Investigation of electromagnetic fields in the arctic zone with uneven ice cover

Vladimir Korochentsev^{1,*}, Vey Syue², Sergey Gorovoy¹, Vasily Chernenko¹, Artem Em¹, Timur Tagaev¹.

¹FEFU, Engineering school, Department of instrumentation, Russia

²HIU, College of underwater acoustic engineering, China

Abstract. Numerical investigation of electromagnetic waves propagating near an ice cover with hummocks of different height has been carried out. Half-wave vibrators, melted into ice at the depth of about 20 sm, were used as an antenna. Transmitted signal frequencies were from 10 to 30 MHz. A mathematical model for amplitude spatial distribution of electromagnetic wave source, placed inside an ice cover with hummocks, was developed. The results of numerical study show that, when antenna is inside hummocks, the signal is amplified. Experimental investigations show good agreement with the theoretical model.

1 Mathematical model

We consider the following problem. We are to estimate the field of electromagnetic wave point sources placed in the ice layer of uneven form (Fig. 1) [1-3]. The following medium characteristics are known: magnetic and dielectric permeability of mediums; power applied to the radiating antenna; signal frequency.

Fig. 1. Geometry of the problem under consideration:

M_0 – radiation source; 1 – air half-space, 2 – ice layer, 3 – water half-space; d – ice layer thickness

*Corresponding author: gai_uzt@mail.ru

We introduce generalized angular coordinates for $\varphi = 0$:

$$\begin{aligned}U_{1n} &= k_0 \sin(\alpha \pm \alpha_n); \\U_{2n} &= k_0 \cos(\alpha \pm \alpha_n); \\k_0 &= 2\pi/\lambda.\end{aligned}$$

Point M can be located in the air, ice layer or water. To estimate by “directed” Green’s functions, we consider the effect of each plane of ice relief on the resulting field. Radiation point source is located at M_0 point with the coordinates x_0 and y_0 . The resulting field at the selected point M with the coordinates x and y is equal to the sum of “directed” Green’s functions $E_0^{(n)}(x_0, y_0)$, estimated from all the planes of ice relief.

“Directed” Green’s function of the waves radiated by a point source is written as

$$E_0^n(x) = \frac{i}{2\pi} \int_{U_0^{(n)} \min}^{U_0^{(n)} \max} \frac{F_0^{(n)}(U_0)n}{\sqrt{k_0^2 - U_0^2}} e^{i(x-x_0)\sqrt{k^2 - U_0^2} + [y-y_0]U_0n} dU_0n,$$

where $F_0^n(U_0n)$ is the diagram function:

$$F_0^n(U_0n) = \begin{cases} 1 & \text{if } U_0^{(n)} \min \leq U_0n < U_0^{(n)} \max \\ 0 & \text{in other regions} \end{cases}. \quad (1)$$

“Directed” Green’s function of the reflected waves has the form

$$E_l^n(x) = \frac{iV}{2\pi} \int_{U_l^{(n)} \min}^{U_l^{(n)} \max} \frac{F_l^{(n)}(U_l)n}{\sqrt{k_0^2 - U_l^2}} e^{i(X-X_0)\sqrt{k^2 - U_l^2} + [Y-Y_0]U_0n} dU_{ln}, \quad (2)$$

where V is the interface reflection coefficient determined by the formulas:

$$V = \frac{Z_2 - Z_1}{Z_2 + Z_1} \text{ for the reflection from upper interface;}$$

$$V = \frac{Z_2 - Z_3}{Z_2 + Z_3} \text{ for the reflection from lower interface;}$$

Z_1, Z_2, Z_3 – air, ice and water impedans.

“Directed” Greens’ function for the waves, which transmitted through the interface, is

$$E_l^n(x) = \frac{iW}{2\pi} \int_{U_l^{(n)} \min}^{U_l^{(n)} \max} \frac{F_l^{(n)}(U_l)n}{\sqrt{k_0^2 - U_l^2}} e^{i(X-X_0)\sqrt{k^2 - U_l^2} + [Y-Y_0]U_0n} dU_{ln}, \quad (3)$$

where W is the coefficient of transmission though the interface:

$$W = 1 - V.$$

Resulting field amplitude at M is determined by the sum of “directed” Green’s functions

$$E_\Sigma(x) = \sum_{n=1}^N [E_0^n(x) + E_l^n(x)]. \quad (4)$$

As an example, applying formula (4) we estimate the field from one point source for the several frequencies.

Fig. 2. Amplitude distribution of point source field for the frequency of 10 MHz

Fig. 3. Amplitude distribution of point source field for the frequency of 15 MHz

Fig. 4. Amplitude distribution of point source field for the frequency of 28.5 MHz

The calculation time on a medium-powered computer is not more than 2 minutes.

2 Aims and tasks of the experimental investigations

The aim of the experiment is to measure amplitudes of the signals with the frequencies of 10 MHz, 15 MHz, 28,5 MHz in the ice layer.

In the course of the experiment, the antennas were arranged as follows (Fig. 5)

Fig. 5. Antennas arrangement

In Fig. 5, x_i is the receiving antenna coordinate, radiating antenna is installed at point 0 (origin of coordinates), d is the ice layer thickness.

The measuring bench (Fig. 6) consists of a radiating (blocks 1–3) and receiving (blocks 4–6) paths.

The measuring bench is operating as follows:

1. The radiostation (block 1) forms an electric signal with required parameters.
2. A signal from the radiostation (block 1) goes to a tuner (block 2), the device for matching the radiostation and the antennas. From the tuner (block 2) output, the signal is sent to the radiating antenna (block 3).
3. The signal is received by the antenna (block 4), then it goes to the receiving radiostation (block 6) through the tuner (block 5). The power applied to the radiating antenna is 30-35 W.

Fig. 6. Installation diagram

Wave propagation is affected by medium boundaries, ice layer thickness and distribution of solid and fluid phases in it.

The investigations were carried out in Novik bay (Fig. 7) located on the territory of Russkiy Island.

Fig.7. Laying of antenna into the ice

3 Results of experimental investigations

It is clear from Fig. 2 – Fig. 4 and Fig. 6 – Fig. 8 that the dependences of signal amplitudes obtained in the result of numerical and experimental investigations coincide.

Fig. 8. Dependence of signal amplitude on the distance between the antennas. Signal frequency is 10 MHz

Fig. 9. Dependence of signal amplitude on the distance between the antennas. Signal frequency is 15 MHz

Fig. 10. Dependence of signal amplitude on the distance between the antennas. Signal frequency is 28,5 MHz

4 Conclusions

We have developed a valid mathematical model to investigate electromagnetic wave fields in the air and in the ice layer. The experimental investigation of electromagnetic wave propagation in the ice layer with hummocks show good agreement with theoretical calculations.

References

1. V.I. Korochentsev, Wave problems of the theory of directed and focus antennas (Dal'nauka, Vladivostok, 1998) (in Russian).
2. A.V. Korchaka, A.A. Em, V.I. Korochentsev, The Far Eastern Federal University: School of Engineering Bulletin, **38**, 1 (2019) (in Russian).
3. V. Korochentsev, A. Em, Y. Shpak, W. Xue, G. Shabanov, E3S Web Of Conf., **127** (2019).