or prohibited areas and water activities, noise from the use of bottom trawls for fishing, etc., which may cause significant harmful effects. Their timely registration and response to the authorities authorized by law can significantly reduce the harmful consequences [5].

2. Assumptions and ways to solve the problem

As an element of an underwater monitoring system in the national marine areas, Institute of Metal Science, Equipment and Technology with Hydroaerodynamic Center at Bulgarian Academy of Sciences /IMS-BAS/ has developed a prototype of "Audio recording system for underwater monitoring with rapid notification of detected sound anomaly" */ARSUM/* (Fig. 1), designed for recording, classification and recording of sounds from biological sources (marine mammals, fish, shrimp, etc.), anthropogenic noise - pulsed (as a result of seismic surveys, laying pylons for wind farms and platforms on the seabed, use of pulsed sonar, underwater communications, underwater explosions, etc.) or long-term (caused by shipping, dredging, leaks in underwater gas and oil pipelines, actions of power plants, acoustic signals from artificial radiation [6]. When detecting, recording and classifying a sound anomaly (eg sound of a leaking gas in the event of a pipeline breakage, noise from the use of bottom trawls for fishing or an uncharacteristic level of anthropogenic noise in protected or prohibited areas and for certain activities in the water area and etc.) a fragment of the information is recorded, with a duration sufficient for the classification of the event [7]. This fragment is transmitted wirelessly in an autonomous beacon from the device kit, where it is overwritten. Upon completion of the information transfer process, the radio beacon floats and transmits the critical information via radio to a shore, ship or air base station acting as an operations center. It is then used as a radio beacon to indicate the location of the event.

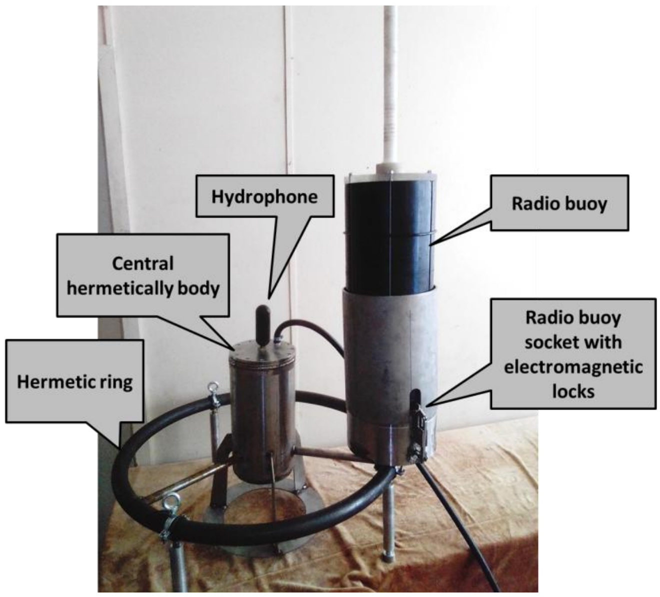

Fig. 1 *General configuration of an experimental sample of ARSUM*

When conducting tests with "Audio recording system for underwater monitoring with rapid notification of detected sound anomaly" it was concluded that its effectiveness is significantly increased when in addition to the information about the presence of classified noise in the area of the device is determined and the direction to it, and subsequently the vector of motion of the noise source is determined, even with tolerances in accuracy [8].

For this purpose, an experimental model of the product was developed, and in place of the hydrophone was mounted a linear antenna array of two hydrophones (for experiments - 2 microphones) - Fig.2.

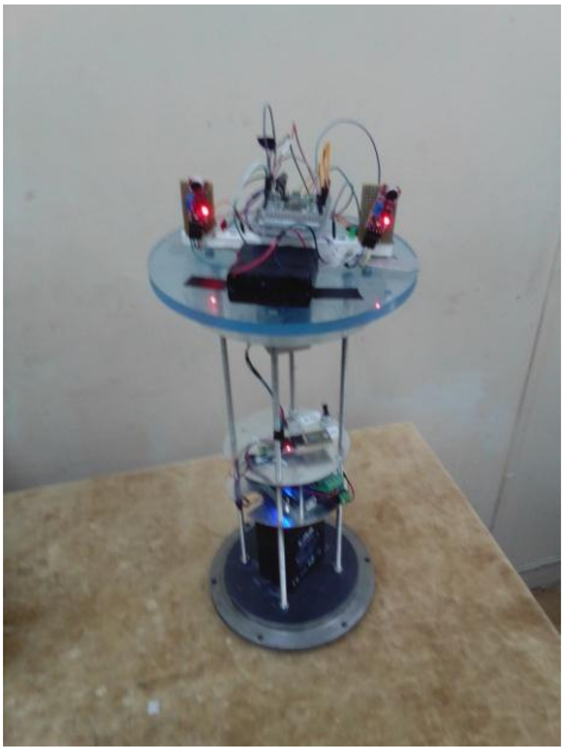

Fig.2 *Electronic equipment located in the central airtight body*

In order to achieve good accuracy characteristics, it was necessary to make a comparative assessment of applicable adaptive methods of beamforming using a linear antenna array for broadband signal processing [9].

3. Results and discussion

Two methods for adaptive beam formation based on the two-element linear antenna array shown in Fig. 3.

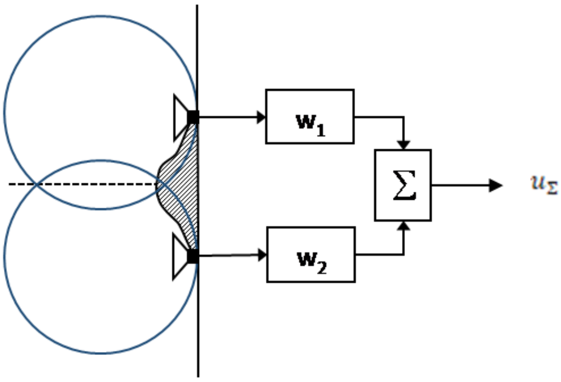

Fig.3 *Two element ULA.*

Adaptive beamforming methods calculate the weights w_1 and w_2 based on statistics of the signal received from the individual elements.

The first method, called "Sub band MVDR Beam former", forms the spatial beam by the method of minimal dispersion in the distortion of a broadband signal, using the technique of processing in sub bands. This type of diagram formation is also called the Capon method of beam formation [1, 2].

The second method "Sub band Phase Shift Beam former" processes the broadband signal in sub bands by introducing phase delays.

The aim of the study is to analyze their ability to detect a broadband signal against the background of their own noise and interference. The comparison of the two methods is performed by computer implementation of the algorithm shown in Fig. 4.

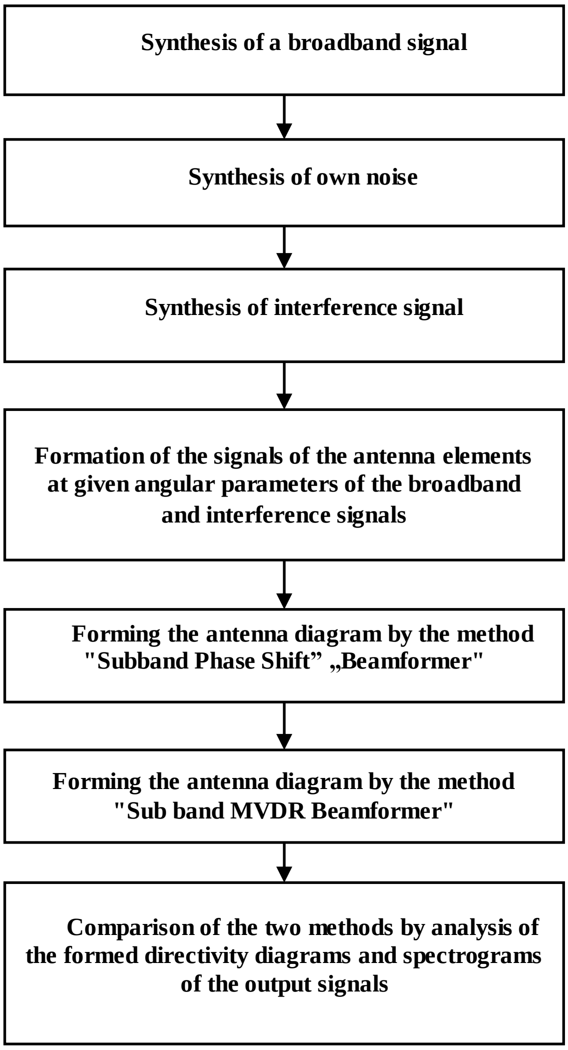

Fig.4 *Algorithm for simulation of adaptive diagram formation by the methods "Sub band Phase Shift Beam former" and "Sub band MVDR Beam former"*

In the simulation model, as a broadband signal (Fig. 3), a signal with linear frequency modulation with length 2 s, carrier frequency 2 kHz and frequency deviation 1 kHz is used, whose angular position relative to the perpendicular to the phase center of the antenna is 20°. The intrinsic noise of the antenna is Gaussian with a rms value equal to 0.3 of the amplitude value of the broadband signal.

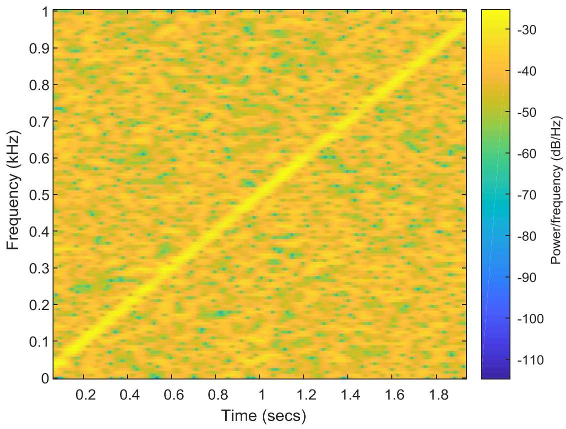

Fig.5 *Spectrogram of noise signal and noise at the output of an antenna element*

In the model, two interference signals with amplitudes twice as large as the broadband signal with angular positions of 10° and 30° are superimposed on the broadband signal and noise - Fig. 6.

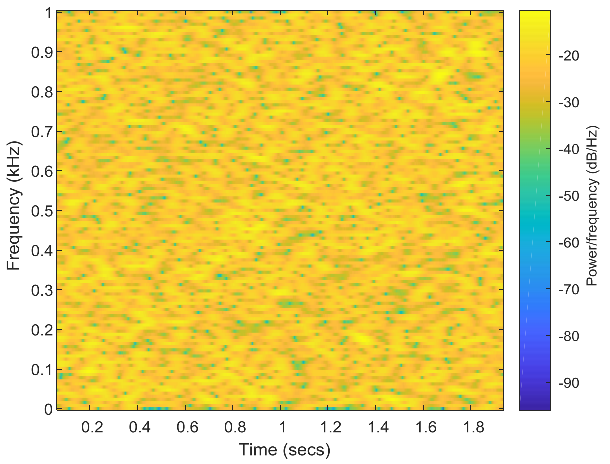

Fig.6 *Spectrogram of a broadband signal with superimposed noise and two interference signals*

Two non-directional microphones with a frequency band from 20 Hz to 20 kHz located at a distance of 10 cm are used as elements of the antenna array. The processing of the received signals is performed in eight frequency bands with medium frequencies 1000, 1250, 1500, 1750, 2000, 2250, 2500, 2750 Hz. For the purposes of the research the formation of the beam in a frequency band with medium frequency 1 kHz is analyzed. The obtained radiation patterns as a result of the operation of the two beamformers are shown in Fig. 7.

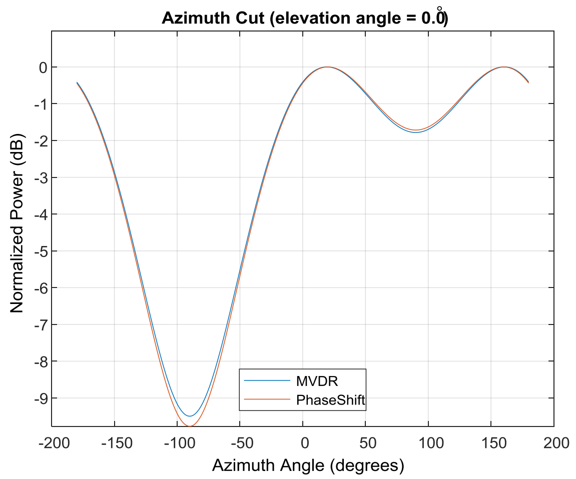

Fig.7 *Directivity pattern formed by "Sub band Phase Shift Beamformer" and "Sub band MVDR Beamformer".*

The main maximum of the directivity diagram is electronically directed in the direction of the 20° signal.

In the absence of an interference signal, the quality of operation of the two beam generators is identical. The advantage of "Sub band MVDR Beamformer" is manifested in the presence of interference. In this case, the average value by which the level of the output signal from the "Sub band MVDR Beamformer" beam generator exceeds the level of the "Sub band Phase Shift Beamformer" beam generator is 3.02 times.

Spectrograms of the output signals from the two beam generators are shown in Fig. 8 and Fig. 9.

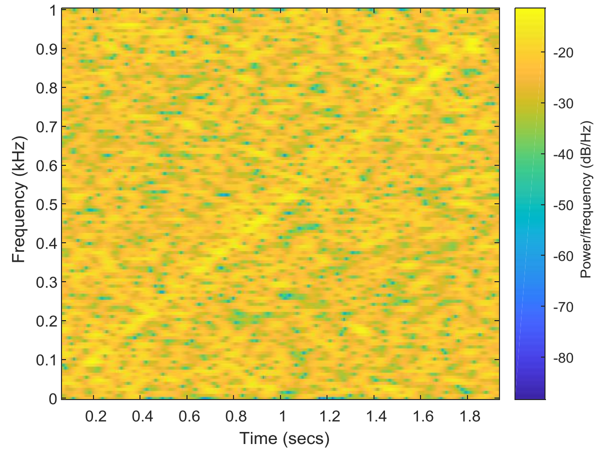

Fig.8 *Spectrogram of the output signal of the antenna during interference in beam formation by "Sub band Phase Shift Beamformer"*

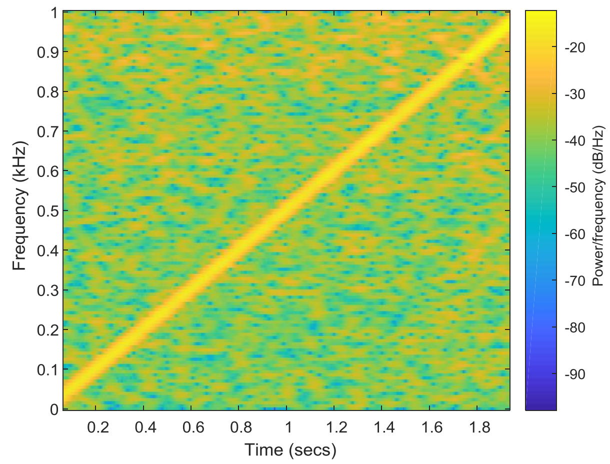

Fig.9 *Spectrogram of the output signal of the antenna in case of interference during radiation formation through "Sub band MVDR*

5. Conclusion

The effectiveness of the actions taken by the authorized bodies in response to information received from the "Audio recording system for underwater monitoring with rapid notification of detected sound anomaly" is significantly higher when data on the directions to the detected and classified events are included. The need to determine the direction of the noise object as a function of the time of the passive sonar system requires to study and experiment an adaptive processor for dynamic determination of the weights of the two-element antenna array according to the criteria for minimum square error and maximum noise ratio of the signal.

Beam formation is used to amplify the signal against the background of noise. In real systems, the presence of interference signals received on side sheets leads to a strong masking of the signal by the target of interest [9]. In this case, the use of the method of minimum dispersion in signal distortion allows to form zeros in the directional characteristic in directions that coincide with the interference signal.

6. Acknowledgements:

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