Analysis of Sea Bottom Relief Details by Means of Interferometric Side Scan Sonar AGKPS-300

Prof. V.I.Kaevitser, Dr. V.M.Razmanov, Dr. A.I.Zakharov
Institute of Radioengineering and Electronics, RAS
Vvedensky square 1, 141190 Fryazino, Russian Federation

E-mail: kvi@ire.rssi.ru / razik@ire.rssi.ru / aizakhar@ire.rssi.ru

SUMMARY

Side scan sonars were shown to be efficient instruments for implementation of wide spectrum of hydrographical tasks. Interferometric side scan sonars of AGKPS-300 type provide information about relief along with acoustic image of seafloor in a wide (up to few hundreds meters) survey swath. An efficiency of side scan sonars application is determined by the techniques of data processing in addition to the parameters of the instrument used. In a given report we demonstrate some preliminary results of application of digital filtering technique for analysis of some seafloor relief features based on the data of interferometric side scan sonars of AGKPS-300 type exploiting both tone and chirp pulses. In order to increase signal-to-noise ratio and, consequently, an accuracy of the depth measurement, regular algorithm of data processing was complemented by tracking narrow-band filtering of complex conjugate multiplication of signals of interferometer channels. Pre-calculated coefficients of narrow-band filter were used further in a number of versions of tracking algorithms in order to lock interference signal frequency in the filter bandwidth. The necessity to monitor interference frequency is a specific feature of the side scan survey technique and is a key moment in a development of filtering algorithms. In a given report we demonstrate some examples of application of tracking narrow-band filtering in two cases: for identification of a bright feature on the acoustic image obtained in a Baltic sea and in the case of attempt to detect furrows of glacial origin on seafloor on the interferometric side scan sonar images.

1.0 INTRODUCTION

Acoustic sounding is an effective way of seafloor mapping, allowing to gain both common view of seafloor state over the large areas and more detailed information about natural and artificial objects at the seafloor and in a soil layers, the stratification of soil depositions, etc. The most common devices being used in the acoustic studies of seafloor are the sonars, giving intensity (ultrasonic) image of seafloor, single-beam and multibeam echo-sounders designed to derive the information about bottom relief and also profilers, designed to acquire information about stratification of ground depositions and presence of a various type of objects in high layers of a soil.

Researchers of Institute of Radio Engineering and Electronics of RAS conduct investigations on the design and application of hard- and software tools of acoustic sounding of sea bottom since a beginning of 1980th. They apply modern achievements in the area of digital technology, the optimum acquisition and signal processing techniques, the ideas of experiments automation. The main peculiarities of the developments being made at the Institute are the application of compound signals like as chirp signals along with traditional tone signals, interferometric processing of a signals, fully digital schemes of signal synthesis and processing and a wide application of modern computer hardware. Application of chirp signals in sonar studies been started at IRE RAS in 1980th, was a pioneering one in our country, and if speaking about involvement of interferometry and digital signal processing approaches, also in the world. The wide application of computer equipment allowed them to create the automated hard – and software

Paper presented at the RTO SET Symposium on "Capabilities of Acoustics in Air-Ground and Maritime Reconnaissance, Target Classification and Identification", held in Lerici, Italy, 26-28 April 2004, and published in RTO-MP-SET-079.

complexes, which ensure all the cycle of collection, handling, representation and archiving of huge data volumes (tens - hundreds Gbytes).

2.0 DESCRIPTION OF THE INSTRUMENTATION AND PRINCIPLES OF OPERATION

Practically all the spectrum of modern ultrasonic devices intended for a sea bottom sounding was developed at IRE RAS by now. Among them are:

- side scan sonars of various frequency bands (from 6 kHz up to 400 kHz) and of various configuration (shipborne and towed)
- interferometric side scan sonars intended for collection of the information about sea bottom relief (as an alternative to multibeam echo-sounders)
- profilers (including instruments with multielement antennas) for the frequency band of 5 kHz- 30 kHz.

The sounding signals with chirp modulation used in all the designed devices, allow meet a number of the contradictory requirements to demand to the performance of the instrumentation. For example, in order to increase the range of operation it is required to increase the energy of the transmitted signal via power magnification and/or pulse duration (in the case of a use of regular tone signals). On the other hand pulse duration is restricted by the requirement of proper range resolution, and the peak power is restricted by the sonar antenna (so-called cavitation threshold – the vesicultion on the antenna radiating surface). The application of chirp signal and subsequent coherent signal processing allows to remove restriction on pulse duration, since the range resolution is defined by a frequency band of the chirp signal, which can be made large enough. That allows to raise power performance of the system at some orders and to improve noise immunity, but requires the design of the coherent scheme of signal synthesis and processing, provided the coherence of echoes propagation in water and at bottom scattering is kept.

The interferometric side scan sonars are the systems with several (minimum two) receiving antennas. That is an alternative to multibeam echo-sounders in the area of sea bottom relief studies. The multibeam echo-sounders are widely adopted in the world. Those are rather expensive systems, since they consist of several tens calibrated ultrasonic antennas and include a complicated electronics, which provides shaping of separate beams. Moreover, the synthesis of regular (intensity) sonar image in multibeam echo-sounder is a special problem, which got good-enough solution just recently. All these disadvantages are not a case for interferometric sonars, designed at IRE RAS - they are much cheaper, they require a presence only two ultrasonic antennas (on each board) and allow simultaneous acquisition of the ultrasonic image of sea bottom and the information on the relief in a wide (up to several hundreds meters) survey swath. In the text below we will discuss the results of application of such interferometric sonar – three antennas interferometer with bases of 5,9 and 15 wavelengths, operating at the frequency of 85 kHz. Chirp pulses with 50/10 ms duration, 10 kHz frequency deviation and 300 W pulse power were used here. Slant range resolution in the case of such a frequency deviation is about 7.5 cm.

3.0 DEMONSTRATION OF PRIMARY STAGE DATA PROCESSING RESULTS FOR INTERFEROMETRIC SONAR WITH CHIRP SIGNAL

Numerous experiments with a use of instrumentation and software, designed in Institute, as well as the numerous field measurements were conducted last years. It is necessary to underline experiments in the Baltic sea, and also in Arctic Ocean (in a scheme of a motion in the channel behind the ice breaker). The latter experiment was remarkable for the complication of the sonar operation in the ice conditions because of necessity to provide ice protection for the antennas (see fig. 1). Moreover, the increased level of noise because of ice floes collisions complicated the sea bottom mapping by corrupting images to be obtained by systems with short tone pulses.

Figure 1: Sonar antenna on the bottom of the ice-"Kola" ship in the Arctic Ocean mission of 2003 devoted to the studies of bottom conditions for optical cable cabining (PolarNet project)

On the figures 2 and 3 we represent typical sonar intensity images and interferograms obtained by our sonar in real time. The interferometric fringes on a figure 2 comprise the information on the relief of bottom in an implicit way, to be extracted at the secondary (post processing) stage. On the figure 4 there is sonar image of wrecks in Baltic sea, on the figure 5 the marks of ice exarations (scars at the bottom formed by floating ice - grounded hummock and icebergs) in Arctic Ocean are visible.

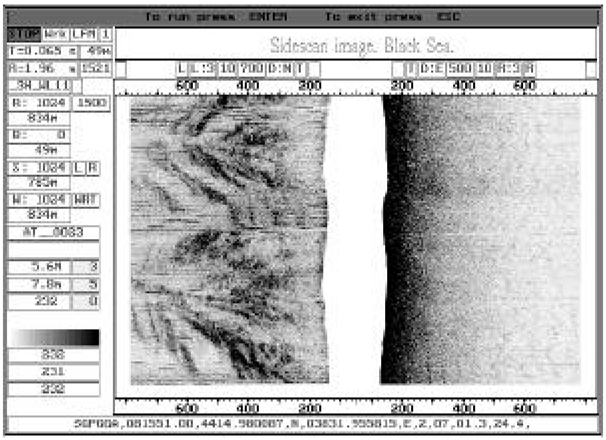

Figure 2: Typical intensity sonar image.

It is necessary to mark out especially the survey works for optic cable cabining being conducted in Arctic Ocean in 2002-2003 (PolarNet project). Sonar mapping of sea bottom in ice conditions with simultaneous use of interferometric sonar, multibeam echo-sounder and profiler was carried out for the first time in the world. The simultaneous operation of interferometric sonar and multibeam SeaBat 8111 echo-sounder by Reason Corporation has allowed to yield analysis and comparison of the results gained by these systems.

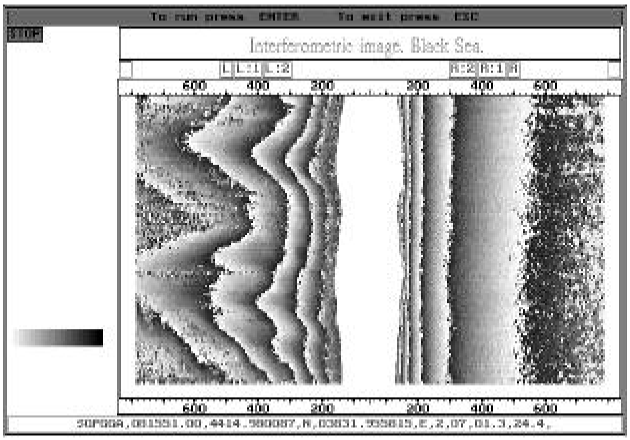

Figure 3: An example of a typical interferogram obtained by interferometric sonar

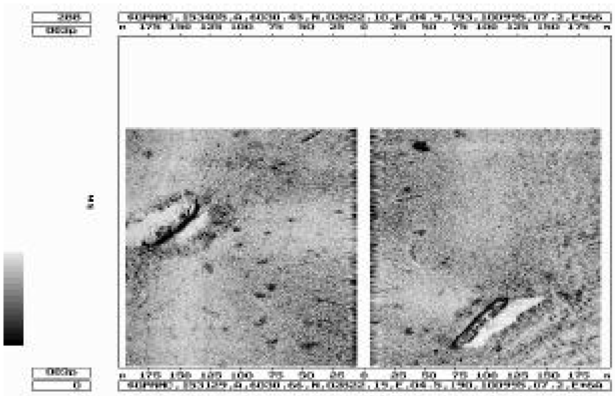

Figure 4: An example of sonar image of the wrecks in the Baltic sea.

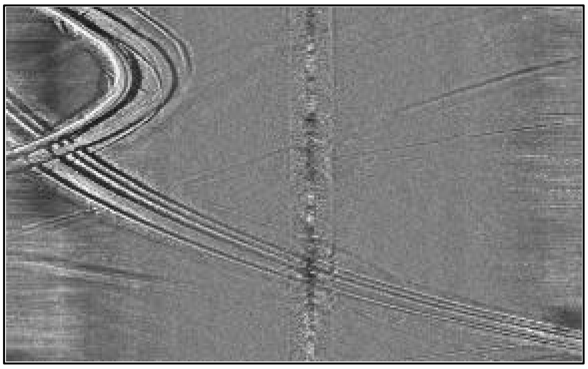

Figure 5: Ice exaration scars on the Arctic Ocean bottom.

The SeaBat 8111 multibeam echo-sounder generates a set of 101 beams enumerated from left (0) to the right (100) at the carrier frequency of 100 kHz. The analysis has shown good average coincidence of gained results. SeaBat 8111 bathymetry data have somewhat smaller mean square error, but the ultrasonic image of interferometric sonar is preferable (fig. 6). The most trouble-free instrument keeping efficiency in the most extreme requirements was a profiler with a multielement antenna and chirp sounding signal.

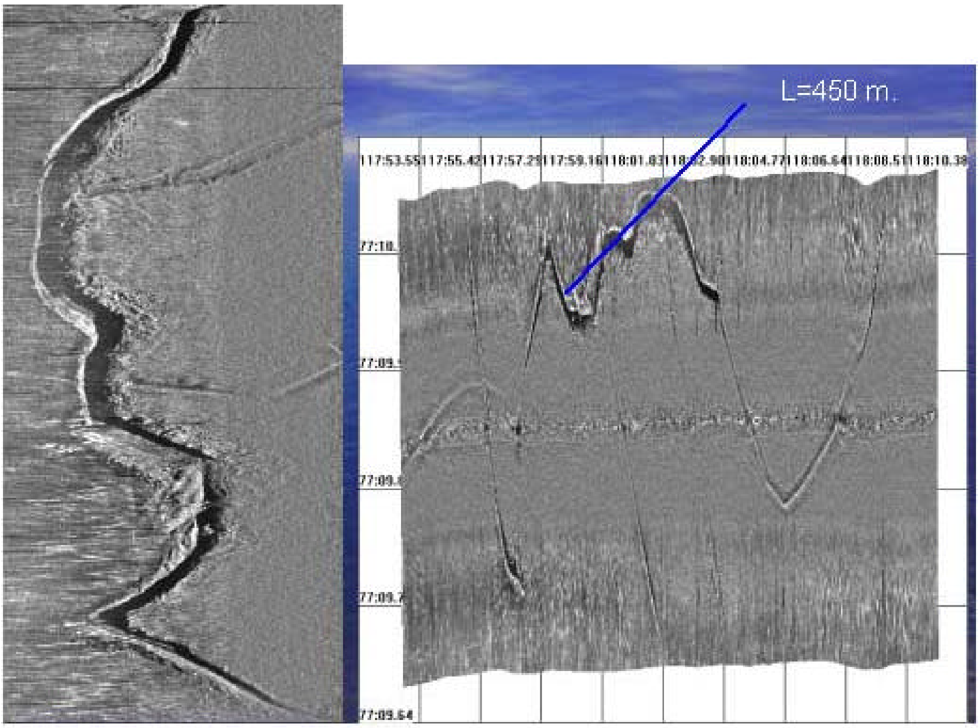

Figure 6: Examples of the images of similar details on the sea bottom obtained by AGKPS-300 sonar (on the left) and a multibeam echo-sounder SeaBat 8111 (on the right).

4.0 SECONDARY STAGE OF INTERFEROMETRIC SONAR DATA PROCESSING

The efficiency of sonar utilization is defined not only by performances of the instrumentation, but also the signal processing techniques being used for the data analysis. As an example, it is possible to demonstrate some results of application of digital filtration for the analysis of separate details of sea bottom relief on the AGKPS-300 interferometric sonar images. To increase signal to noise ratio and consequently an accuracy of the depth measurements the commonly used processing algorithm was supplemented by narrow-band tracking filtering of the complex conjugate product of signals from a pair of interferometer channels. Precalculated coefficients of the narrow-band filter were used further in several variants of tracking algorithms in order to keep signal frequency within a filter pass band. The necessity to monitor the interference frequency is a key peculiarity of the side scan survey technique at the stage of filtration algorithms development.

The visual representation of idea of potential efficiency of narrow-band filtration algorithms usage is given on a fig 7 on the image of interference signal phase variations before the filtration (figure on the left) and after filtration (right figure) for the identical records of input datasets. The specific form of phase patterns is stipulated by the way of phase evaluations - phase value estimates are restricted to (-3.14 - 3.14) interval.

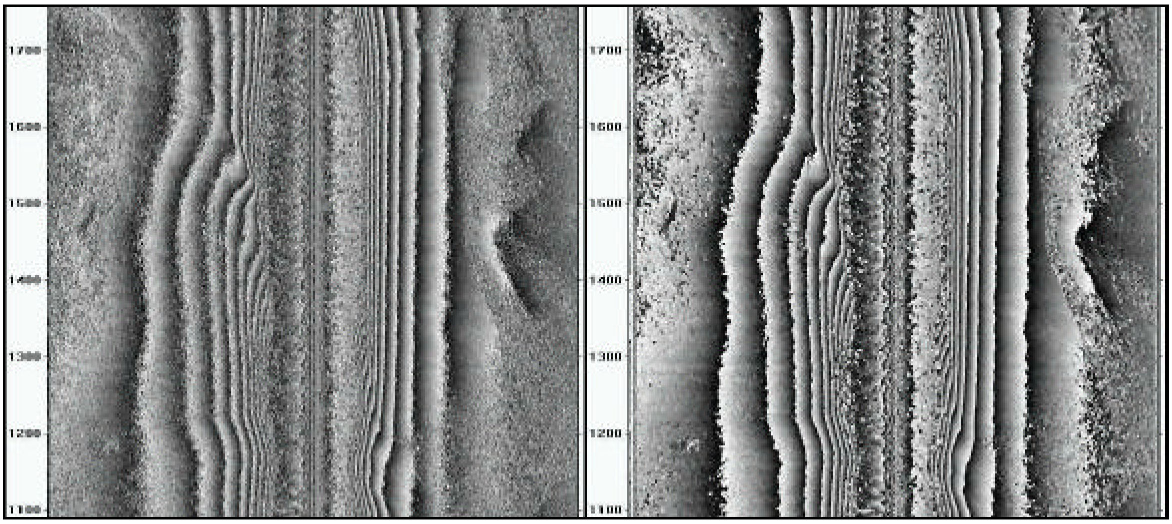

Figure 7: Phase variations on the interferogram: on the left - before filtration, on the right - after filtration.

Further we will give some examples of utilization of narrow-band tracking filtration algorithms for identification of bright area on the sonar image in the Baltic sea region, the detection of furrows of glacial origin on the seafloor using interferometric sonar data, and also an identification of glacial exaration tracks in the experiments within the PolarNet project being conducted in Arctic Region in 2003.

In the first case the analysis the ultrasonic image did not allow us to solve the question about origin of the bright feature in the center of image strip on the fig. 8. It was unclear, whether the feature mentioned is a local concretion on the flat bottom (i.e. that is a manifestation of a reflectivity variations on the flat surface) or that is a relief feature, such as a stone or crater. In case of the interferometric sonar data usage the problem was solved unambiguously, as the phase information reflects the depth variations, i.e. relief.

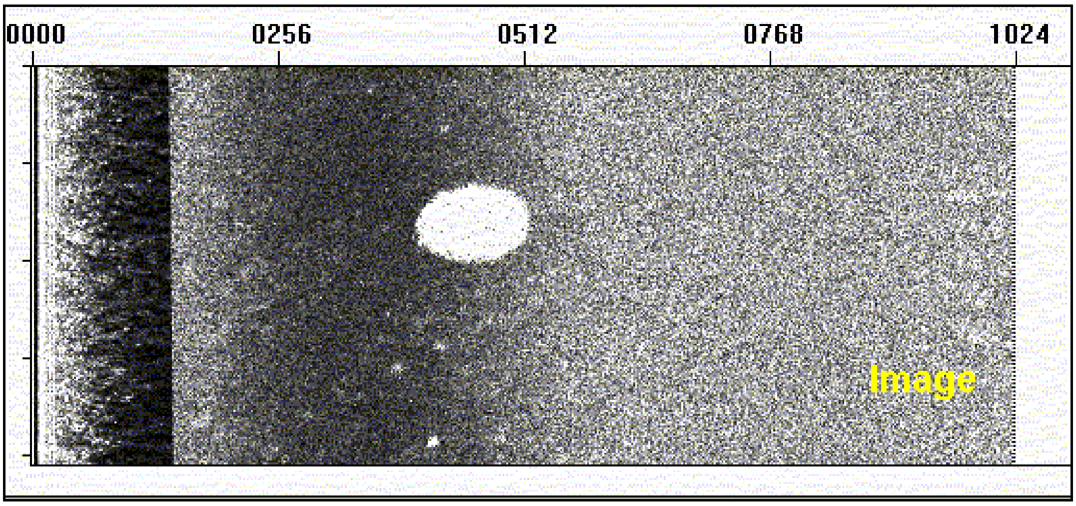

Figure 8: Fragment of the sonar image with a feature.

Application of a filtration allowed us to distinguish clearly this feature via the interference frequency measurements (see fig. 9) and to solve the identification problem. In this case the interference frequency (derivative of a phase) appeared to be most informative for a detection of local isolated features.

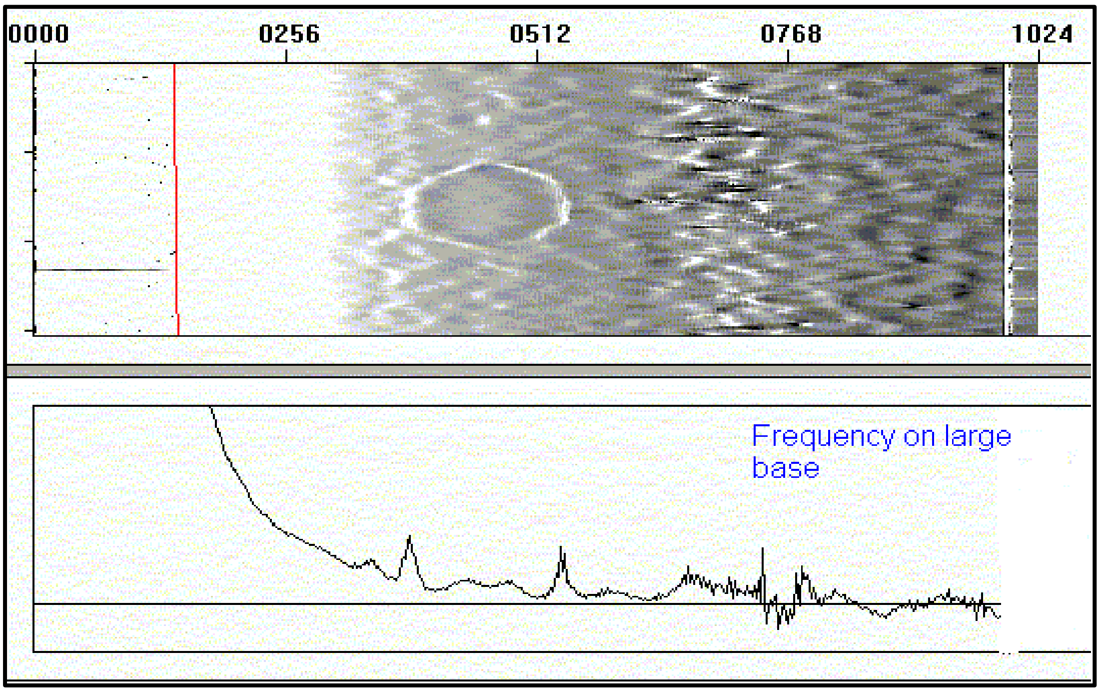

Figure 9: Variations of interference frequency in the vicinity of the feature. At the bottom of the figure a plot of interference frequency variations is presented. Specific sonar feature is visible on the figure also – an abrupt change of interference frequency in the area of first entrance of a sounding signal (red line on the top of a figure).

Similar procedure was used to examine relief features on the seafloor (furrows of glacial origin) located sideways in a swath. It is necessary to mention that because of low signal to noise ratio the frequency variations are comparable with range resolution. Like as in the first case, it was still possible to identify glacier furrows on the plot of interference frequency variations, though less clearly. On the fig. 10 a fragment of the sonar image with glacial exaration tracks is shown. The data were obtained in high-latitude Arctic expedition within the framework of PolarNet project. On a fig. 11 the image of interference frequency for this fragment is shown and the results of narrow-band filtration are shown on a fig. 12.

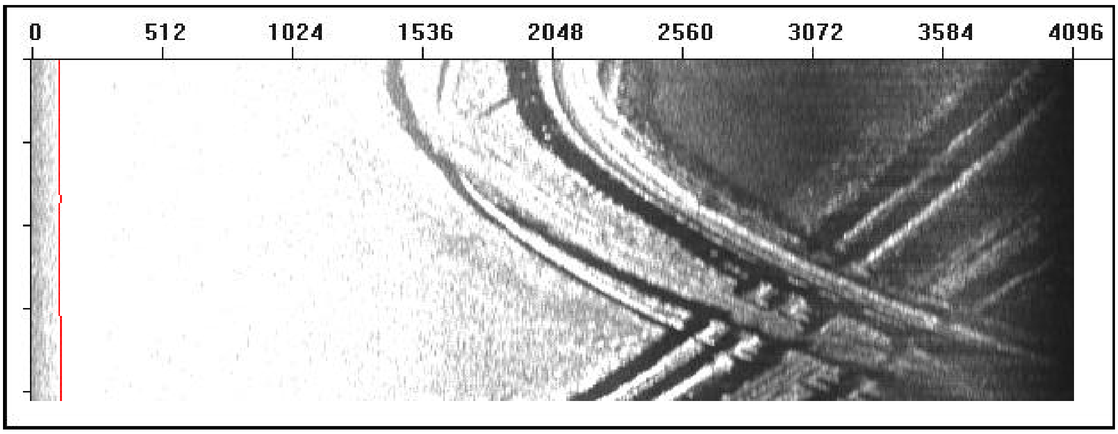

Figure 10: Sonar image of glacial exaration tracks in Arctic Region. PolarNet project, 2003

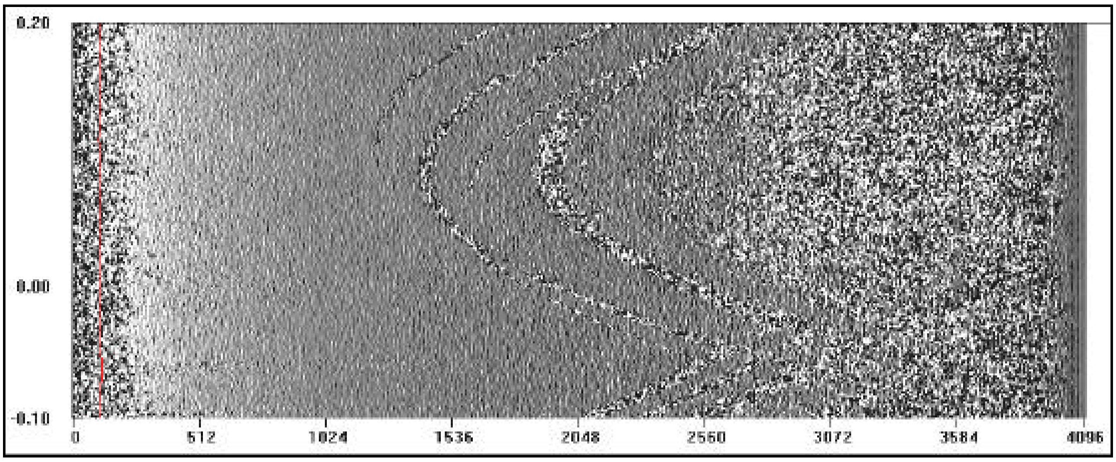

Figure 11: Image of interference frequency before filtration.

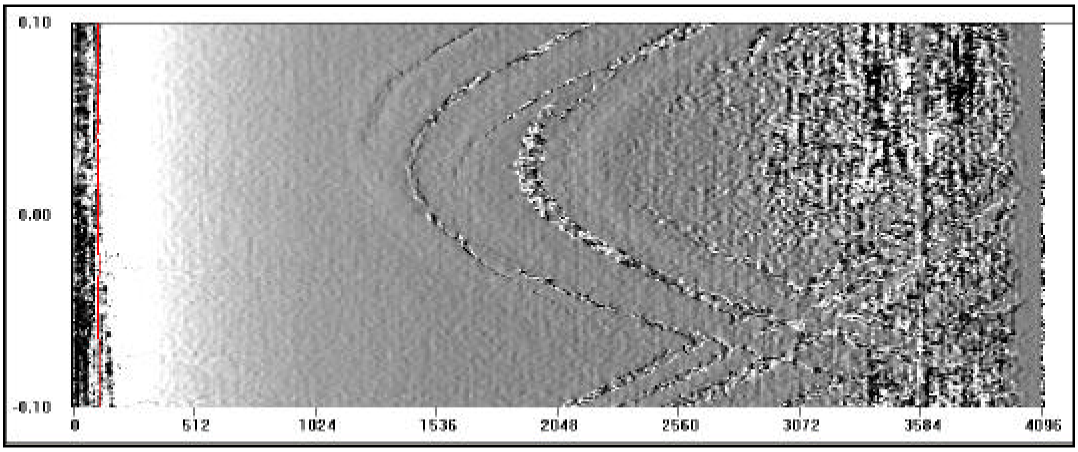

Figure 12: Image of interference frequency after filtration.

The most difficult stage of interferometric sonar data processing is phase unwrapping stage. Variety of existing phase unwrapping algorithms are based on integration of frequency of the interference. Consequently, a robust method of interference frequency estimations is required. Next figures illustrate effect of the filtration for derivation of robust estimations of interference frequency.

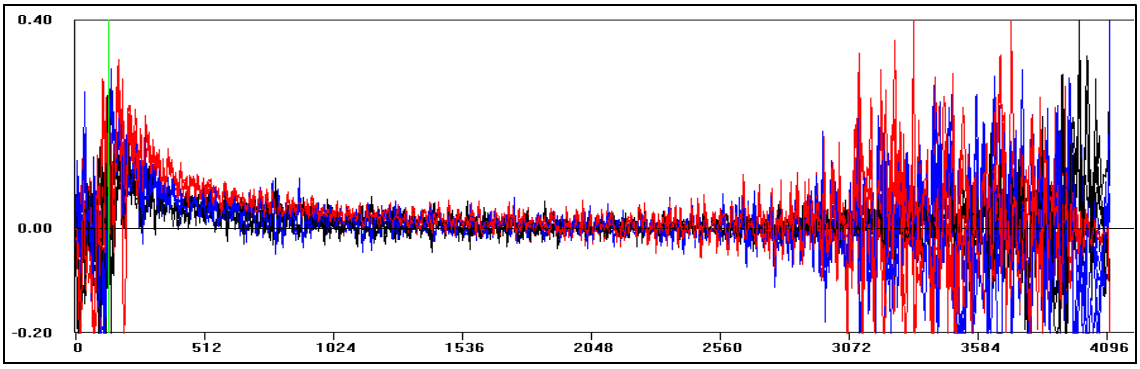

Figure 13: Interference frequency variations for the three baselines of interferometric sonar. Black plot corresponds to small baseline (6 wavelengths), dark blue is intermediate (9 wavelengths) and red - larger baseline (15 wavelengths). Data filtration was not applied.

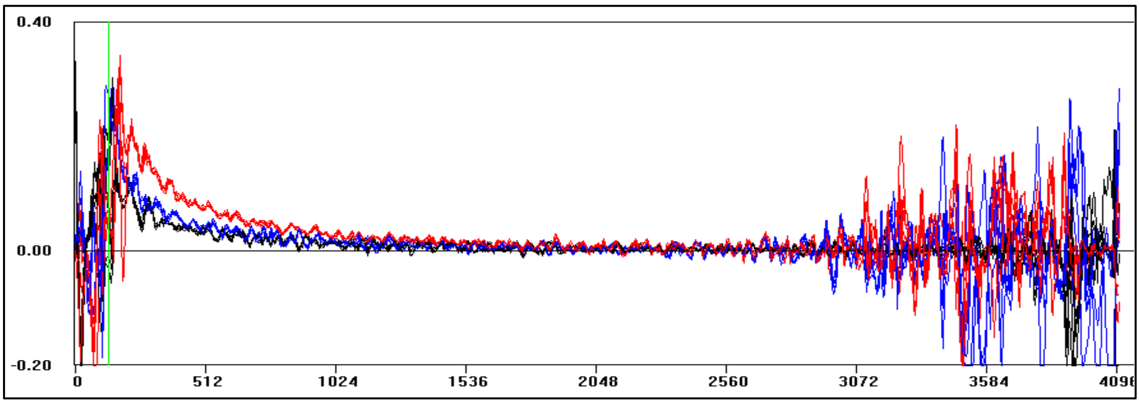

Figure 14: Interference frequency variations in the filtered data.

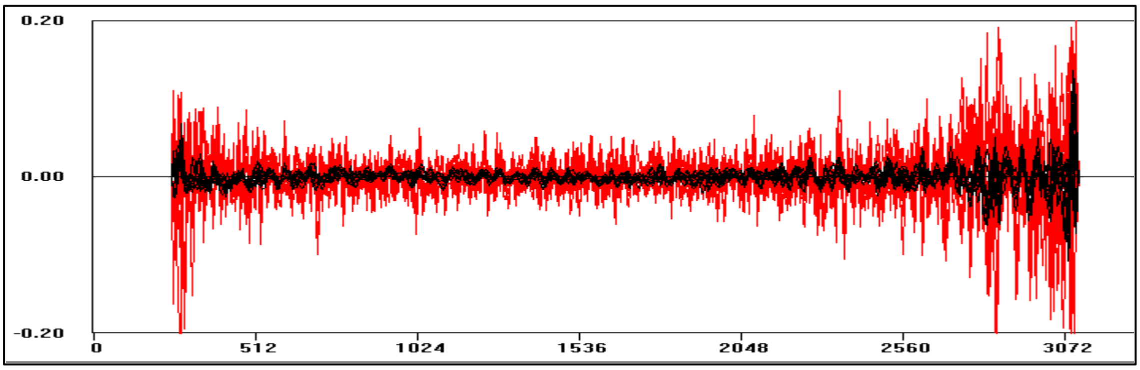

Fig. 15. Plot of variations of interference frequency fluctuations for large baseline. Monotonous frequency trend was removed by 6thr order polynomial. Red color marks a case of unfiltered data, black color corresponds to the case of filtered data.

The application of a filtration reduces root-mean-square values of interference frequency fluctuations approximately 4 times and makes phase unwrapping process for sonar interferograms to be more robust.

5.0 CONCLUSION

The use of chirp modulated pulses on the transmission in the side scan sonar systems allows to increase a range of sonar operation as well as to get higher immunity to the environmental noise like as pulse noise from ice floes collisions observed in our case during operation in high-latitude Arctic Ocean. Such a unique feature of new instrumentation designed at IRE RAS as interferometric capability based on a use of 2 or more acquisition antennas allows to get a sensitivity to sea bottom relief. The new dimension obtained allows to increase identification capabilities of sonar system in a combination with a new second stage processing techniques like as band pass tracking filters, etc, what was clearly demonstrated in a series of field experiments described above.

6.0 REFERENCES

[1] V.M. Razmanov, S.A.Dolotov, V.I.Kaevitser, On the peculiarity of sea bottom topography mapping by means of side scan interferometric sonar, Acoustic Journal, 1997, v 43, no 4, pp. 559-562.

[2] S.A.Dolotov, V.I.Kaevitser, I.V.Smolianinov, The precision of the measurement of the echosignal angle of arrival in the interferometric side scan sonar, Navigation and Hydrography, 1996, no 3, pp. 100-103.

[3] V.I.Kaevitser, A.P.Krivtsov, V.M.Razmanov, I.V.Smolyaninov, A.V.Zhukov, Acoustic sounding of seafloor with a use of chirp modulated pulses, Radiotekhnika, 2004, no. 1, pp. 42-46