SHL-101/T SONAR – RESULTS OF THE HARBOUR AND SEA TRIALS

ANDRZEJ KOTŁOWSKI, WŁADYSŁAW MĘCIŃSKI,
MARCIN OKUNIEWSKI, EDYTA POROSIŃSKA, RYSZARD ZAJĄC

Research & Development Marine Technology Centre
ul. Dickmana 62, 81-109 Gdynia, Poland
anko@ctm.gdynia.pl

The safeguard of seaways, naval basis, harbours and sea frontiers from minefields, attackers, gun-running is essential in hazardous nowadays. Particularly modern sea mines sometimes buried and make in stealth technology are very difficult to detect.

Therefore the echo-ranging detection systems require state-of-the-art hardware and efficient processing algorithms to protect sea areas. Such up-to-date hydroacoustic equipment was developed by R&D Marine Technology Centre. The SHL-101/T system is the triple frequency, wideband and very high resolution hull-mounted minehunting sonar. It was put into service to Polish Navy minesweeper on April 2007. Sonar underwent factory, harbour and sea acceptance trials. Presently Polish Navy carries out further exploitation and military tests. The results are remarkable and they enable to explore mysteries of the sunken objects in the Gdansk Gulf.

The paper presents the results of SHL-101/T sonar harbour and sea trials. Its performances for different detection and classification modes are also depicted. Additionally displays of the found various underwater objects are included and detailed discussed.

INTRODUCTION

The research and development work at the SHL-101/T sonar began in 2000 year. Six years later its prototype version was mounted on the Polish Navy minesweeper. The first sea trials took place in December 2006 year. Sonar positively passed factory and military harbour and sea acceptance trials in February 2007. The equipment was introduced into armaments of the Polish Navy in April 2007.

Sonar operates at three different frequencies LF (low frequency), HF (high frequency) and VHF (very high frequency). Usage of the FM (frequency modulated) signals enables pulse compression leading to signal-to-noise ratio increase and higher range resolution. This feature significantly improves detection and classification performance especially against stealthy mines in noise and reverberation limited conditions.

Sonar is equipped with two modern hydroacoustic transducers manufactured by Thales Underwater System from France. At LF mode sonar uses the vertical cylindrical antenna (VA) for transmission and horizontal linear antenna (HA) for reception. At HF and VHF modes sonar utilizes the HA antenna for both transmission and reception. The detection task is carried out at LF and HF frequencies, depending on environmental conditions (ambient noise, reverberations, sea depth) and detected target type (moored mine, bottom mine, stealth mine, etc). The VHF mode is mainly dedicated shadow classification purposes.

OPERATION MODES

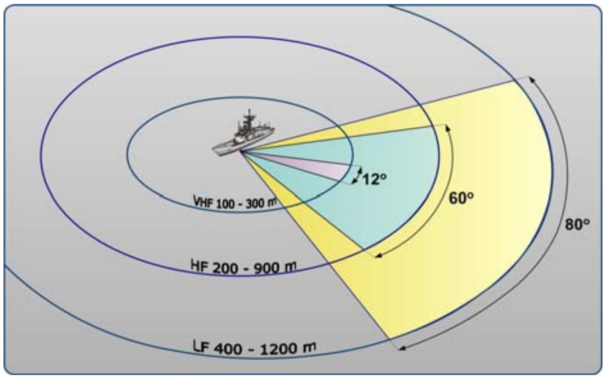
The LF mode is assigned to long range target detection and depth classification. The horizontal observation sector is the widest. Whereas in elevation are available three transmission beamwidths: narrow 3.2°, medium 6.4° and wide 12.8°. Therefore the vertical beamwidth can be matched to the sea dept and sea state i.e. the narrow beam is preferred in shallow waters and high sea states to limit the surface backscattering noise level. The echo signals are received by HF antenna of 16° vertical beamwidth. To obtain moored mines draught, narrow beam is evenly electronically tilted. Echo signals received from 5 consecutive pings are simultaneously presented on oscilloscope display. The target draught is computed on the basis of detected signal maximal amplitude, range and sound propagation conditions i.e. ray paths.

The HF wideband mode significantly improves the sonar detection performances in difficult environmental conditions characterized by high level of reverberations. This mode is mainly dedicated small object and stealthy mines detection. Its very high range resolution of 2.5cm enables very efficient target echo classification.

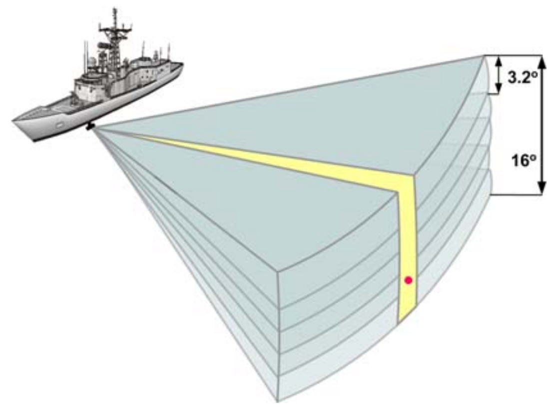
The VHF very high angular and range resolution mode is essentially oriented for shadow classification of the previously detected targets. Object lying on the seabed can be efficiently recognized due to analysis of its echo signal and associated cast shadow. Object exact recognition consists in determination of its shape and dimensions. Meaningful improvement in target dimensioning is obtained by target multiview observation. For that purpose the ship should encircle the target at the distance less than 300m. The input data from different directions of target sonification are recorded and make possible further omnidirectional dimensioning.

The steering of VA and HA antennas is mutually independent. This feature enables location of both antennas in such manner to their beams contact in vertical plane of view. Application of alternate sonar operation at LF and HF modes (ping-to-ping operation) enables observation of the sub-surface zone, sea water volume and seabed and the same time i.e. simultaneously detection of floating, suspended, and bottom objects.

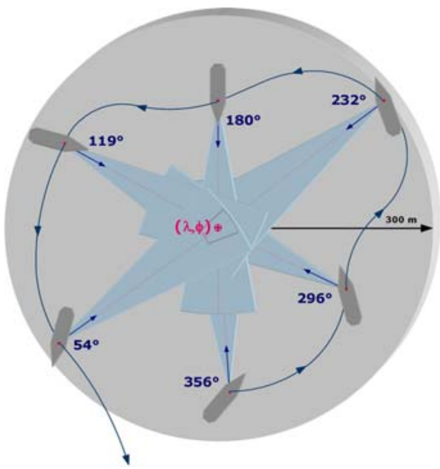
To maximize minehunting effectiveness sonar is provided with Range Prediction System. It computes sonar performances taking into consideration environmental conditions, sound velocity profile, weather conditions, and sonar operational parameters. Sonar collaborates with external ship's system i.e. receives navigation data from Ship's Navigation System and two way interchanges data on detected targets with Combat System. Minehunting real data can be also recorded and afterwards replayed for post mission analysis or training purposes.



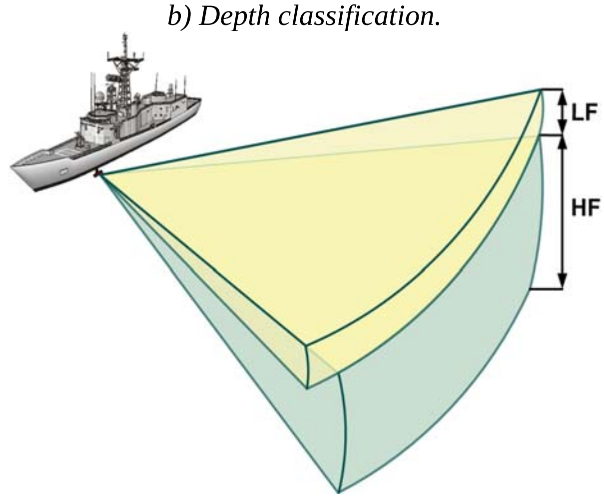
a) Horizontal sector coverage.



b) Depth classification.



c) Multiview acoustic shadow classification.



d) Ping-To-Ping mode.

Fig.1 Sonar operating modes

MAIN FEATURES

- Minehunting in very shallow, brown and blue waters and in areas of strong stratification or high clutter density for the sea state up to 4 at the ship's speed up to 6 knots
- Operational modes:
  - LF - long range detection, echo signal and depth classification
  - HF - high resolution (range and angular) detection, echo signal classification
  - VHF - echo signal and shadow classification
- Detection and classification of classic and stealth mines
  - Laying on the seabed - bottom mines and partly buried mines
  - Situated in water volume from near the surface to the seabed - moored and suspended mines
- Automatic target tracking
- Sonar Range Prediction Systems
- Storage and play-back of the sonar data
- Built-In-Test-Equipment

- Antenna accurate electronic and mechanical stabilization against ship's roll and pitch
- One-man operation, comprehensive display, operator's support functions
- Co-operating with Ship's Navigation System and Combat System
- Sonar characterizes modular structure with usage commercial-of-the-shelf units, enabling its adaptations to meet specific requirements of the various ship's types.

<u>CONSTRUCTION</u>

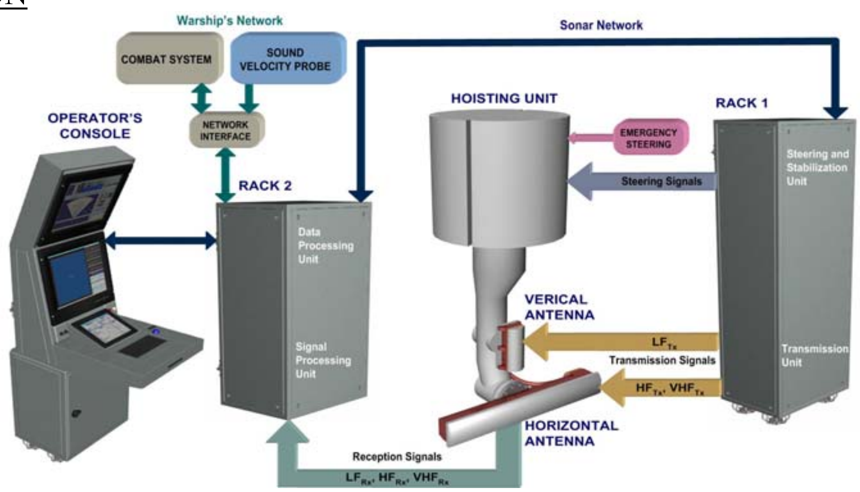


Fig.2 Sonar block diagram

SHL-101/T sonar performance parameters are comparable with newest world achievements. Its construction is very complex. Equipment manufacturing demanded elaboration and usage of many up-to-date hardware and software technologies.

<u>Following modern technologies were applied in sonar construction:</u>

- FPGA (*field-programmable gate array*) boards with 20 Xilinx Virtex II units to realization beamformer algorithm and matched filtering
- FDPD (*front data panel port*) to transfer up to 160MB/s of sonar data from HA antenna interface to signal processing unit and data processing unit
- DSP (*digital signal processing*) to matching, beamforming and postprocessing of sonar data
- Computationally efficient PCI-X ring of PowerPC G4 processors which support SIMD (Single Instruction Multiple Data) - AltiVec
- Ultra320SCSI (*small computer system interface*) to record wide stream of date on SCSI discs
- Parallel compensation of piezoelectric transducer reactance to minimize and equalize phase shifts in broad bandwidth on transmission
- Pulse compression:
  - Transmission – linear and hyperbolic, increasing and decreasing frequency modulation of transmitting pulses
  - Reception – filtration matched to transmitting pulse
- Titanium alloy to construct underwater mechanical unit

- Stabilization unit to precise control movement of the both antennas: ships movement compensation 0.5°, positioning accuracy 0.03°
- CAN (*controlled area network*) network to collect the data from sensors of the mechanical unit by control computer, all sensors are duplicated to increase system reliability
- Frequency synthesizers to form and control the amplitudes and phases of over hundred independent transmission signals.

The sonar was constructed in cooperation with three companies:

- T.U.S. - Thales Underwater Systems from Brest, France – the supplier of hydroacoustic antennas
- OBRUM - Research and Development Centre for Mechanical Appliances Ltd. from Gliwice, Poland – the manufacturer of mechanical unit hardware
- MIL - Microtech International Ltd. from Wrocław, Poland - the producer of signal processing hardware based on FPGA which implement developed by CTM beamformer algorithm.

1. LABORATORY BASIN TESTS

The basin measurements of sonar parameters were carried out at the Design and Research Centre (CTO) in Gdańsk in 2005 year. The large towing tank of size 260 × 12 × 6 m (length × width × depth) enabled realization the functional tests as well. To tests accurate execution the special test bench equipped with electrical drive and computer positioning system was developed and constructed. During tests the antennas hydroacoustic parameters specified by T.U.S. were exactly verified. The complete signal link with the effect from antennas throughout transmitter, signal processing, and data processing was examined. Te results of complex functional tests were displayed on operator's console. Furthermore the parallel compensation of piezoelectric transducers reactance was checked. Those tests confirmed the correctness of sonar performances.

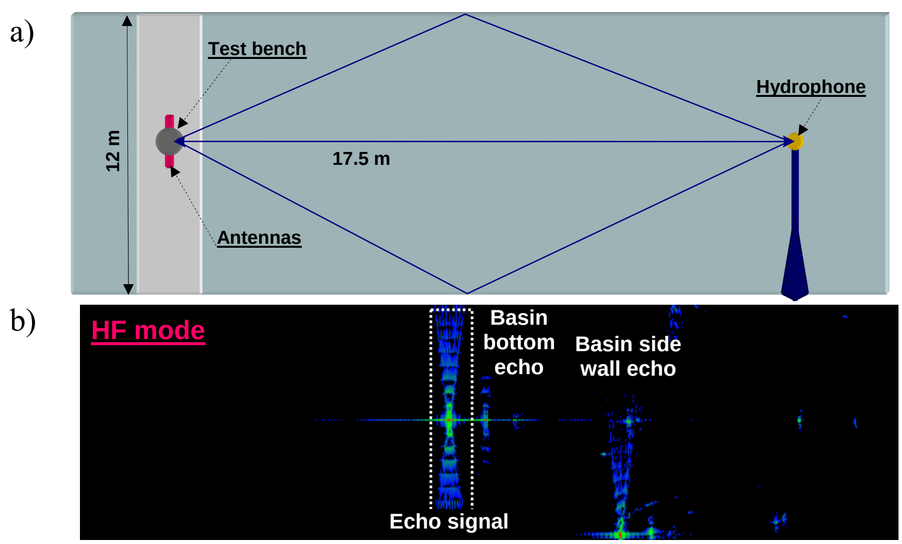


Fig.3 a) Test bench at the model basin, b) Example of recorded echo signals

2. HARBOUR TRIALS

The harbor trials began in 2006 year. The first practical observations of the Polish Navy naval base in Gdynia were satisfactory and suggested few innovations. The most significant improvements are following:

- Introduction of additional conformal representation of data (PPI - plan-positioning indicator). Up to harbour trials only B-type display was available for target detection purposes. Nevertheless observed on this display wharf walls were deformed i.e. for short ranges the display was stretched and for far ranges it was compressed.

a) b)

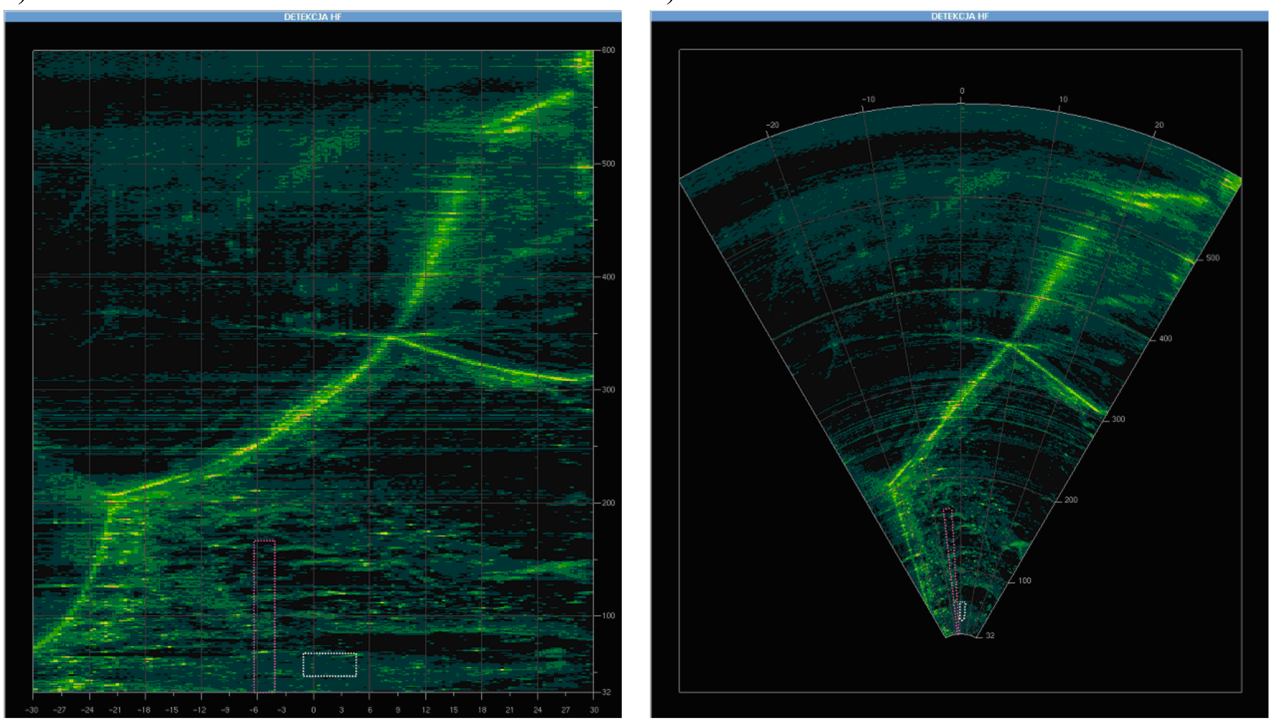
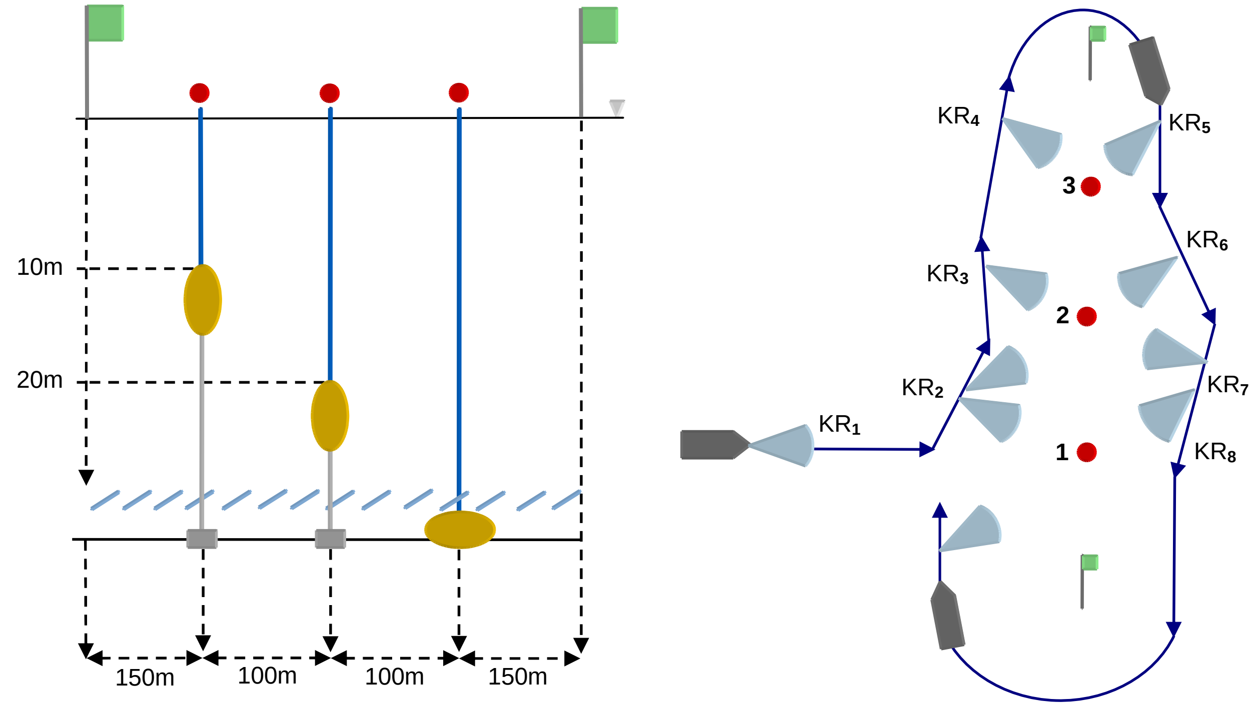


Fig.4 Sonar display of wharf walls: a) B-type display, b) PPI-type display

- Betterment of sonar resolution
- Implementation of target multiview observation and dimensioning
- Addition of antennas 2D point stabilization (longitude and latitude) forwards advisable by operator target

3. SEA TRIALS

The first sea trials were carried out in Gulf of Gdańsk in December 2006 year. Two moored mines and on bottom mine were spaced according to the scheme on figure 5. The testing sea area was marked by spar buoys at the beginning and end of the mines arrangement. The mines geographical positions from the moment of their submergence were stored by Command and Control System “Bełtwa”. The mines were minehunted by sonar and position of their detection were compared with the data stored by “Bełtwa” system.



Legend:
- Training mine t.OD
- Training mine t.OTW
- Spar buoy
- Anchor-buoy rope

KR_1 – orthogonal to mine line
$KR_2 = KR_1 – 80°$
$KR_3 = KR_2 – 80°$
$KR_4 = KR_2$

KR_5 – parallel to mine line
$KR_6 = KR_5 – 10°$
$KR_7 = KR_6 + 20°$
$KR_8 = KR_5$

Fig.5 Scheme of the testing sea area and ship's maneuvering during sea trials

The sea trials confirmed that sonar parameters fulfill the requirements of the Polish Navy. Selected displays of underwater target detections and classification processes are presented on figures beneath.

a) b)

Fig.6 "Bełtwa" system displays: a) Map of testing sea area,
b) Convergence of the mines markers:  - position of mine submergence,  - position of mine detection

a)

b)

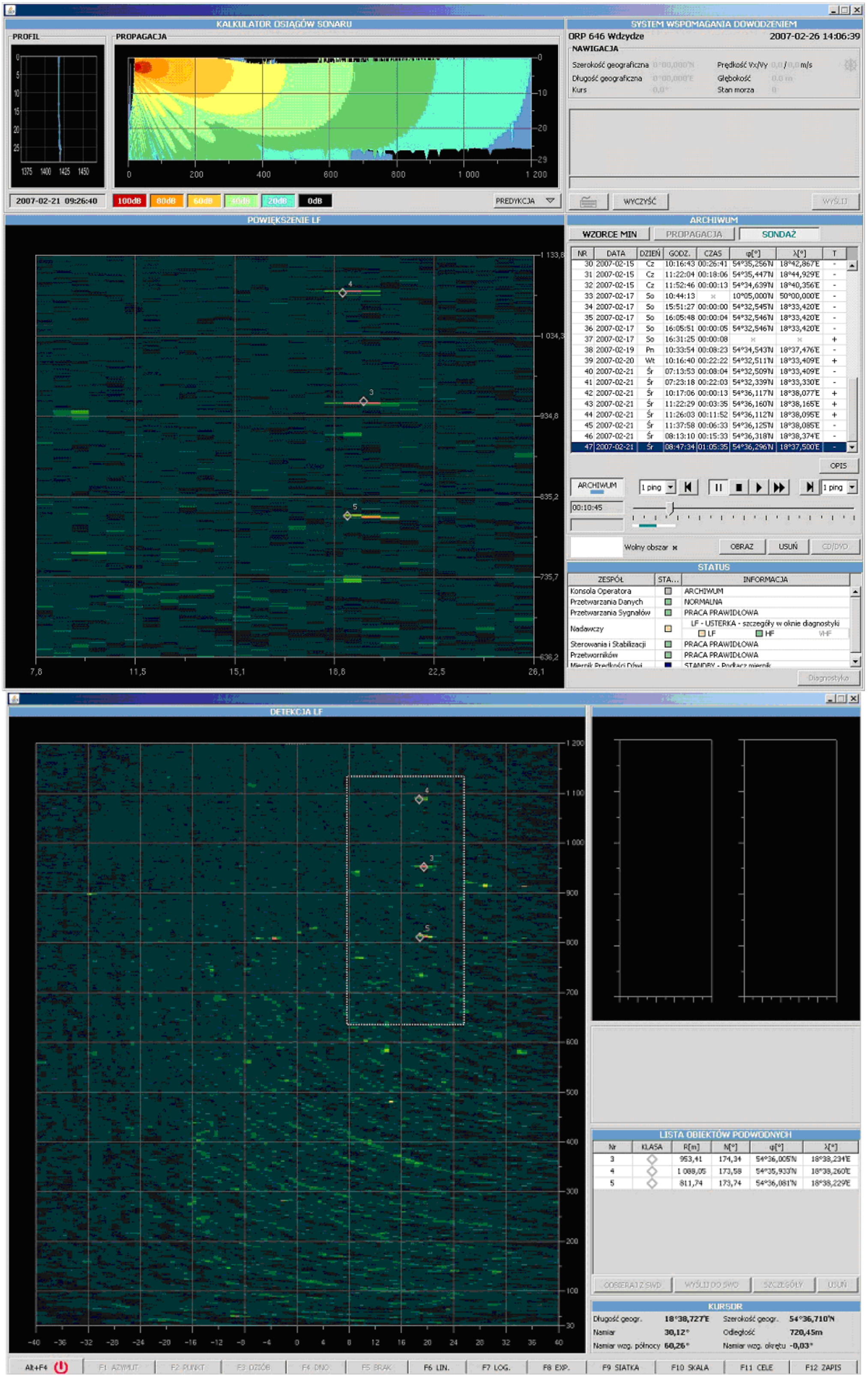
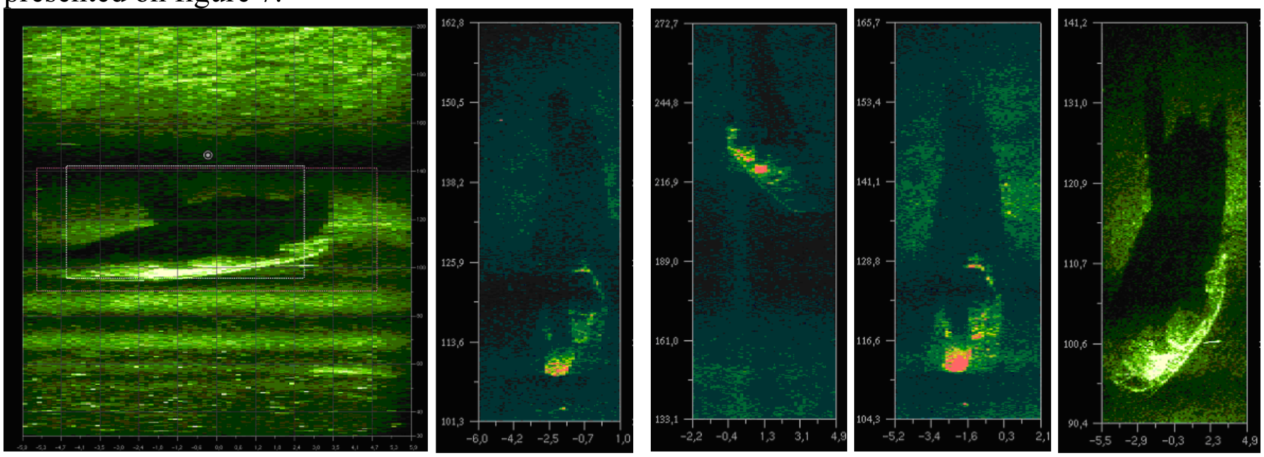
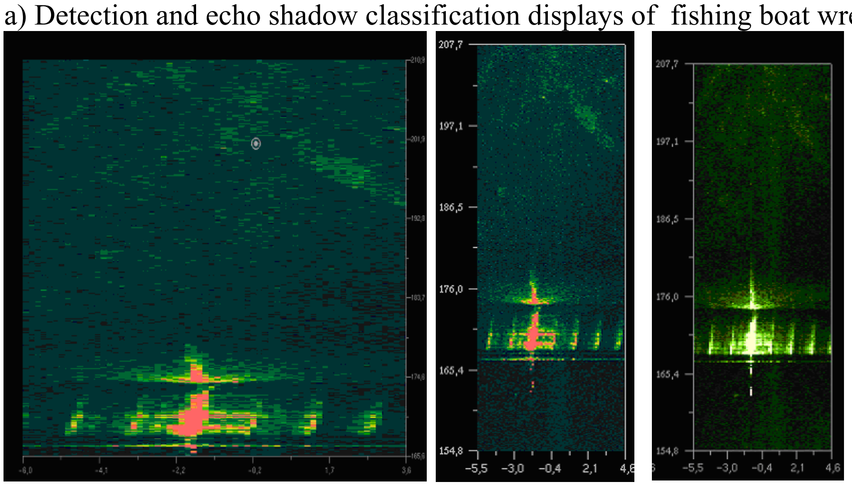


Fig.7 a) Auxiliary sonar display, b) Main sonar display

The sonar was introduced into armaments of Polish Navy in April 2007. The military trials confirmed correctness of different underwater object detection, location and classification. The minehunting trials provided surprising findings in Gulf of Gdańsk. The most interesting are presented on figure 7.



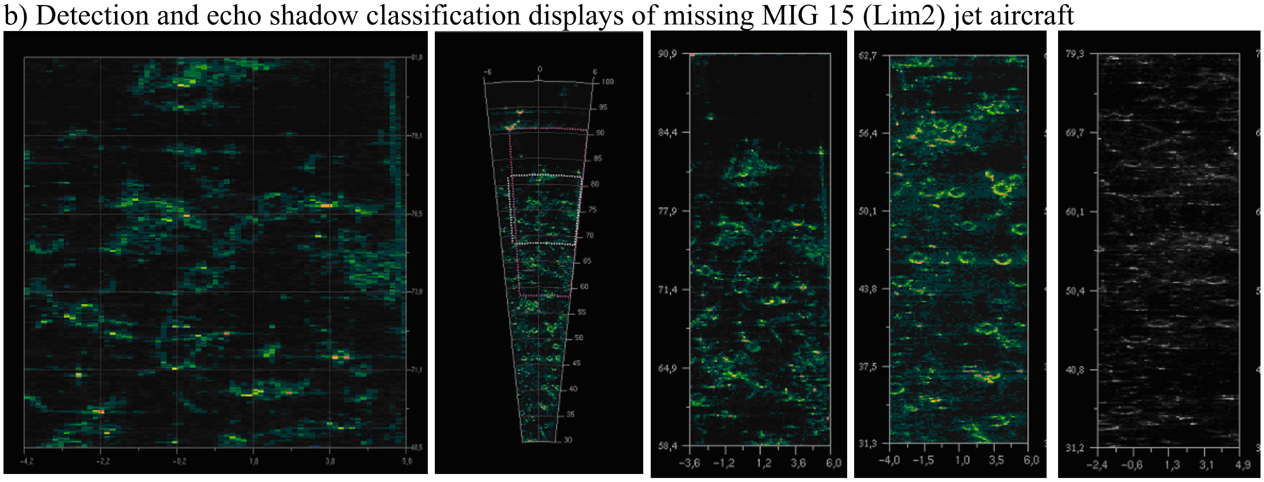
a) Detection and echo shadow classification displays of fishing boat wreck



Front view of the MIG 15 (LIM 2)

Location of jet aircraft detection

b) Detection and echo shadow classification displays of missing MIG 15 (Lim2) jet aircraft



b) Detection B-type, PPI-type and echo shadow classification displays of sunken tires in harbor

Fig.7 Detection and classification displays of detected fishing boat, jet aircraft, and tires

4. SUMMARY

SHL-101/T sonar efficiently detects objects located in sea water volume and lying on the seafloor due to its very high angular and range resolution. Bottom or partly buried mines can be effectively recognized due to analysis its echo signal and arising behind the target cast shadow i.e. lack of reverberations. Thanks to target multiview observation functon it is possible to determine its multi-directional sizes and approximate minimal height over the seabed. Presented sonar has been still tested and updated. Further development will supplement new functions such as:

- Antennas 3D point stabilization (longitude, latitude and depth) forwards advisable by operator target,
- 3D spatial detection display.

Sonar characterizes modular structure enabling its adaptations to meet specific requirements of the ships itself and minehunting mission.

REFERENCES

1. W. Męciński, M. Okuniewski, E. Porosińska, R.Zajac, “SHL-101/T Wideband High Resolution Minehunting Sonar”, Undersea Defence Technology UDT, Hamburg 2006.
2. W. Męciński, M. Okuniewski, “Badania Stacji Hydrolokacyjnej SHL-101/T”, Naval Armament & Technology NATCon’2007, Gdynia 2006.
3. E. Porosińska, M. Cyms, “Zespół Konsoli Operatora Stacji Hydrolokacyjnej SHL-101/T”, Naval Armament & Technology NATCon’2007, Gdynia 2006.