PARAMETRIC ARRAY SIGNAL COMPRESSION IN SHALLOW WATER WAVEGUIDE

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Abstract: *Results of experimental research of parametric array application for marine shallow water waveguide excitation by chirp modulated signal are presented. Acoustical signal of 1-3 ms duration is generated in frequency band of 7 kHz-15 kHz by parametric array with a primary frequency 150 kHz. Sharp directivity of the parametric array transmission provides a single mode underwater waveguide excitation in the whole frequency band. It was shown a frequency modulated signal changes it form due to shallow water waveguide dispersion. Chirp modulated signal compression experimentally shown for single mode signal propagation in shallow water. This signal is transmitted in single lobe along the path up to 750 waveguide thicknesses. Wide-frequency band signal compression increases the efficiency of waveguide propagation. Discussion of the efficiency parametric array application for shallow water marine sounding is presented as well.*

Keywords: *Parametric array, single mode excitation, waveguide sound speed dispersion, virtual acoustical barrier.*

1. INTRADUCTION AND EXPERIMENT SET UP

The parametric array (PA) is acoustical nonlinear transduction process, which develops in a medium through the interaction of co-linear, intense sound waves, called pump waves. PA is well known in oceanography as a tool for precision subbottom profiling. The specific feature for PA, is extremely narrow directivity pattern (several degrees in angular resolution normally) for low frequency acoustical signals [1]. The effective width of this directivity pattern is practically constant in a wide frequency range. Sounding signal is forming in the marine environment, which is stimulated by intensity modulated high frequency power acoustical pump. As a result the end-fire array is forming in the marine environment, which excites sharp directional signal radiation at modulation frequency. Such a low frequency signal, generated by parametrical means will propagate in underwater waveguide independently from the pump radiation. Due to non-resonance properties for low frequency signal generation, PA provides sounding signal transmission in extremely wide frequency band (more than 2 octaves). The main objective of this paper is to discuss the ability of such underwater array, working on the principles of nonlinear acoustics for shallow water long-range hydrographic research.

To our knowledge, there was only one actually long-range ocean experiment using a parametric array for up to 1000 km range signal propagation [2, 3]. This experiment was performed in the early 1990s in the region of Kamchatka and Kuril in the Pacific Ocean. The 6 m long and 2 m high side-scanning array in the bow of the ABK was used as a parametric array with pump wave power of 20 kW at the primary frequency of 3 kHz. This array transmitted parametric signals in a frequency range of 230-700 Hz. The parametric sonar was used to investigate synoptic eddy structure at far distances. A region of the Kuril Strait with typical ocean eddies was chosen for this experiment at the range of 400 km [3].

The research has been done in Taganrog bay, Azov sea in August 2018. Transmitting array was installed vertically at the bottom and could scan horizontally the bay by narrow beam with the rotating device. PA has been done as a mosaic of high frequency transmitting elements; half of them were exciting at pump frequency of 150 kHz and the other at frequency 5-20 kHz lower. Vertical size of the array was 30 cm and 20 cm – is it width. Electricity power of the transmitter was 1 kW for each pump frequency.

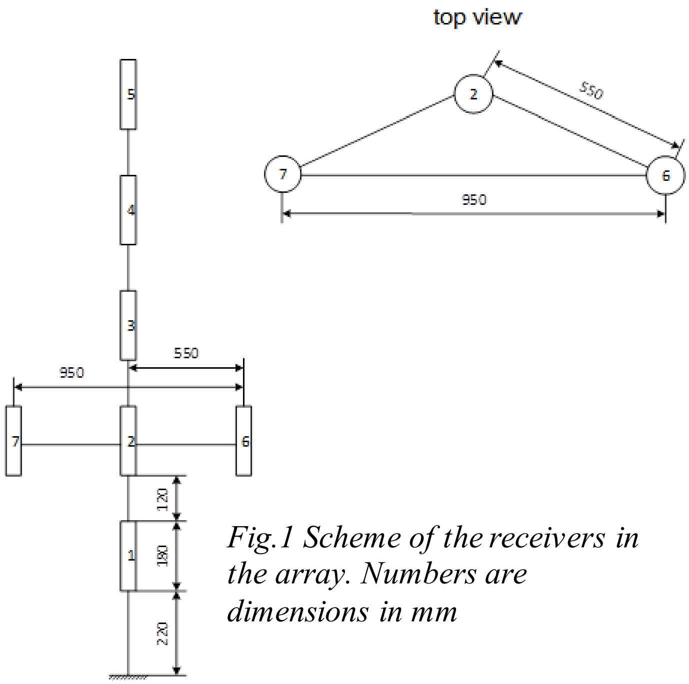

Fig.1 Scheme of the receivers in the array. Numbers are dimensions in mm

The receiving array was arranged as a vertical chain of five receivers, which were installed at the metal rod with interval of 30 cm. This rod as a part of rigid construction was installed at the bottom vertically and overlaps the whole waveguide. Two more receivers were attached at the level of the 2nd receiver, as it is shown at Fig. 1, to direction-finding of the receiving signals.

The sea depth at the range of experiments slightly changes at about 2 m. Vertical sound speed profile provided near-bottom signal propagation.

2. RESULTS OF THE EXPERIMENT

A sequence of acoustical pulses was transmitted by PA. The duration of a single pulse was from 0.7 ms to 3 ms, and the interval between pulses was about 300 ms. Signals were simultaneously received from all of the gages of the vertical array. The measurements were carried out for transmitter–receiver distances of 0.5 to 1.5 km. At the greater distance the signal amplitude decreases rapidly because the attenuation due to near-bottom propagation. The frequency–time characteristic for pulses with initial duration of 3 ms and a carrier frequency linearly modulated within 7–15 kHz was investigated while pulses propagate through the shallow-water waveguide. And at that time the frequency sweep in the transmitting signal was arranged from lower frequency to higher, which corresponds to normal shallow water dispersion.

As analysis shown, the choice of that frequency range for the signals was optimal for our experiment. It is known that waveguide dispersion increases with the frequency decrease, but at that the PA transmission efficiency falls. PA transmission efficiency increases with the frequency, but the dispersion rapidly decreases at the same time. PA transmission efficiency was sufficient to make an experimental research up to 1500 m with emphasized waveguide frequency dispersion for signals in chosen frequency range. Fig. 2 shows signals from the gages of the receiving array at 1000 m distance, while PA transmits linear frequency modulated pulses of 3 ms duration. One could see the main energy of PA signals in shallow water is concentrated at the middle and near-bottom part of the waveguide and the signals from the gages installed at the different levels of the array are proved in the phase, which is corresponded to the first mode of the waveguide excitation.

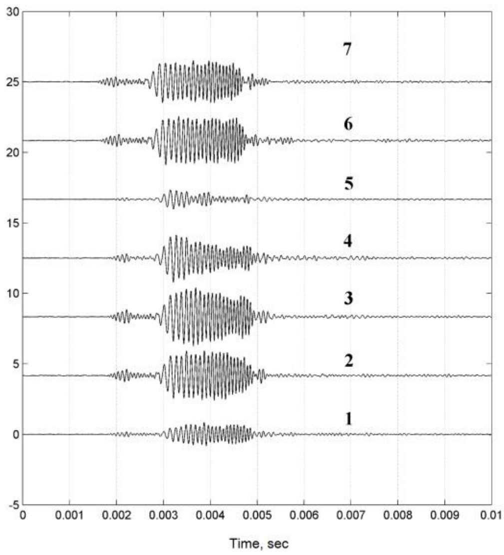

Fig.2. Oscillograms of the signals from the gages of the receiving array 1000 m distance. Numbers correspond to the gage number at Fig.1. Maximum level was registered at gages 2 and 3, which correspond to near-bottom propagation.

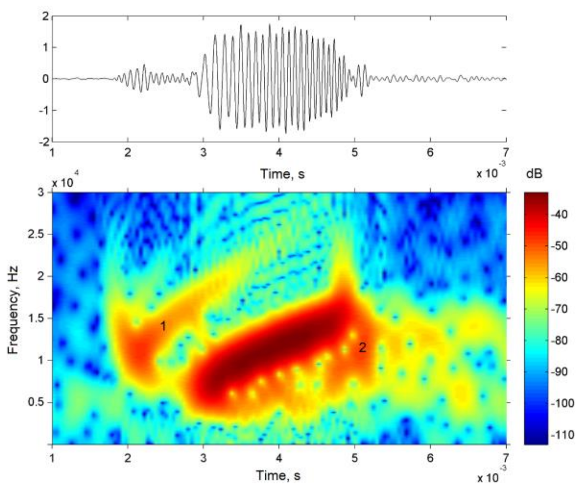

Fig. 3. Spectrogram for linear frequency modulated signal, received by the gage 2 at 1000 m distance. 1- is a forerunner, 2 is a reflection from the supporting boat. Signal level is in relative units. Forerunner corresponds to the second harmonic of the main body of the signal and propagates faster.

Oscillograms at Fig.2 show the typical special features related to the PA signal propagation in marine shallow water waveguide. One can mark a forerunner which runs faster than the main body of the signal. Forerunner is related to the second harmonics excitation in process of parametric signal transmission. It has higher frequencies and therefore runs faster. One could see that the main body of the registered signal lasts 2 ms, as while as the duration of the signal transmission was 3 ms. Wide frequency band signal became shorter at 1 ms while it propagates through the distance of 1000 m long. These specific features have been already marked earlier under investigation of PA signal propagation in shallow water waveguide [4, 5].

After analysis of the frequency dispersion of the waveguide sound transmission in that environmental conditions we could expect of full compression for wide frequency band parametric signal of 1.7 ms duration under transmission at 1500 m distance. We could note that the distances of 1000 m and 1500 m correspond to the far-distance propagation in full measure. Distance of the signal propagation excides the vertical scale of the marine waveguide in 500-750 times. Fig. 4 shows the result of wide frequency band signal compression. The signal forerunner is proved not so notable as it was at 1000 m distance because of attenuation, but the higher frequencies in forerunner came earlier that the lower ones. The main body of the signal with duration of 1.7 ms under transmission is compressed in the pulse of 0.4 ms duration after shallow water propagation (depth of the sea approx. 2 m) through the pass of 1500 m long. Signal compression occurs in more than 4 times in that experiment. After the compressed pulse one could see the signal reflection from the boat.

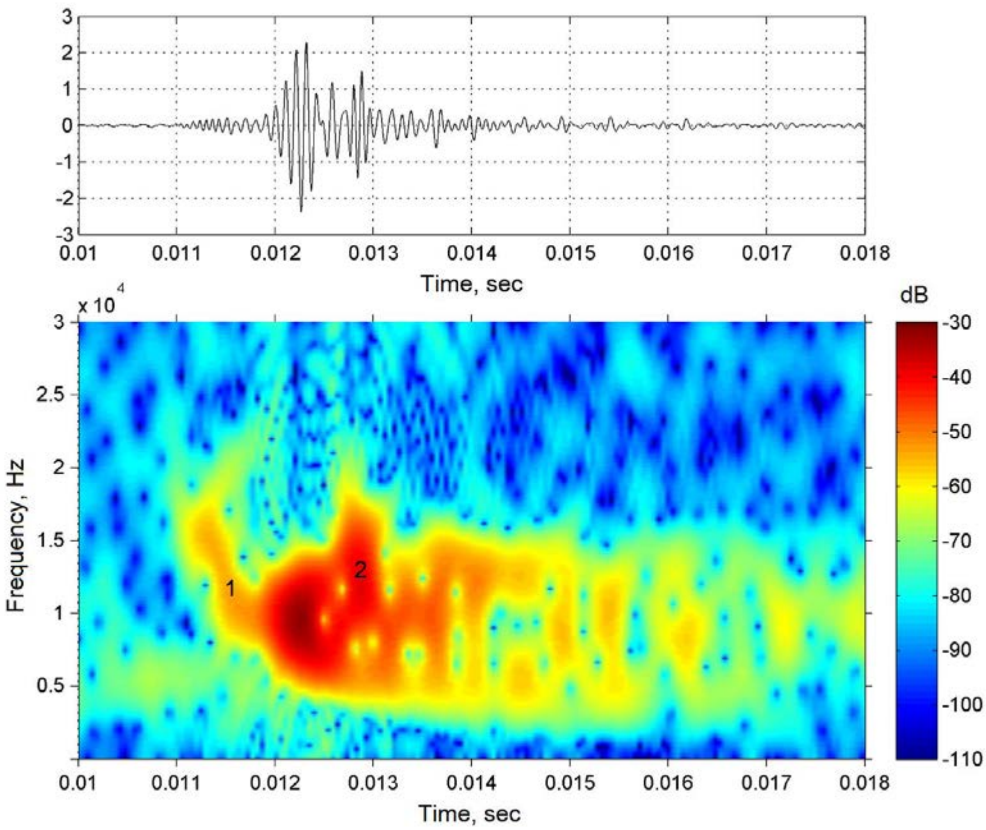

Fig. 4. Spectrogram for frequency modulated signal of 1.7 ms under transmission and received by the gage 2 at 1500 m distance. 1- is a forerunner, 2- is a reflection from the supporting boat. Signal level is in relative units.

3. SINGLE MODE FREQUENCY DISPERSION FOR A WIDE FREQUENCY BAND SIGNAL IN UNDERWATER WAVEGUIDE.

In shallow water the sound field usually consists of a series of modes exhibiting frequency dispersion of the speed of signal propagation. Mode dispersion in underwater waveguide means that the modes of the same number have different envelope speed of propagation at different carrier frequencies. The value of the dispersion depends, among others, on the vertical sound speed profile. The frequency dispersion provides either a spread in time of short broadband pulses that travel long distances, or concentration of acoustic signal energy within a short time interval when the frequency modulation of the signal corresponds to the dispersion conditions of the medium. Therefore wide frequency band signal changes it form in process of the waveguide propagation. Fig. 5 shows the results of the modeling of the signal form transformation for the propagation along the pass of 500 km long in the Black sea underwater waveguide. Sound speed minimum corresponds to 50-70 m depth for the Black sea environment conditions. Short acoustical pulse was excited in frequency band of 200-1200 Hz as the first mode of the typical Black sea waveguide. As one could see signal is rather short at the distance of 1 km (pulse duration less than 5 ms), but for distance of 500 km it duration becomes about 80 ms with emphasized frequency modulation corresponding to the waveguide dispersion. Pulse duration changes in 16 times in that example. Fig. 6 shows a proper spectrogram of the signal at 500 km distance. It shows the Black sea waveguide dispersion for the first mode signal propagation. Thus, if we excite the first mode as a signal of 80 ms in frequency band of 200-1200 Hz with frequency modulation corresponding to the waveguide dispersion, it could compress to the short pulse of 5 ms duration with a proper intensity increase. Note, the lower frequencies run faster than the higher ones for the Black sea underwater waveguide. Therefore, to get a full compression for the wide frequency signal in the Black sea underwater waveguide one should make a sweep of frequency modulation from high to lower frequencies in process of signal transmission.

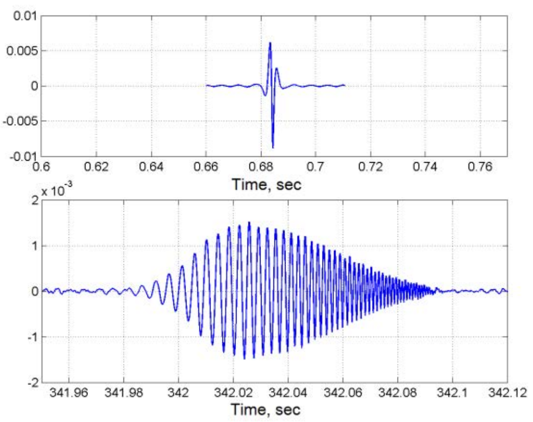

Fig. 5. Single mode shot pulse waveguide excitation in frequency band 200-1200 Hz. Top – signal at 1 km distance (the first mode). Bottom – signal at 500 km distance. X axis shows absolute time. Signal level – in relative units.

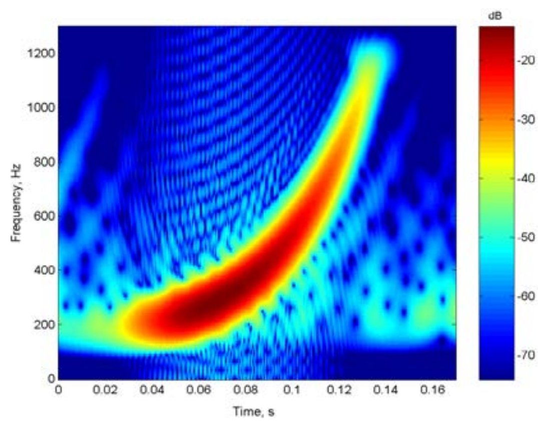

Fig. 6. Spectrogram for the signal of 200-1200 Hz frequency band. The first mode of the Black sea waveguide at 500 km distance. Spectrogram corresponds to signal shown at Fig. 5 bottom.

4. CONCLUSION

Results of the experimental research lead us to the following conclusion.

1. Parametric array application could provide acoustical single mode excitation in wide frequency band in the waveguide. Frequency band of PA signal modulation can reach an octave or rather more.
2. PA signal compression under it propagation in shallow water waveguide was experimentally shown.
3. Signal frequency modulation used in our experiments didn't correspond in the full measure of the experimentally measured wave guide dispersion. Therefore the compensation of the times propagation of the different frequencies at signal compression is proved not for the total frequency band of signal modulation and just only for limited number of frequency components. Experimentally signal was compressed in 4 times at distance of 1.5 km. Calculations show that in conditions of our experiment the signal could be compressed in 10 times.
4. Signal compression leads to relative increase of signal intensity in process of it propagation and to signal-to-noise gain for signal receiving. Therefore the parametric array could be the most effective instrument for the long-range acoustical propagation in shallow water [6].
5. Signal compression is pure linear acoustical process. But to realize it a single mode wide frequency band acoustical signal is needed in the waveguide. It is shown that such a signal could be excited in the marine waveguide due to sharp directed parametric array, operating on principals of nonlinear acoustic.

5. ACKNOWLEDGEMENTS

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REFERENCES

[1] **B. K. Novikov, O. V. Rudenko, V. I. Timoshenko**, *Nonlinear Underwater Acoustics*, (AIR-Press, NY, 1987).

[2] **I.B. Esipov, A. I. Kalachev, A. D. Sokolov, A. M. Sutin, and G. A. Sharonov**, Long-range propagation experiments with a powerful parametric source," *Acoust. Phys*. 40(1), 61−64 (1994).

[3] **I.B. Esipov, S.V. Zimenkov, A. I. Kalachev, and V. E. Nazarov**, Sensing of an ocean eddy by directional parametric radiation, *Acoust. Phys.* 39(1), 89−90 (1993).

[4] **I. B. Esipov, O. E. Popov, V. A. Voronin, and S. P. Tarasov**, Dispersion of the signal of a parametric array in shallow-water, *Acoust. Phys*. 55(1), 76–80 (2009).

[5] **Igor B. Esipov.** New approach to oceanography research on elongated paths on principals of nonlinear acoustics. *Proceedings of Meeting on Acoustics (POMA)*, 24, 1, 005005 (2016); htpp://dx.doi.org/10.1121/2.0000146.

[6] **I. B. Esipov, O. E. Popov, G. V. Kenigsberger, I. I. Sizov**. A parametric antenna for hydrophysical research on long-distance paths. *Bulletin of the Russian Academy of Sciences: Physics*, 80(10), 1209–1217, (2016)