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Modeling of underwater sonar barriers

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The commonly used Diver Detection Sonar (DDS) can detect, track, and warn about intruders in a limited range of 300 m ÷ 600 m, depending on weather and propagation conditions. To increase an effectiveness of the DDS coverage, a few acoustic sensors should be integrated with superior system responsible for safety of defined object, area or border. A new approach to underwater protection is focused on a multi–monostatic, bistatic and multistatic active sonar barriers (ASB).
The paper describes key features of a multi–monostatic (MM), bistatic (BS) and multistatic (MS) operation in the littoral water and depicts the system configuration, his performance and constraints imposed by shallow water environment. A new type of acoustic devices in form of transmitting/receiving module and their application in active sonar barriers (ASB) has been presented also. Coverages and ranges of barriers for various technical parameters, environmental conditions, wave propagation as well as modules location (includes transducer's depth, azimuth and inclination) had been studied.
The application of active sonar barriers (ASB), especially in protection systems, has been presented as barriers protecting docks, harbour basins, ships at the piers or entries to the harbour. The new type of a monostatic/bistatic acoustic barrier in technology demonstrator form has been designed and manufactured. In order to confirm of the barrier abilities to detection and localization of the small underwater objects as well as their tracking and classification, the performance tests of the barrier will be conducted. The results of the first tests are shown in the paper.

1 Introduction

During last years we have observed a new approach in construction of specialized sonars intended to detection and recognition of the underwater small objects (i.e. divers, swimmer), particularly in the shallow water. DDS may use various configurations of linear or cylindrical arrays and should be integrated to superior system which is responsible for safety of defined object, area or border. Presently, underwater protection systems build on the basis of classic active sonars covers mainly the some important single objects or parts of vast objects i.e. harbour entry. Antiterrorist protection should cover also ships or ships groups both in the vast harbours and the anchorages. R&D MTC began to create the Active Sonar Barrier (ASB) for underwater protection of extensive harbour or anchorage areas [1] instead of protection systems based on the typical DDS. The main advantages of this new approach to harbours protection are complex barrier systems, easy installed, portable or stationary, able to match to harbours configuration, adapted to changes of sound propagation conditions and also minimize bottom reverberation and mutual interferences.
Configuration of each barrier depends on the size and shape of the protected area, sea water features as propagation conditions, sea depth, sea floor slope and underwater obstacles, acoustic devices parameters as source level, pulse length, processing gain and type of modulation. On the basis of those input data, the ASB configuration can be established.

2 Active Sonar Barrier Configuration

The basic ASB configuration consisting in two DDS are shown in Fig. 1. Each DDS may operate in mono- and bistatic mode creating as a whole a tight underwater barrier (see Fig. 3) which can works independent or as subsystem in protection system. Supplementing the ASB configuration with the third DDS at a proper location, creates multistatic system which enables still better protection than bistatic system – detection probability grows and target tracking is easier thereby probability of proper target identification significantly increases.

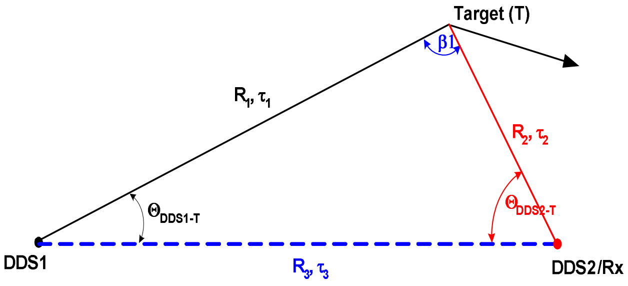

Fig. 1 ASB configuration

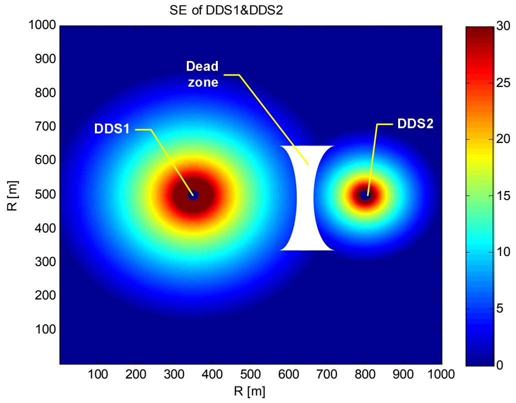

Fig. 2 DDS1 and DDS2 operates in monostatic mode

Figs. 2 and 3 illustrates how in configuration two DDSs, detection dead zone (white area in Fig. 2) might be removed by applying bistatic mode. Another example of simple ASB configuration is that one presented in Fig. 1, where instead of DDS2, Rx module is placed. The ASB operated in monostatic (DDS1) + bistatic (DDS1 and Rx) configuration. Only one DDS with narrow directional beam is the simplest ASB configuration called Monostatic Acoustic Barrier (MAB). Wideband MAB system presented in Fig. 4 comprises lightweight transducer head and command workstation with processor and display.

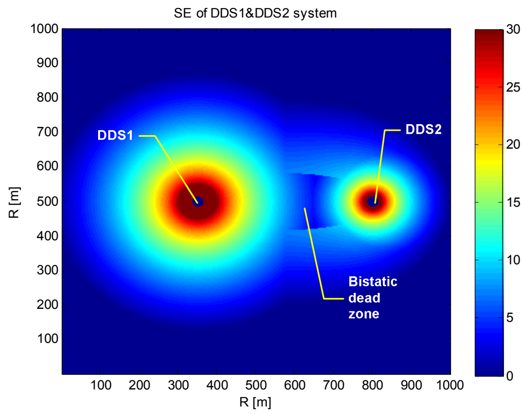

Fig. 3 DDS1 and DDS2 operates in mono – and bistatic mode

The selection of a wideband transducer, its location at the pier, break–water or on the bottom are the most significant factors during the MAB design process. Transducer parameters, such as transmitting and receiving beam width (horizontal and vertical), source level, signal modulation type, receiving sensitivity has a significant influence upon detection range. Received target echoes subject to sophisticated and specific data processing provide very useful information about detected object: its position, velocity, target strength and course/azimuth – object can be classified on the basis of those data. MAB is the prototype of underwater sonar barrier, and its first trials have been performed in harbour range applying a small underwater object with target strength equals approx. -25 dB. The tests results are shown in item 4.

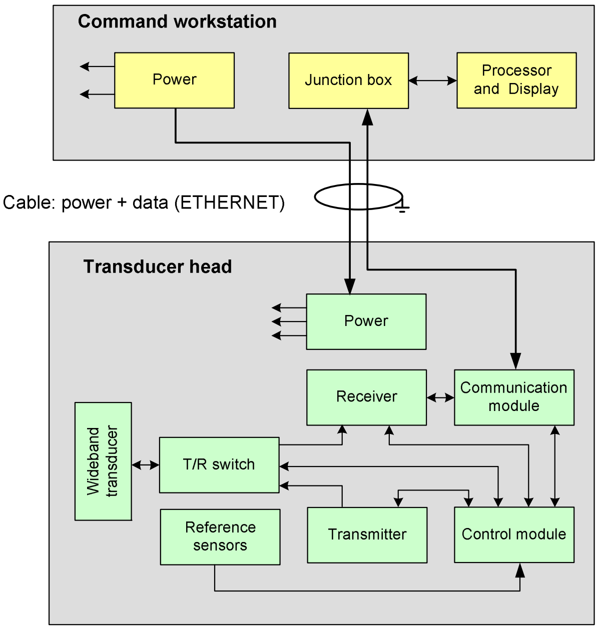

Fig. 4 Block diagram of the MAB

3 ASB modelling

3.1 Bistatic active sonar equation

Target is detected if SE (1) is greater than zero;

$$SE = SL + TS - TL - N_0 - 10*\log_{10}B + DI - DT \qquad (1)$$

where:

$TL = TL_{TxT} + TL_{TRx}$

TL_{TxT} – transmission loss between source–target, TL_{TRx} – transmission loss between target–receiver,
SE – signal excess, SL – source level, TS – target strength, N_0 – noise (sea + environment: ships movement mainly) + bottom forward reverberations mainly, B – bandwidth, DI – directivity index, DT – detection threshold.

Transmission loss was calculated according to (2)

$$TL = 15*\log_{10}(R) + \alpha*R + A \qquad (2)$$

where:
R – path length, α – attenuation coefficient, ***A*** – empiric correction covering wave refraction, diffraction and scattering on small objects in sea water (we assume A = 5 dB). *Note: in monostatic mode, classic active sonar equation has been used.*

3.2 Parameters for modelling

The modelling was performed in MATLAB for the following parameters:

1. **Source**: level SL = 165 dB ÷ 206 dB (some modelling carried out at SL=165 dB); frequency f_0 = 60 kHz;bandwith B = 20 kHz; pulse length T = 10 ms and 20 ms; Θ_{-3dB}: 13,5° ÷ 360°.
2. **Environment:** water temperature WT = 10°C; salnity S = $7{,}5^o/_{oo}$; pH = 8; sea bottom: sand; wind: 13 knots (sea state 4).
3. **Target:** target strength TS = -25 dB.

3.3. Examples of ASB modelling

ASB modelling is shown for three selected examples: basin protection, harbour entry protection and protection of ships mooring at berth, assuming real geometry of protected object and real technical parameters of source as well as typical (for Baltic Sea) environmental conditions.

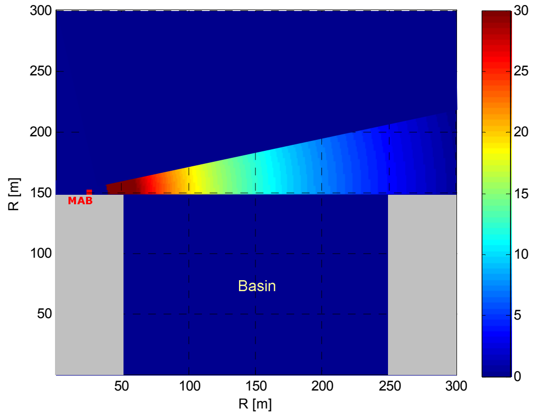

Fig. 5 Basin protection
Monostatic barrier: MAB: Θ = 15°, Φ = 75°,
Px = 25 m, Py = 150 m, Pz = 2 m,
MAB is located on the basin outer wall.

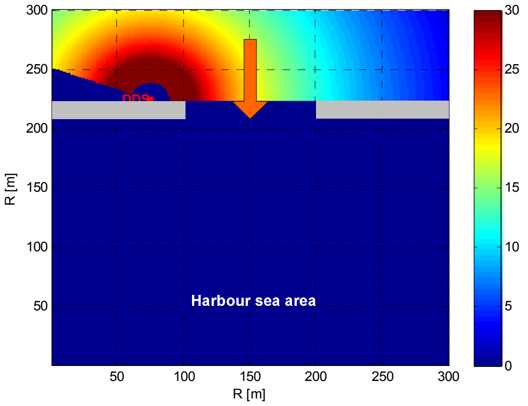

Fig. 6 Protection of harbour entry
Monostatic barrier: DDS: $\Theta = 160^o$, $\Phi = 0^o$,
$Px = 75$ m, $Py = 225$, $Pz = 2$ m,
DDS is located on the outer wall of breakwater.
This protection is applied in Polish Navy base.

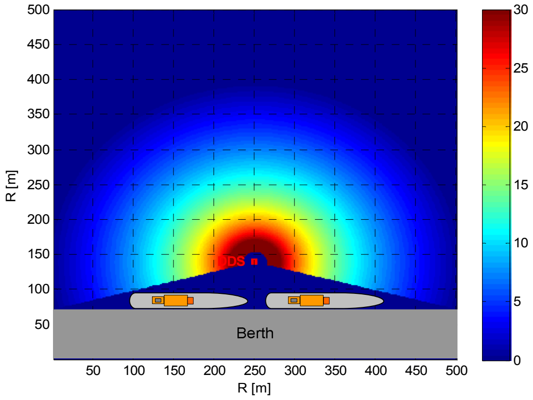

Fig. 7 Protection of ships mooring berth
Monostatic barrier: DDS: $\Theta = 200^o$, $\Phi = 0^o$,
$Px = 250$ m, $Py = 75$ m (in relation to berth), $Pz = 9$ m,
DDS is located on the sea bottom.

Cartesian coordinates of source are described by Px, Py. Pz is the transducer depth. Θ is the horizontal beamwidth and Φ is the DDS's transducer bearing. SE is expressed in color scale at (0 dB ÷ 30 dB) range.

4 Tests of Monostatic Acoustic Barrier

The MAB first trials were conducted on the harbour range – Fig. 8 with 2.5 m target depth, 13.5^o transmitting and receiving beam width, 203 dB source level, 20 ms pulse length, 60 kHz frequency, 20 kHz bandwidth and LFM modulation. ***TS*** of target equal approx. -25 dB.

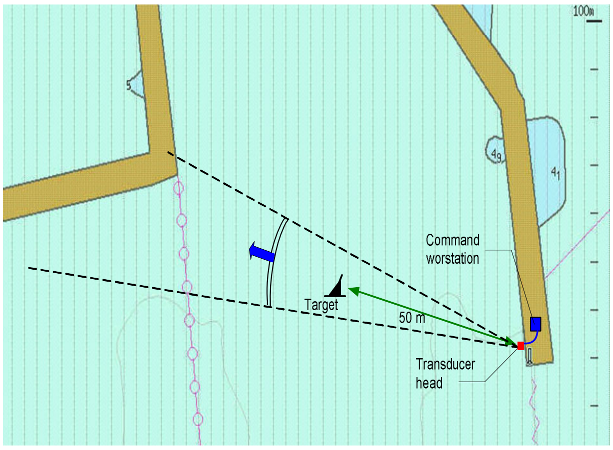

Fig. 8 Harbour range

The emitted signals and signals reflected from the target were recorded and analysed by FFT, results of this are illustrated in Fig. 9 A, B: emitted signal and Fig. 10 A,B – echo of the signal

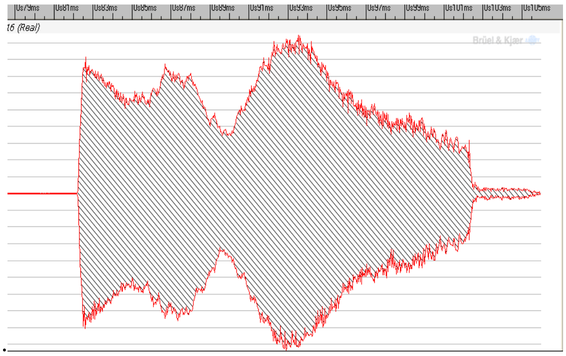

Fig. 9 A Emitted signal

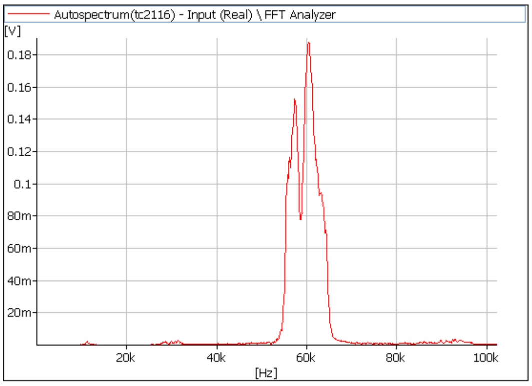

Fig. 9 B Spectrum of the emitted signal

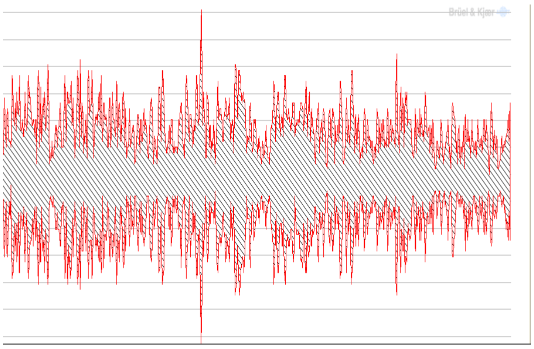

Fig. 10 A Echo of the emitted signal

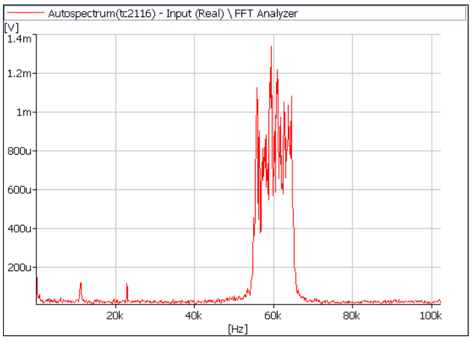

Fig. 10 B Spectrum of the echo

Recordered signal echoes were subject to correlation processing, results of detected targets are presented in Figs. 11 and 12. Time Variable Gain didn't apply during these trials.

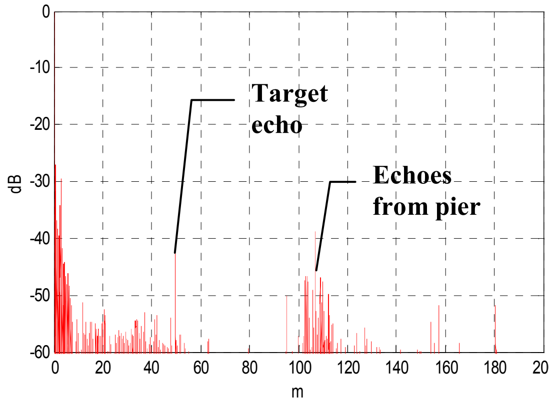

Fig. 11 Echoes of received signals

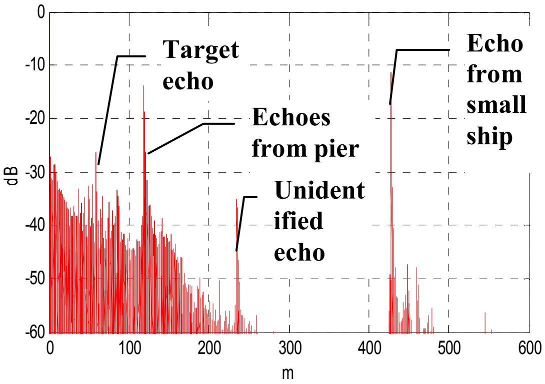

Fig. 12 Echoes of received signals but with another transducer bearing

It should be noted that results of small underwater object detection obtained by utilization of the correlation processing even without TVG, prove that MAB is the effective tool for protection systems and may be used for protection of harbour entries, basins etc.

5 Conclusion

1. Smaller harbours, shore or off-shore installations can be protected by individual low cost short range sonar or MAB.
2. DDS dedicated to protect harbour or other objects on shallow water should be adjusted to parameters of protected object and all operational conditions. It especially refers to the MAB's transducer, in many case the transducer may have a narrow beamwidth ($\Theta \leq 15^{o}$) then reverberation level significantly decrease therefore probability of detection increases.
3. The barriers comprising DDS with wide and narrow beamwidth cooperating with receiving modules are very effective protection mean on condition that configuration, technical parameters and arrangement of the barrier equipment will be adjusted to protected object (to provide the best coverage) and propagation conditions.
4. The barrier protection efficient increases if DDS technical parameters are changed according to current propagation conditions – their monitoring is needed.

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