LONG-RANGE PROPAGATION OF A NOISE SIGNAL: ARCTIC OCEAN ACOUSTIC MONITORING

V.M. Kudryashov, L S. Vilentchik***

*N.N. Andreeev Acoustic Institute, Russian Academy of Sciences,
Shvernik Str. 4, Moscow 117036, Russia
**MCB "Electron", A/YA 51, Moscow 125190, Russia

ABSTRACT

Propagation of acoustic signals along a range-dependent track in the Arctic Basin is considered. The structure of the envelope of the temporal correlation function of a narrowband noise signal propagation in a waveguide is investigated. The form of a model pulse is compared with the wave form obtained in acoustic monitoring in the Arctic Basin. Calculations were carried out with a program based on the coupled mode method. This program takes into account the hydroacoustic waveguide parameters affecting the amplitude-time signal structure. This allowance yielded a satisfactory agreement between calculations and the experiment. We considered a method, which operates when the signal-to-noise ratio is less than unity.

The Arctic Ocean is an area of particular interest to research global climatic change. P. Mikhalevsky, R. Muench and F. DiNapoli proposed to observe the slow climate change of Arctic water temperature as well as ice cover changes with the help of long-term measurements of the low-frequency acoustic signals propagating over stationary transarctic tracks. The expected warming of integral ocean temperature should lead to change of propagation time of the acoustic signals, while thinning of the ice canopy due to global warming should affect the propagation loss, i.e. should lead to slow amplitude change of the received signals. To ground both possibility and efficiency of Arctic ocean acoustic monitoring it is necessary to realize the conditions of the signal transmission, reliable signal reception and measuring of the required acoustical parameters at such long distance as transarctic track. The transarctic acoustic propagation experiment has been carried out in April 1994 [3].The acoustic signals were transmitted at 19.6 Hz from ice camp TURPAN, drifted 300 km north of Spitsbergen over 900 km to ice camp NARWHAL in the Lincoln Sea. It started with a deep-water waveguide with a depth 3.7 km. The acoustic source was deployed at TURPAN at a depth of 60 m. Receive vertical linear acoustic arrays were located in the Lincoln Sea with a depth 500-530 m. The total array length L was approximately 470 m. The source power was 195 dB relative to 1 μ Pa. The ocean noise level is normalized to a 1 Hz frequency band. It is approximately 80 dB relative to 1 μ Pa. The rough ice cover of the Arctic Basin scatters sound waves propagating in the underice duct. It leads to significant rise of propagation loss increasing with the distance from the acoustical source. Horizontal variations of the sound waveguide parameters along a transarctic track is another factor which complicates the temporal-spatial structure of propagating signals. It is evident that the power of the transmitter is insufficient and the track is too long for the sound pressure signal $p(\mathbf{r},z,t)$ to be seen against ocean noise background.

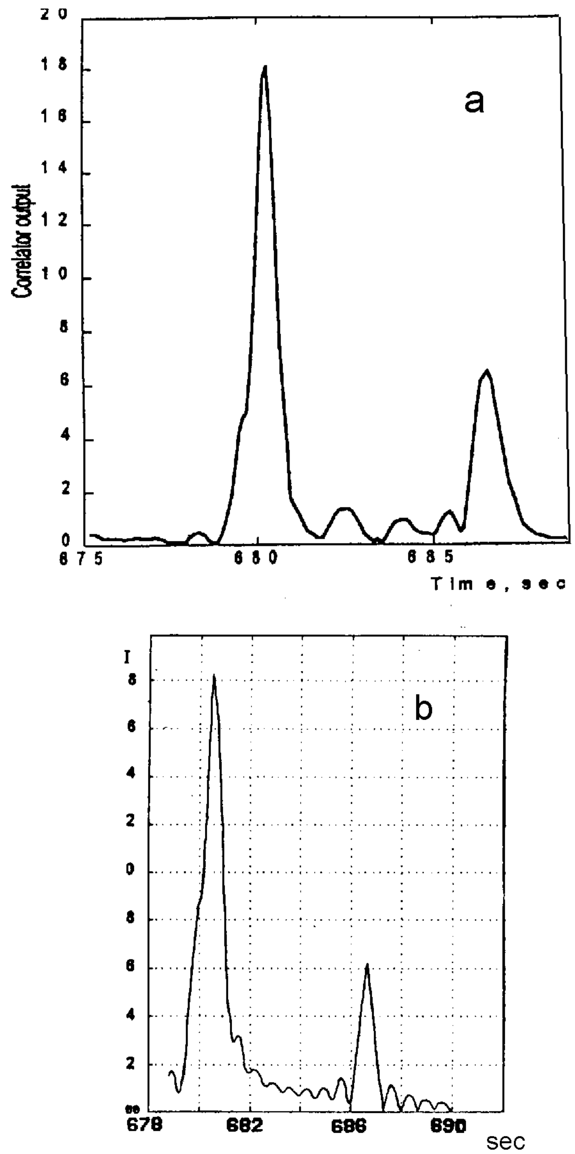

Figure 1. (a and b).

Radiated power can be reduced by using signal accumulation over a long time interval. The broadband signals, lasting 1 hour each, were transmitted in the experiment. The signals were generated via digital modulation of the signal phase by $\pi/2$ synchronized with the pseudorandom Maximal Leng Sequences (MLS). The procedure of primary processing of the signals included complex demodulation, long-pass filtering, and resampling with a lower rate.

Post-processing of the MLS signals included the procedure of pulse compression, i.e. computing correlation of the received signal and MLS replica, and coherent averaging of the resulting complex pulse-compressed signal by the MLS periods. Figure 1(a) shows the arrival pattern (magnitude of the pulse-compressed signal) of the MLS signal received on a single hydrophone at NARWHAL. The latest small peak (~ 686 sec) in the pulse form of signal corresponds to mode 1. The modes of higher numbers are not separated by the travel time - they arrive almost simultaneously, forming a high pulse at 680 sec. Fig. 1(b) demonstrates the results of calculations of the signal form for MLS signal. The experimental results are generally in agreement with the results of modeling. The modified approach of coupled acoustical modes have been used for numerical calculations of low-frequency sound propagation over the irregular transarctic track [1][2]. The ice cover consists of rather smooth ice sites fringed with ridges of ice-hummocks. In calculations we used a model of floating ice.

In experiment for coherent averaging, the phase of the MLS signals was preliminary corrected for the Doppler shift due to relative drift of TURPAN and NARWHAL.

The main disadvantages of prolonged signal accumulation are changes in Doppler frequency shift.

We considered spatial filtering of N-th mode on the vertical array. We used this mode as the reference signal. Next, the cross-correlation of the reference and received on a single hydrophone signals is calculated. This hydrophone was submerged to a depth of z m.

Introduce a Cartesian coordinate system x, y, z with the z -axis directed downwards and with the origin on the free water surface. $\mathbf{r} = \{x, y\}$. Let's consider an omnidirectional acoustic source situated in waveguide at a point $(r = 0, z = z_0)$. Let the source to emit a narrowband signal $F(t)\exp(-i\omega_0 t)$ at the central frequency $f_0, \omega_0 = 2\pi f_0$. $F(t)$ is a statistically stationary ergodic function of time t and $\langle F(t+\tau)\, F(t)\rangle = R(\tau)$, $R(0) = 1$. The angle brackets signify statistical averaging.

A signal produces at the time t the sound pressure at point $(\mathbf{r}, z)$

$$p(\mathbf{r}, z, t) = \sum_{m=1}^{M} F(t - t_m) A_m(\mathbf{r}) \Phi_m(z) \exp(-i\omega t) . \qquad (1)$$

In (1) we expand $p(\mathbf{r}, z, t)$ in a series on waveguide local eigenfunctions $\Phi_m(z)$ corresponding to the local wave numbers $\zeta_m(\mathbf{r})$, where m is the mode number. The eigenfunctions $\Phi_m(z)$ form a complete orthonormal system, t_m is a propagation time for the m -th mode. In horizontally stratified waveguide we have $A_m(\mathbf{r}) = A_m^0 (\zeta_m r)^{-1/2} \exp(i\zeta_m r)$, where $A_m^0 = A_m(r)$ for $r = 1$ m.

Then we investigate the temporal correlation function $\hat{I}_N(\mathbf{r}, z; \tau)$ of a narrowband noise signal. The signal was received with a hydrophone submerged to a depth of z m and with a vertical linear array (VLA). The total array length is L. We used spatial filtering of N -th mode on the vertical array. The sound field on the VLA can be represented as

$$p_N(\mathbf{r}, t) = \int_0^L p(\mathbf{r}, z, t)\, \Phi_N(z)\, dz .$$

The result of mode filtering is

$$p_N(\mathbf{r}, t) = F(t - t_N) A_N(\mathbf{r}) \exp(-i\omega_0 t) \qquad (2)$$

Here we investigate the temporal cross-correlation function $\hat{I}_N(\mathbf{r}, z; \tau)$ of the hydrophone $(\mathbf{r}, z)$ and VLA.

$$\begin{aligned} \hat{I}_N(\mathbf{r}, z; \tau) &= \left\langle p(\mathbf{r}, z; t+\tau)\, p_N^*(\mathbf{r}, t) \right\rangle = \\ &= \sum_{m=1}^{M} R(\tau + t_N - t_m) A_m(\mathbf{r}) A_N^*(\mathbf{r}) \Phi_m(z) \exp(-i\omega_0 \tau), \end{aligned} \qquad (3)$$

$\hat{I}_N(\mathbf{r}, z; \tau)$ is in accord with the channel impulse response.

A similar temporal cross-correlation function (TCF) of the ocean homogeneous and isotropic noise is

$$\tilde{I}_N(z, \tau) = D_N\, \Phi_N(z) \exp(-i\omega_0 \tau) \qquad (4)$$

The resulting TCF can be written in the form

$$I_N(\mathbf{r}, z; \tau) = \hat{I}_N(\mathbf{r}, z; \tau) + \tilde{I}_N(z, \tau) \qquad (5)$$

Let's consider an omnidirectional acoustic source situated in waveguide at 60 m. The source emits a narrowband noise signal at the central frequency 19.6 Hz and effective width 1.57 Hz (as MLS signal). The temporal correlation function I_N of a narrowband noise signal of the array and the hydrophone is very stable for Doppler frequency shifts. Next, I_N is in accord with the channel impulse response.

The possibility and accuracy of acoustical measurements of the assumed signal characteristics depend on signal-to-noise ratio. It is evident that the power of the transmitter is insufficient and the track is too long for the sound field to be seen against ocean noise background. We consider the example. Assume that noise-to-signal ratio (NS) is equal +12 dB.

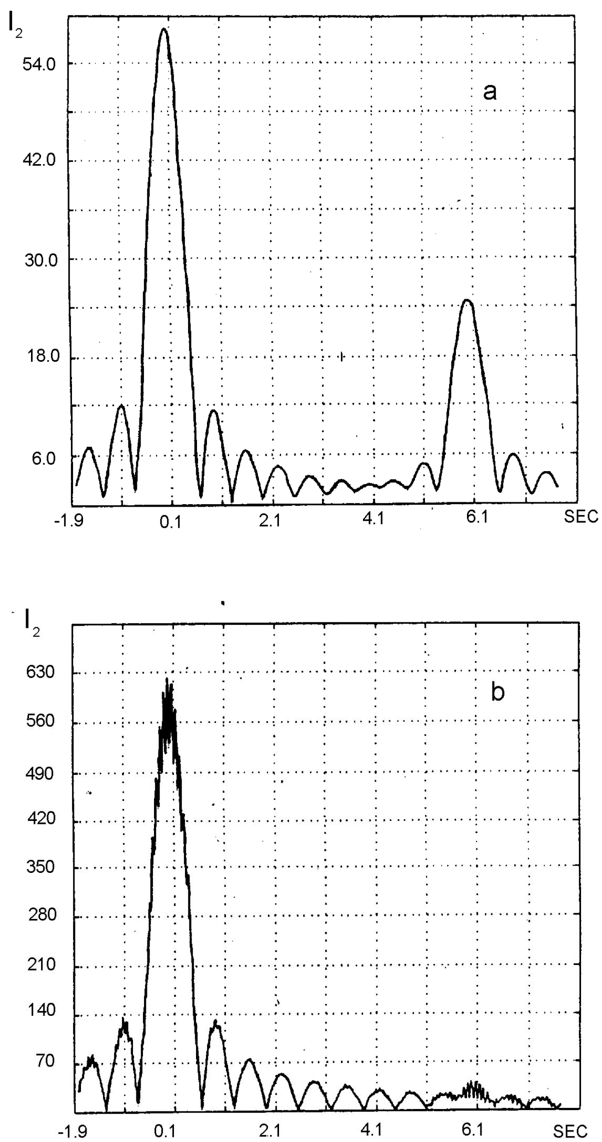

Figure 2. (a and b).

Fig. 2 and 3 show a graph describing the dependence of the envelope of I_N for a) NS=0 and b) NS=12 dB at z=60 m (Fig. 2) and z=205 m (Fig.3) for N=2. As can be seen, the signal can hardly be discriminated from the noise background at z=60 m. Fig. 3 shows that at z=205 m the noise background can be neglected, z=205 m corresponds to the minimum of the eigenfunction of mode 2.

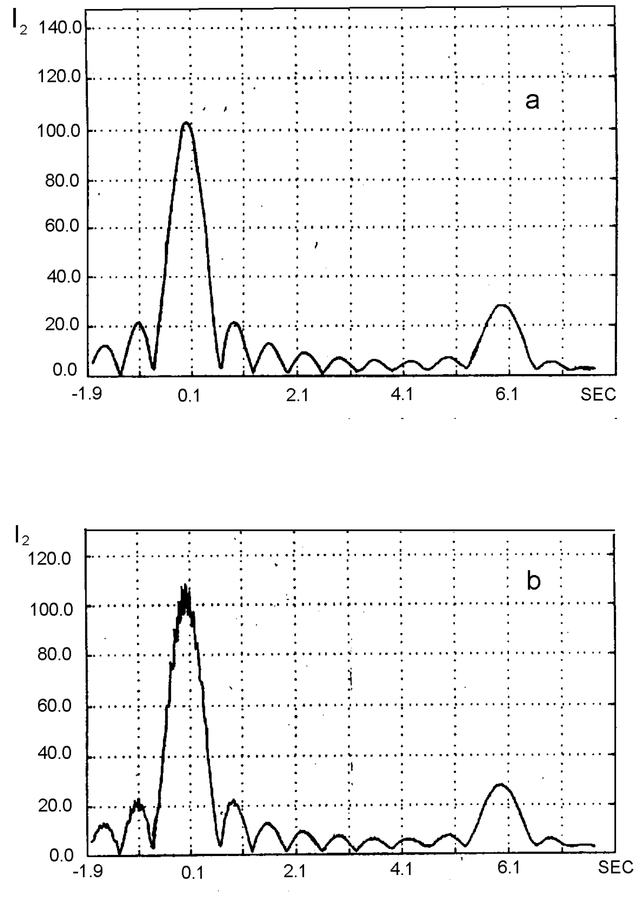

Figure 3. (a and b).

Therefore, radiated power can be reduced substantially by using this system. I.e., we have stable instrument for estimating the channel impulse response, which operates when the signal-to-noise ratio is less than unity.

REFERENCES

[1] Kudryashov V.M. "Sound field in a waveguide with a sloping bottom". *Sov. Phys. Acoust.*, 33(1):32-34, 1987.

[2] Kudryashov V.M. "Temporal correlation function of a narrowband noise signal in an irregular waveguide". *Sov. Phys. Acoust.*, 34(1):63-65, 1988.

[3] Mikhalevsky P.N., Baggeroer A.B., Gavrilov A. and Slavinsky M. "Experiment Test Use of Acoustic to Monitor Temperature and Ice in Arctic Ocean" *Eos. Trans. Amer. Geoph. Union.*, 76(27):265, 268-269, 1995.