MULTISTATIC SONAR PULSE SIGNALS TIME DELAY ESTIMATION

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An application of a multistatic sonar concept is presented. Signal excess areas were simulated for a given configuration of one active source and two passive receivers for different sonar, target and sound speed profile parameters . Time delay estimation algorithm based on convolution in frequency domain is developed. Experimental results are given with real sonar measurements and time delay estimation in test tank and at sea trial.

***Keywords**: multistatic sonar sonar, time delay estimation, digital signal processing.*

1. THE MULTISTATIC SONAR CONCEPT.

In the beginning of sonar systems development the needed sonar range is acquired with powerful sources and monostatic systems. An increased sonar detection range with more power is not always the best solution in modern systems. An alternative way for increasing the range is proposed with the multistatic sonar concept which draws its origin from passive sonobuoys introduced during the second world war. It is based on area distributed or line arranged sensors forming a network [2]. Tactical scenario of a contemporary multistatic underwater surveillance system is shown on fig.1.

In a multistatic system theoretically with less power the signal excess formulas give the same area as with more powerful monostatic source for the sake of distributed sensor area extension [2]. One or more buoys are active sources (actuators for the detection process) of sound waveforms with specific parameters. The target reflected signal is received by passive buoys under constant reverberation and noise fields. The adaptive depth positioning, sound propagation model based algorithms and coherent signal processing can increase total signal to noise ratio.

Critical technology parameters according to MTCL[1] is “Real-time processing of acoustic data from fixed, deployed or mobile arrays operating in the bi-static or multi-static mode to increase target signal-to-noise ratio by over 6 dB in order to increase detection range by over 10%, increase probability of correct decisions and reduce false alarms.”

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[1] MILITARILY CRITICAL TECHNOLOGIES LIST, MCTL DATA SHEET 11.5-2. SIGNAL AND DATA PROCESSING FOR MULTI-SENSORS AND MULTI-PLATFORMS

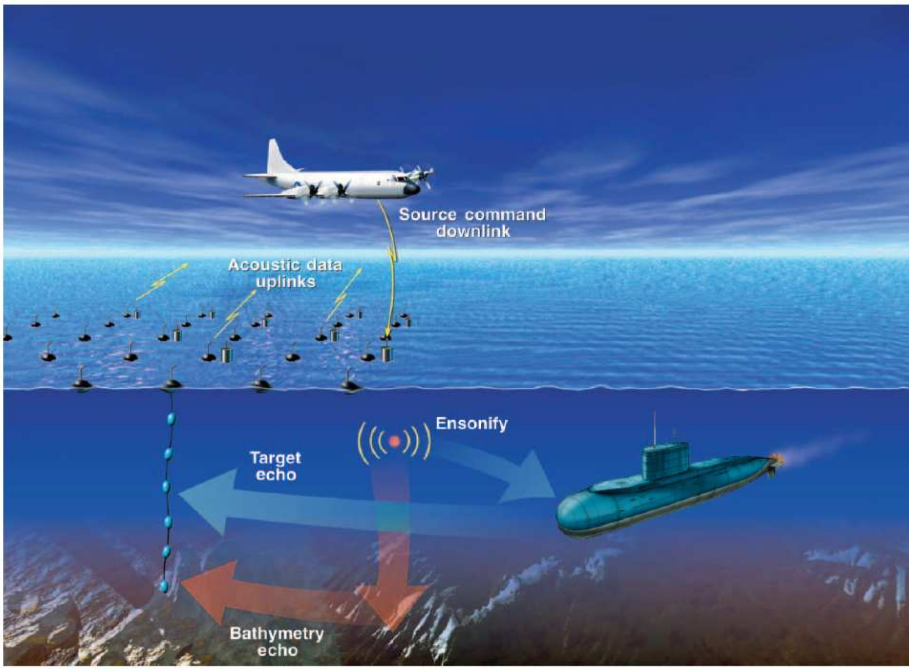


Fig. 1. Tactical scenario of a multistatic underwater surveillance system [3].

A preliminary concept is developed at the academy of a minimal multistatic system which is investigated partially – fig.2. The minimal multistatic sensor network has the following components:

- Active sonar source comprising sensor node with power amplifier and transducer;
- Sensor node end devices comprising hydrophones and receivers;
- Computer with access point sensor node and software for sensor network control;
- The system if fixed at the bottom of the sea or a ship hull or a pier.

Simulated signal excess areas of a multistatic system with one active and two passive nodes are given on fig.3. They are simulated for different sound speed profile, given active node signal parameters, channel depth and configuration.

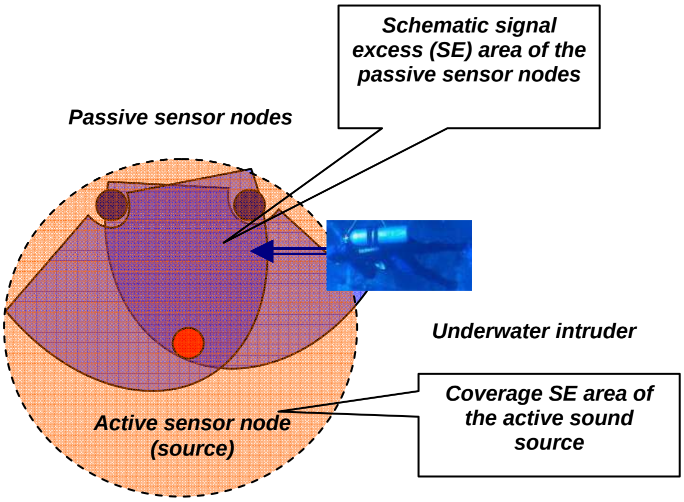
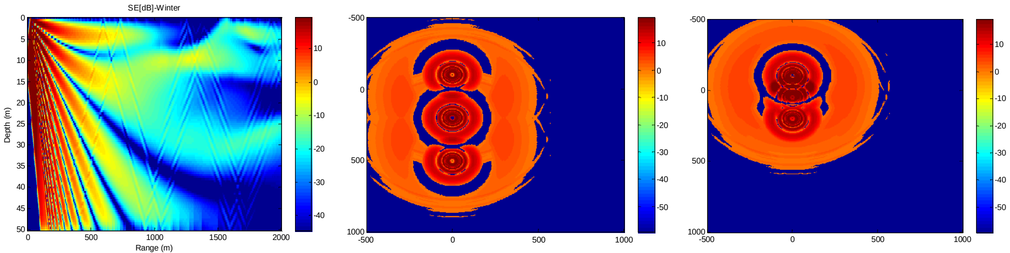


Fig. 2. A multistatic system for diver detection - schematic concept.

(a) winter



(b) summer

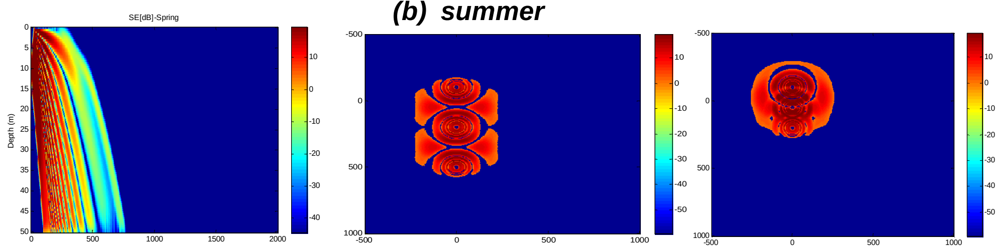


Fig.3. Modeled signal excess for winter (a) and summer (b) sound speed profiles for one active source (center and end positioned) and two passive receiving nodes.

At the moment investigations are going on at the naval academy for establishing the feasibility of the multistatic concept for detection of underwater moving objects in shallow waters. It is closely related with modern sensor network concept. In active multistatic sonar systems a source transducer ensonifies the area of the target and distributed hydrophones (End Nodes) receive and coherently process the scattered signals. After that preprocessed and compressed signals from receiver nodes is transferred to cluster unit (Access Point) where association, target racking and classification is applied. In this case it is expected that the performance of the distributed sonar system will be improved due to the increased signal to noise ratio in consequence of possible coherent signal processing in the distributed sonar.

2. IMPULSIVE SONAR SIGNALS TIME DELAY ESTIMATION.

Impulsive sonar signals time delay estimation (TDE) is needed for underwater objects localization in active monostatic and multistatic sonar systems. Shallow waters are rich of ambient noise and replicas of the emitted signal caused by surface and bottom reverberation. This implies some difficulties in the detection of the signals. One of the main tasks in these sonar systems is time delay estimation of signals at different receivers. In order to process signals and to do TDE in a wireless system the problems of time synchronization and precise positioning of nodes have to be solved.

If S1(t) is the source signal in time domain, n1(t) and n2(t) are additive independent noise components, then the expressions for signals at the two distant receiver nodes are:

$$\begin{aligned} x_1(t) &= s_1(t) + n_1(t) \\ x_2(t) &= as_2(t - t_D) + n_2(t) \end{aligned} \qquad (1)$$

Where t_D - time delay between the two signals due to difference in positions.

For automatic measurement of TDE it is possible to use convolution (cross correlation) in the time or frequency domain (2). At the output of this function there is maximum for discrete offset corresponding to discrete TDE between the two signals.

$$x_1 \otimes x_2 = \sum_{m=0}^{N-1} x_1(m) x_2(n-m) \qquad (2)$$

Implications arise in case of surface and bottom reverberation (fig. 4).

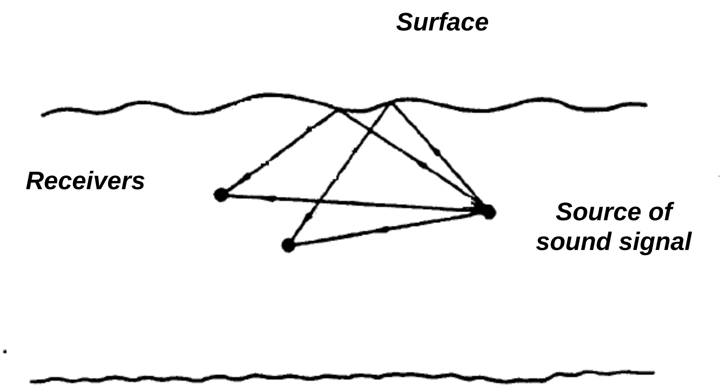


Fig. 4. Direct and surface reflected beams.

3. EXPERIMENTAL RESULTS.

For multistatic system concept performance evaluations and TDE several experiments were carried out at BU naval academy test tank and also at sea.

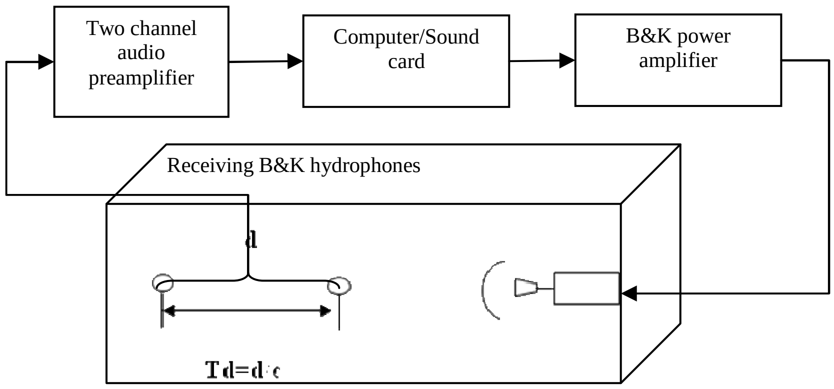


Fig. 5. Test tank experimental setup.

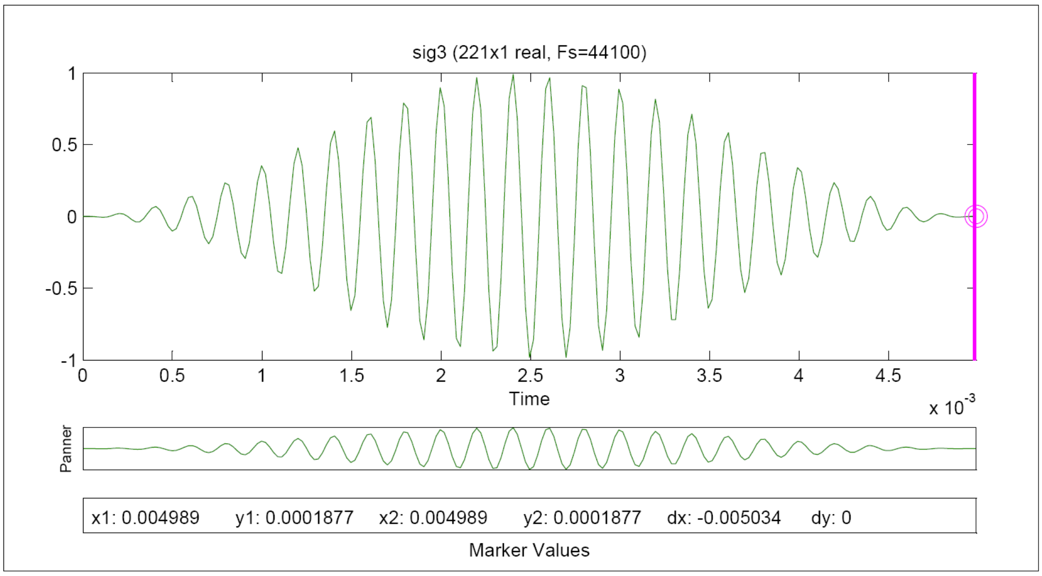


Fig. 6. Synthesized and transmitted signal waveform with parameters – frequency F=5 KHz and pulse width – Ti = 5 ms. The signal is sampled at the output of the power amplifie with frequency Fs=44100 Hz.

On fig.7 the received signals from the two hydrophones are shown. The hydrophone which is near to the source receives the signal X1(t) in the time frame 0.0075 s - 0.0125 s . The signal at the second hydrophone X2(t) is received 1 ms after ensonification of the first hydrophone in consequence of the distance between hydrophones – d. This TDE corresponds to the real distance between the two hydrophones which is 1,5 m.

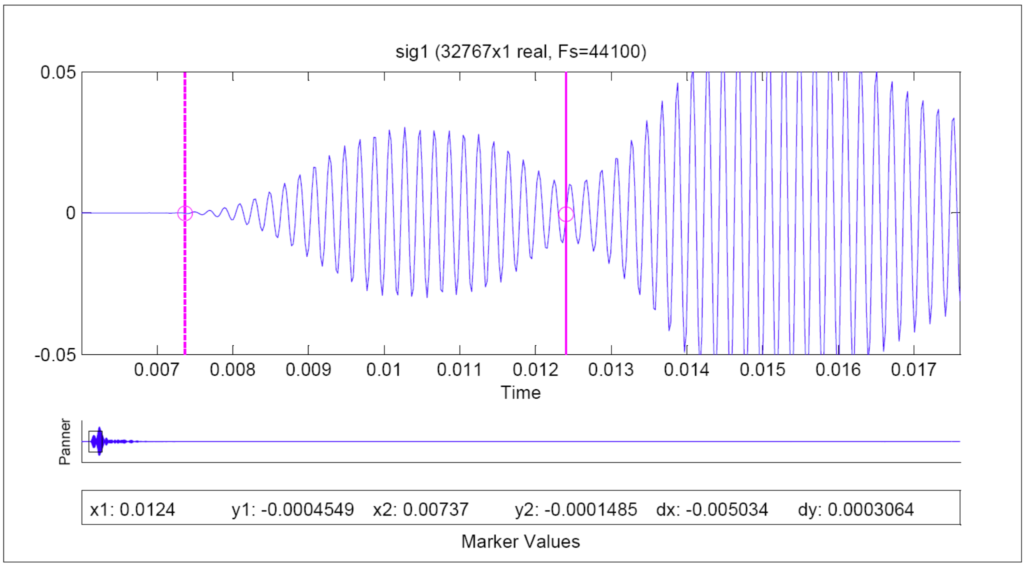


Fig. 7 (a).

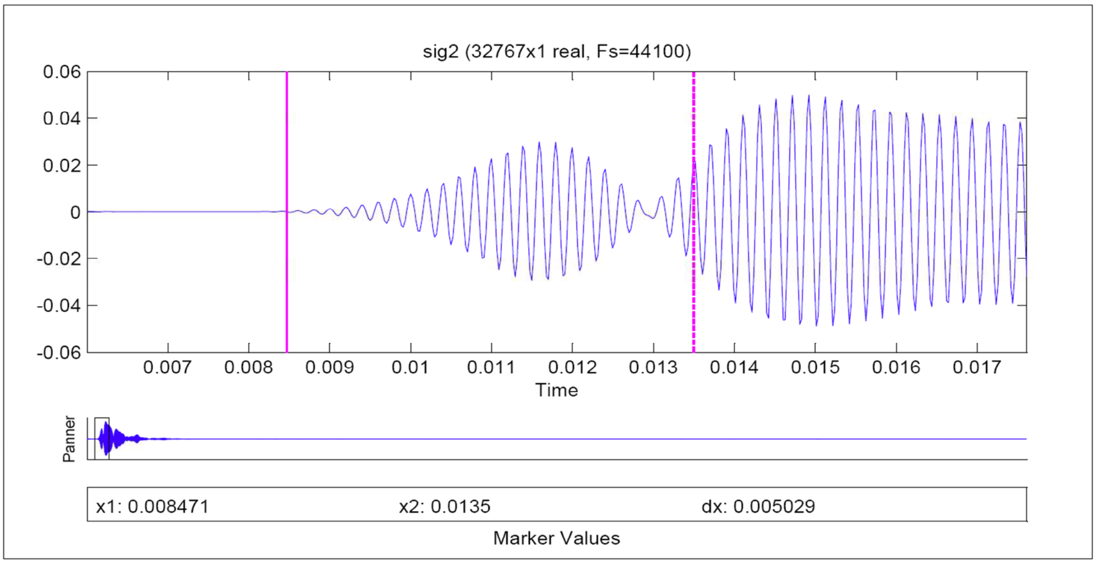


Fig. 7 (b). Analysis of received short sound waveforms which shows possibility for separation of direct and reflected test tank signals and TDE – (a) - signal at first hydrophone; (b) – signal at second hydrophone.

On the 19 and 20-th of august 2008 a sea trial took place near the island of St. Anastasia.

Fig. 8. Island of St Anastasia during the experiment.

The aims of the bistatic experiment for diver detection were:

- Bistatic tests in passive and active mode;
- Synchronized non directional sound waveform generation and data storage with hydrophone on a given distance from the source;

The following types of signals were used in active mode:

  - Simple pulse;
  - LFM pulse;
  - CW.

- Initial signal database forming;
- Database signals digital signal processing and parameters estimation.

Schematic of the experimental set up is given on fig. 7. Some results are given on figs 8-11.

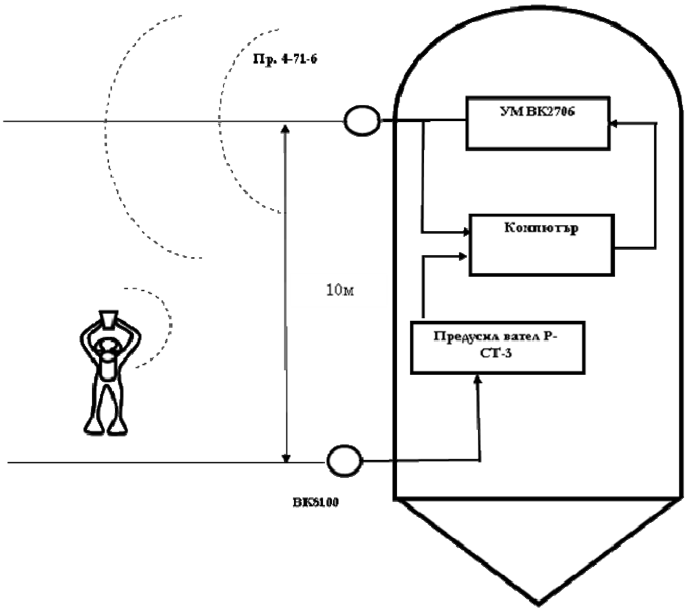


Fig. 9. Experimental bistatic setup during sea trial.

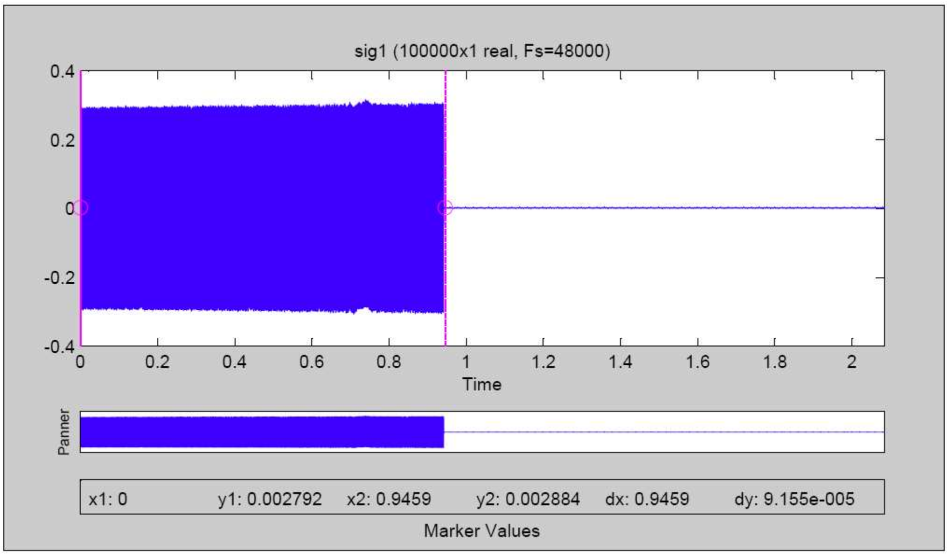


Fig. 10 (a).

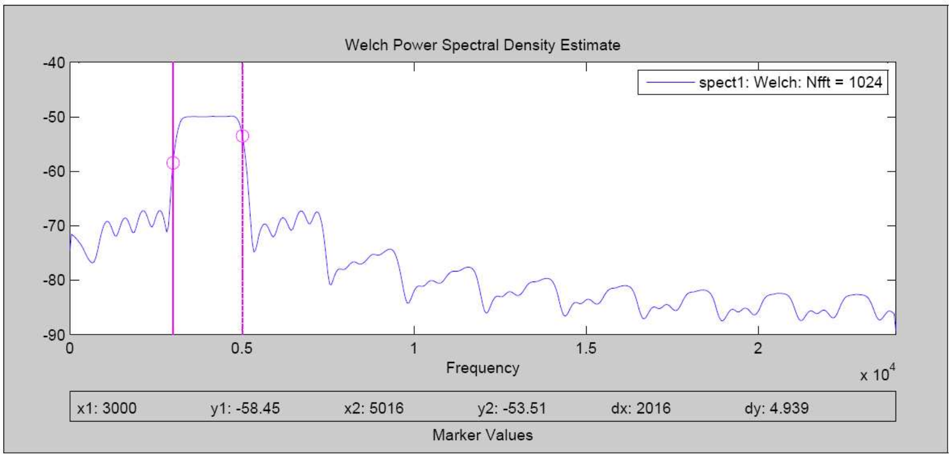
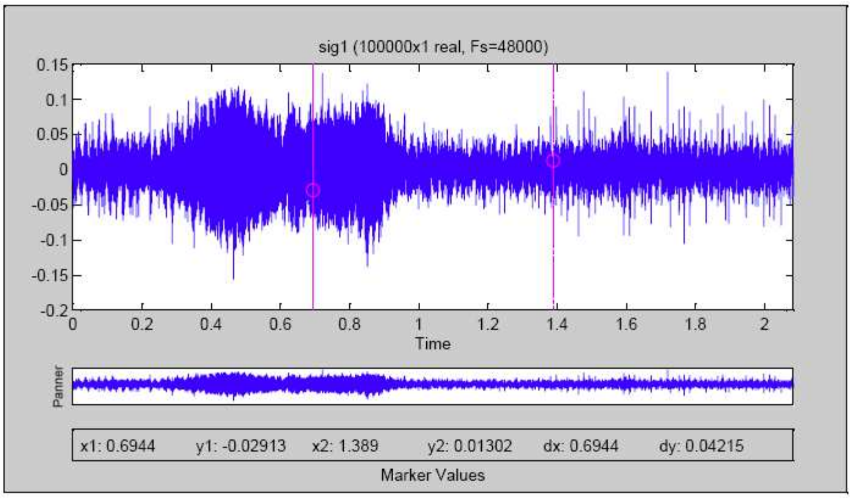


Fig. 10 (b).

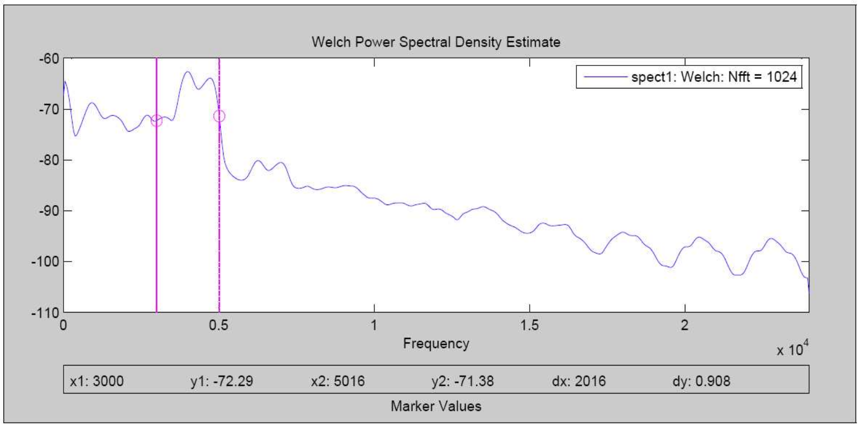
Fig. 10. Synthesized LFM pulse with bandwidth (3000 – 5000 Hz) and duration 1 s, sampled at the output of the power amplifier - (a). Estimation of power spectrum - (b).

The preliminary signal processing of the received signal includes digital filter bandpass filtering which is needed to lower different noises (fig. 12) .



x1: 0.6944 y1: -0.02913 x2: 1.389 y2: 0.01302 dx: 0.6944 dy: 0.04215

Fig. 11 (a).



x1: 3000 y1: -72.29 x2: 5016 y2: -71.38 dx: 2016 dy: 0.908

Fig. 11 (b).

Fig. 11. LFM sampled pulse at the hydrophone after preamplification:
(a) – time domain waveform;
(b) – power spectrum estimation.

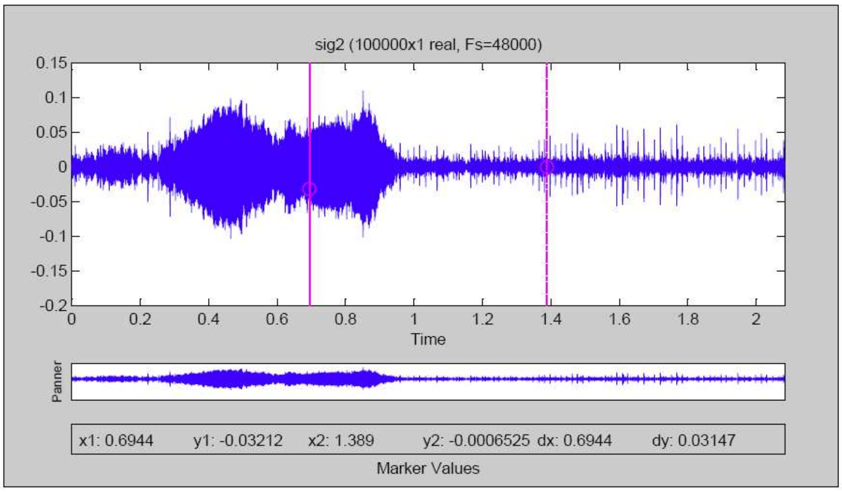


Fig. 12 (a).

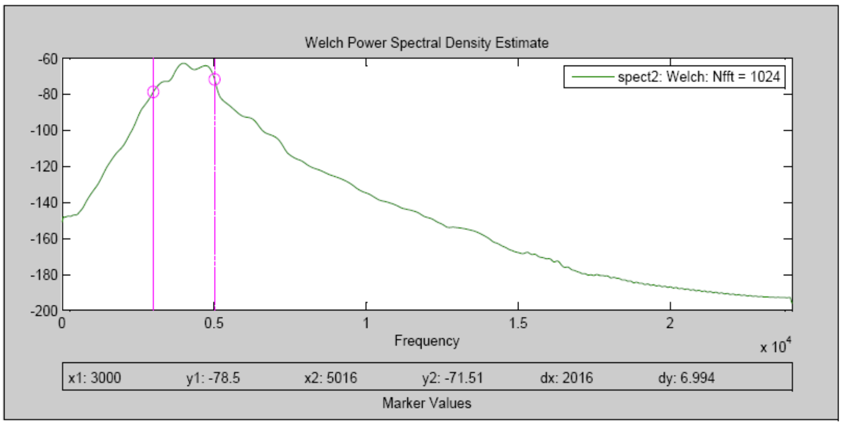


Fig. 12 (b).

Fig. 12. LFM sampled pulse after band pass filtering:
(a) – time domain waveform;
(b) – power spectrum estimation.

On fig. 13 are shown transmitted and received signals sampled synchronously respectively at the output of the power amplifier and at the hydrophone.

The MATLAB algorithm for TDE by means of cross spectrum processing is given on fig. 14.

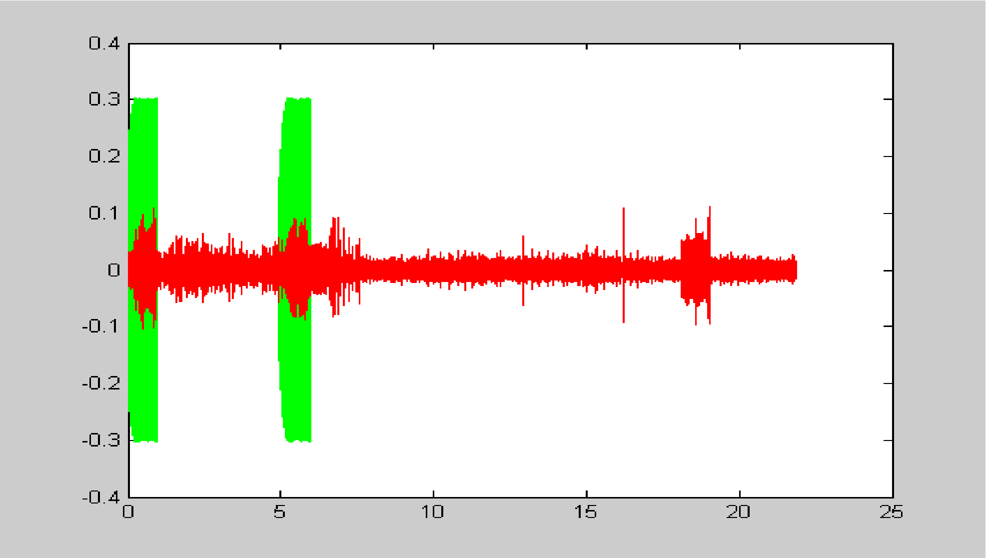
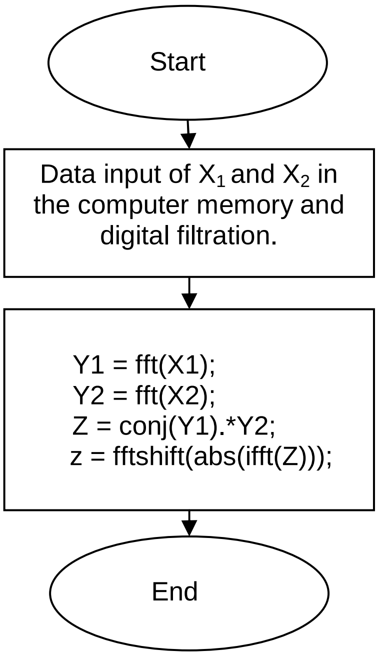


Fig. 13. Waveforms in time domain of two consecutive transmitted (green) and received (red) LFM pulses.



```
Y1 = fft(X1);
Y2 = fft(X2);
Z = conj(Y1).*Y2;
z = fftshift(abs(ifft(Z)));
```

Fig. 14. A Matlab algorithm for optimal processing.

The first peak is due to the direct pulse signal and corresponds to distance between the transducer and hydrophone – 10 m. The other peaks are due to reflected beams from sea surface and bottom- fig. 15.

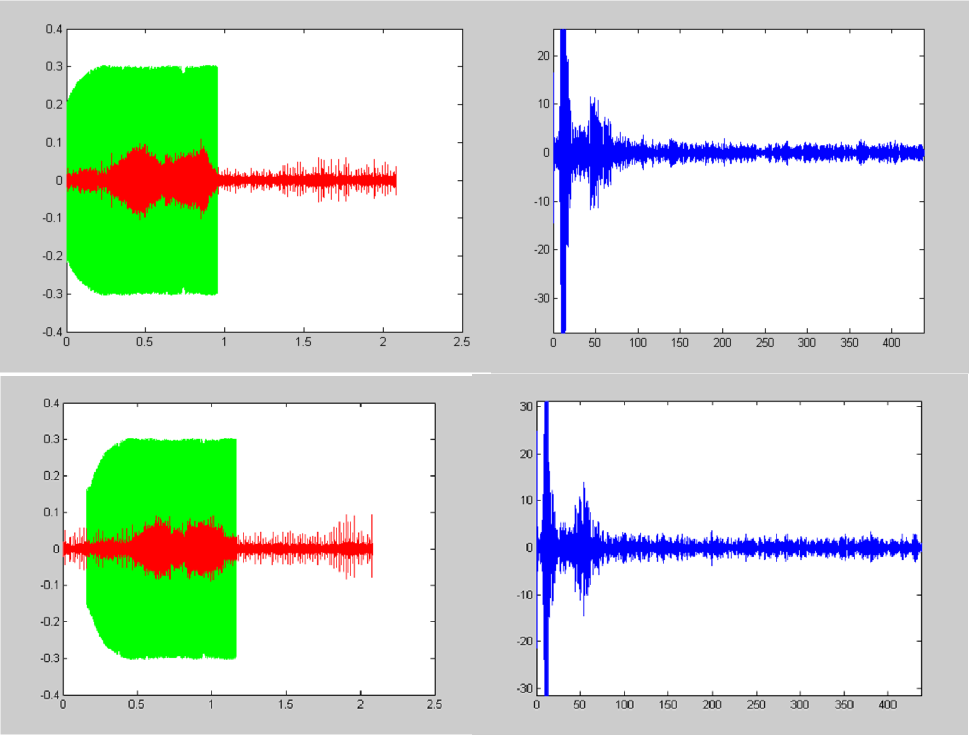


Fig. 15. Optimal signal processing of the first and the second LFM pulses.

4. CONCLUSIONS.

1. Time delay estimation is key factor for signal processing and target position estimation of underwater objects in monostatic and multistatic sonar systems.
2. In real sea shallow water conditions there are numerous reflected signals due to surface and bottom reverberation which implicates signal processing and TDE.
3. TDE experimental trials are useful for further understanding and pointing out the most important shallow water, sonar and transducer parameters influencing signal detection and towards improving signal processing algorithms and especially dereverberation.
4. There is a need for precise channel impulse response modeling and taking into account in the models of the transducer pattern and depth in the water column.

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