SURFACE ELECTROMAGNETIC WAVES OVER HIGH-INDUCTIVE TERRAINS

M.G. Dembelov, Yu.B. Bashkuev, V.B. Khaptanov

Institute of the physical material sciences of the Siberian branch of the Russian Academy of Sciences,
6, Sakhyanova str., 670047, Ulan-Ude, Russia
e-mail: mdembelov@yandex.ru

Abstract **– A propagation over high inductive structure of the field radiated by vertical dipole is considered. A new stage of investigations of the problem of the wave propagation is associated with a generation with a case of the inhomogeneous Earth on a depth. First works in this direction were carried out by James Wait. Consideration of the inhomogeneous underlying surface on a depth allows to reveal some regularities in the EM field behavior. It is shown that the surface electromagnetic waves (SEW) were attenuated less than the "ground" ray. An analysis of the field of radiation from the vertical dipole reveals the presence of a wave with the amplitude decaying with the distance R approximately as $1/R^{1/2}$, which corresponds to the SEW divergence. The absolute values of the radiation attenuation function $|W|$ are significantly greater than unity and reach $|W|=2$, which also corresponds to the SEW. Experimental data on the SEW damping agree with the results of numerical calculations of the electromagnetic field in the system under consideration.**

Fundamental works devoted to the theory of radio wave propagation over an inhomogeneous surface

1. Fock V.A. Electromagnetic diffraction and propagation problems, Pergamon Press, 1965.
2. Makarov G.I., Novikov V.V., and Rybachek S.T. Propagation of electromagnetic waves over Earth’s surface, Moscow, Nauka, 1991. (in russ).
3. Wait, J.R. Electromagnetic waves in stratified media. Pergamon Press Inc, - New York, 1962, - 372 p.
4. Feinberg E.L. Radiowave propagation along Earth’s surface, Moscow, Fismatlit publ., 1999. (in russ).
5. Hufford G.A. An integral equation approach to the problem of wave propagation over an irregular surface. // Quart. Appl. Math., 1952, v.9, - pp.391-404.

V.A. Fock's formula

$$W_0(x,y,q)=\sqrt{\pi x}\,e^{i\frac{\pi}{4}}\sum_{s=1}^{\infty}\frac{e^{ixt_s}}{t_s-q^2}\frac{w(t_s-y)}{w(t_s)}$$

$$x=\frac{D}{a}\left(\frac{ka}{2}\right)^{\frac{1}{3}}\qquad y=\left(\frac{2}{ka}\right)^{\frac{1}{3}}kh\qquad q=i\delta\left(\frac{ka}{2}\right)^{\frac{1}{3}}$$

a – Earth's radius;

$\delta=E_\tau/(H_\tau Z_0)$ – normalized surface impedance, $Z_0=120\pi$;

t_s - roots of the border condition:

$$w'(t)-qw(t)=0,$$

$w(t)$ – the Airy function defined by $w''(t)-tw(t)=0.$

$t_{\infty s}$ - roots of $w(t)=0$ $(q\to\infty)$,

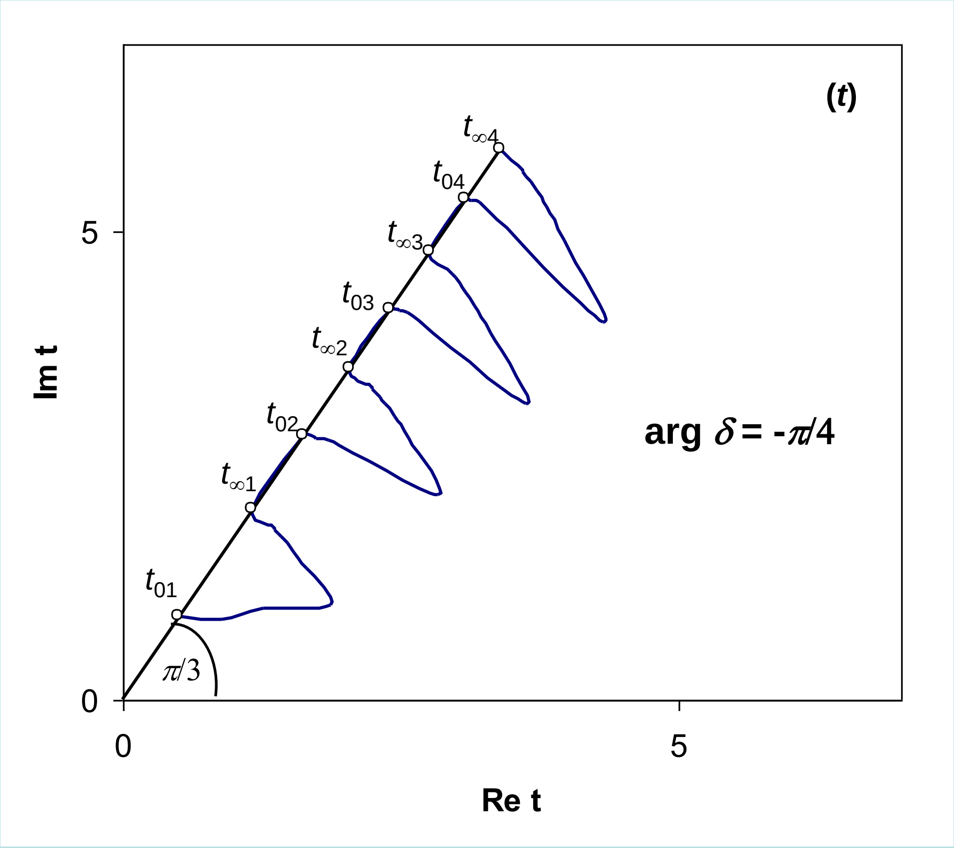
t_{0s} - roots of $w'(t)=0$ $(q\to 0)$.

$$\frac{dt_s}{dq} = \frac{1}{t_s - q^2}$$

$|q|<|t_s^{1/2}|$ $\quad t_s(q)=t_{0s}+q/t_{0s}-q^2/(2t_{0s}^3)+\ldots,$

$|q|>|t_s^{1/2}|$ $\quad t_s(q)=t_{\infty s}+1/q+t_{\infty s}/(3q^3)+\ldots.$

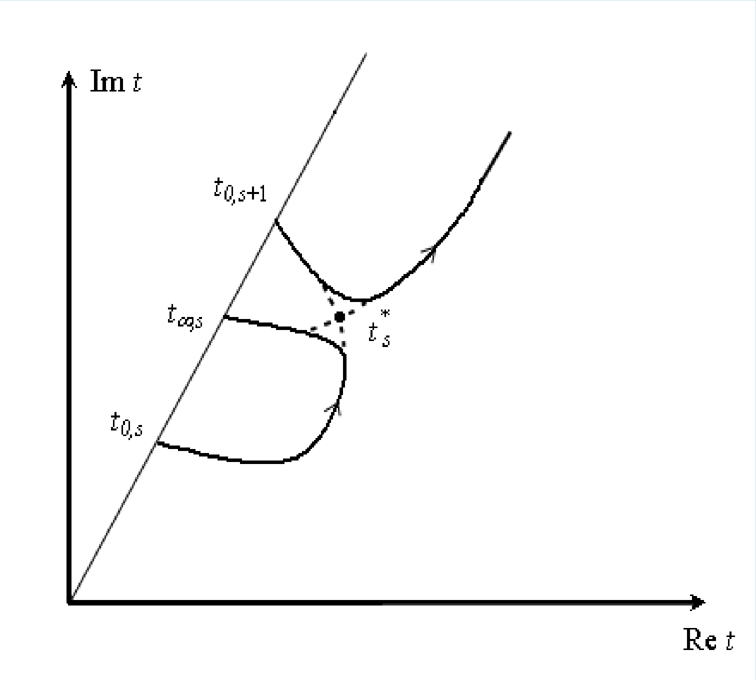
The path of roots t_s for $\arg\delta=-\pi/4$



$-\pi/2 < \arg\delta < -\pi/3$ - the area where dynamics of the roots is more complex

$$t_s^* \approx t_{\infty s} + \frac{2}{\sqrt{t_{\infty s}}} - \frac{9}{(t_{\infty s})^2} \qquad t_s^* \approx t_{0s} + \frac{2}{\sqrt{t_{0s}}} + \frac{9}{4(t_{0s})^2} \qquad t_N = q^2 + \frac{1}{2q}$$

- asymptotic formula



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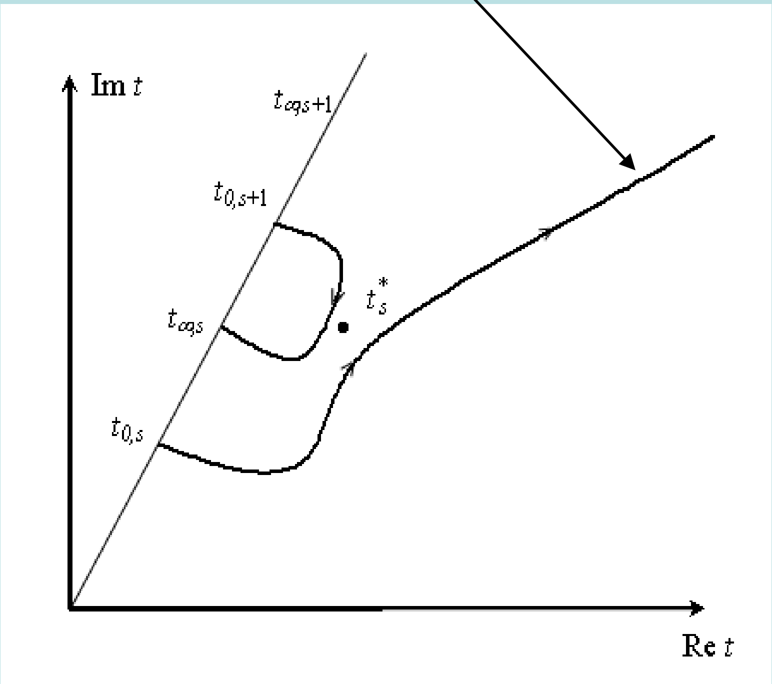
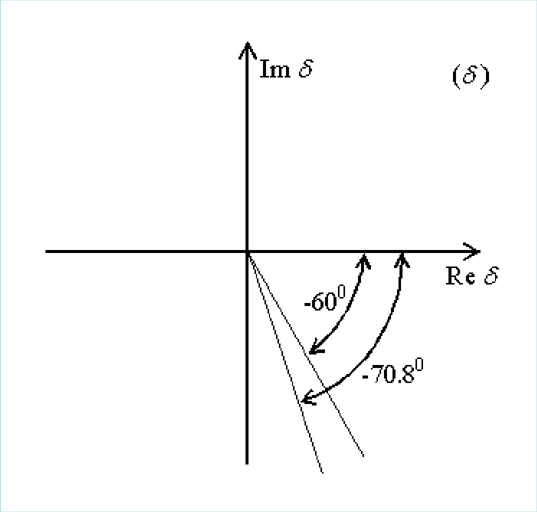
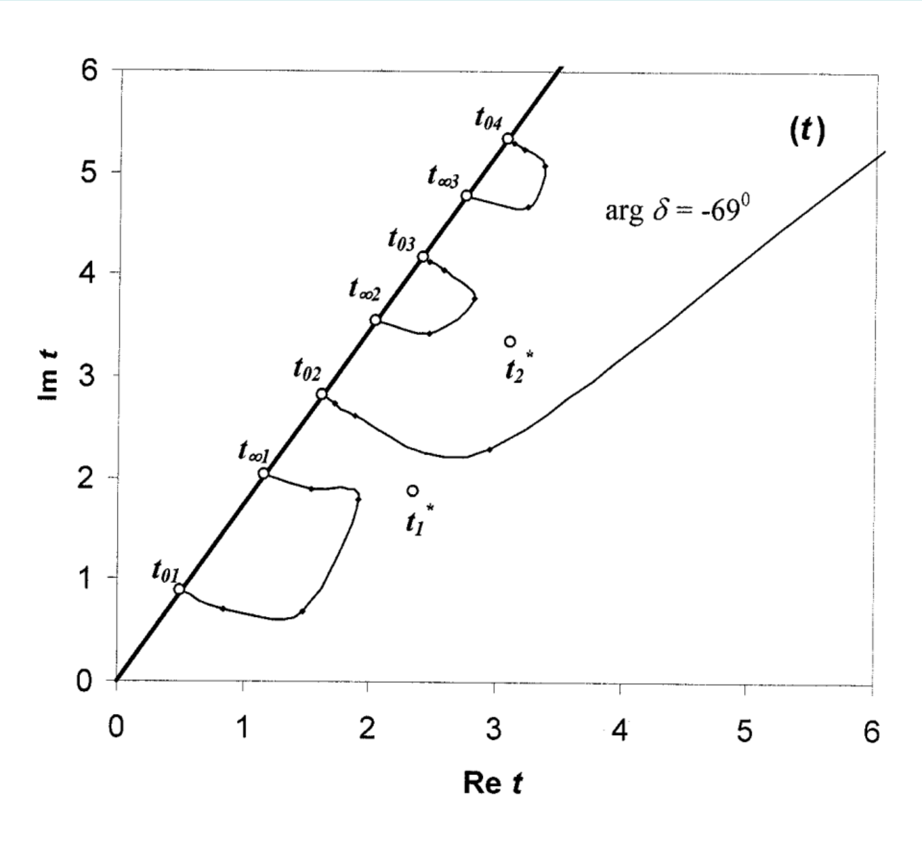


The area of practicable impedances is: $-90^0 < \arg\delta < 90^0$;
$-90^0 < \arg\delta < -45^0$; – the area of high-inductive impedances;
$-70.8^0 < \arg\delta < -60^0$ – the area of degeneration;



The dynamics of roots t_s for arg $\delta = -69^0$



Impedance phases of the degeneration:

arg δ = -70.8^0
arg δ = -66.5^0
arg δ = -64.8^0
……..
arg δ = -60^0

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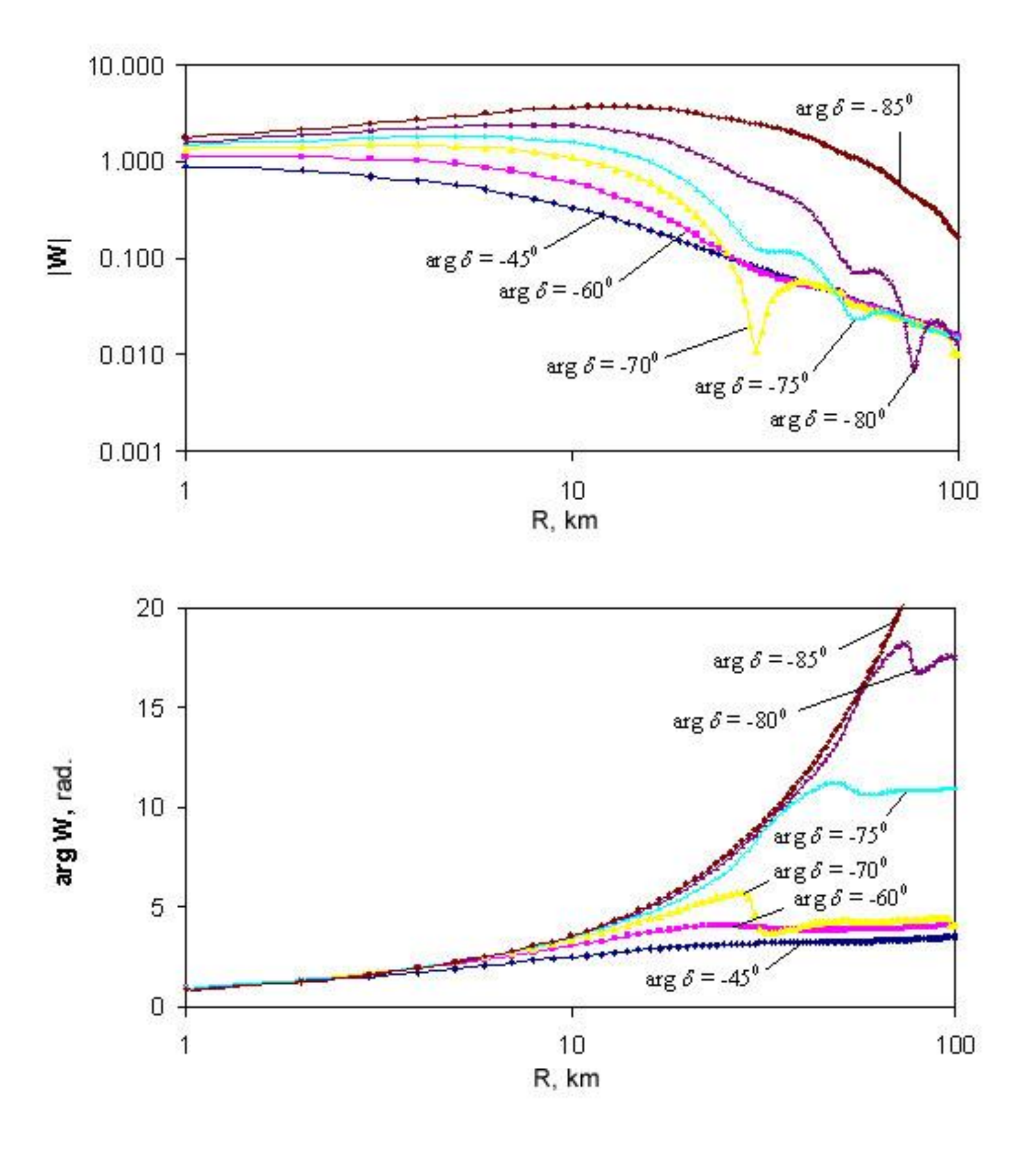

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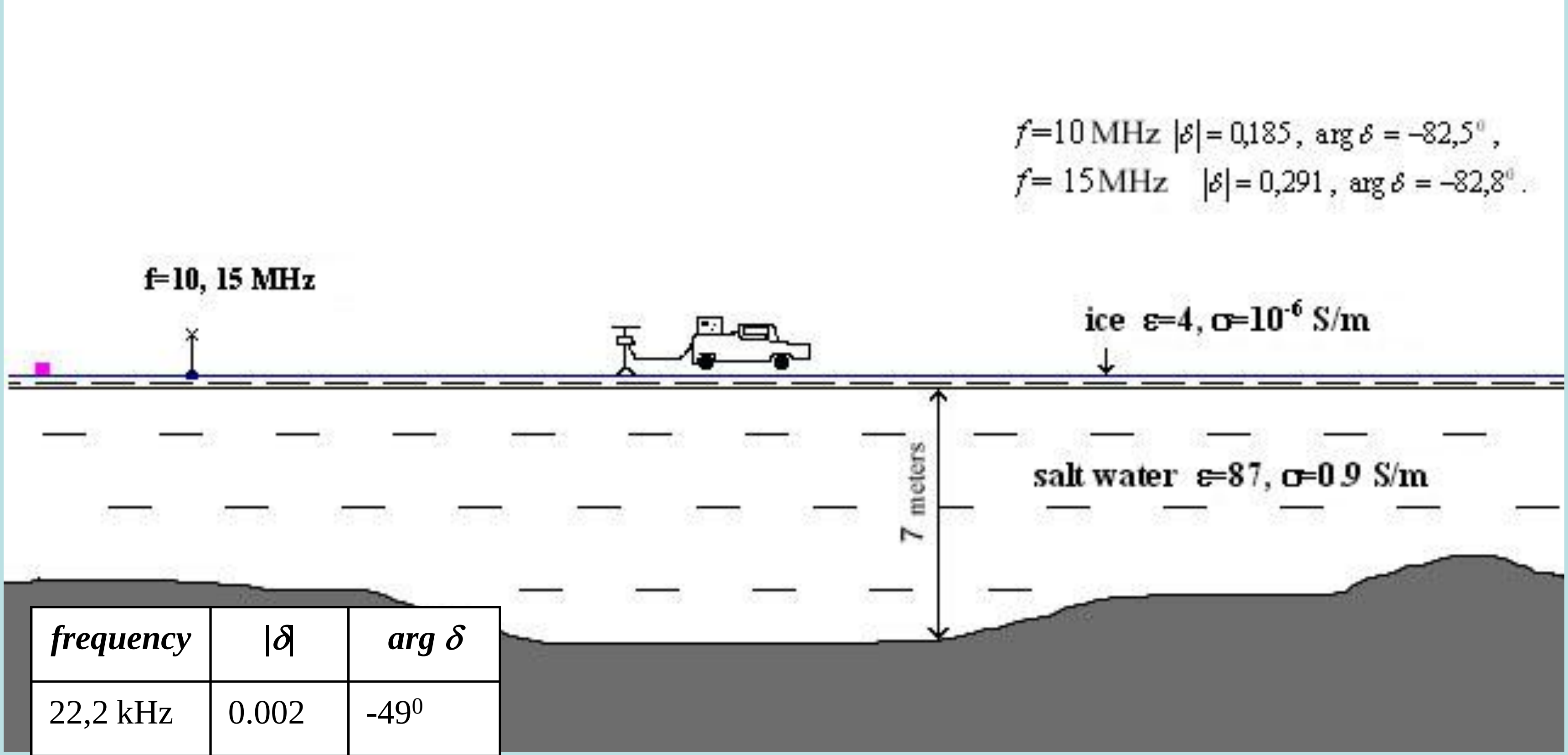
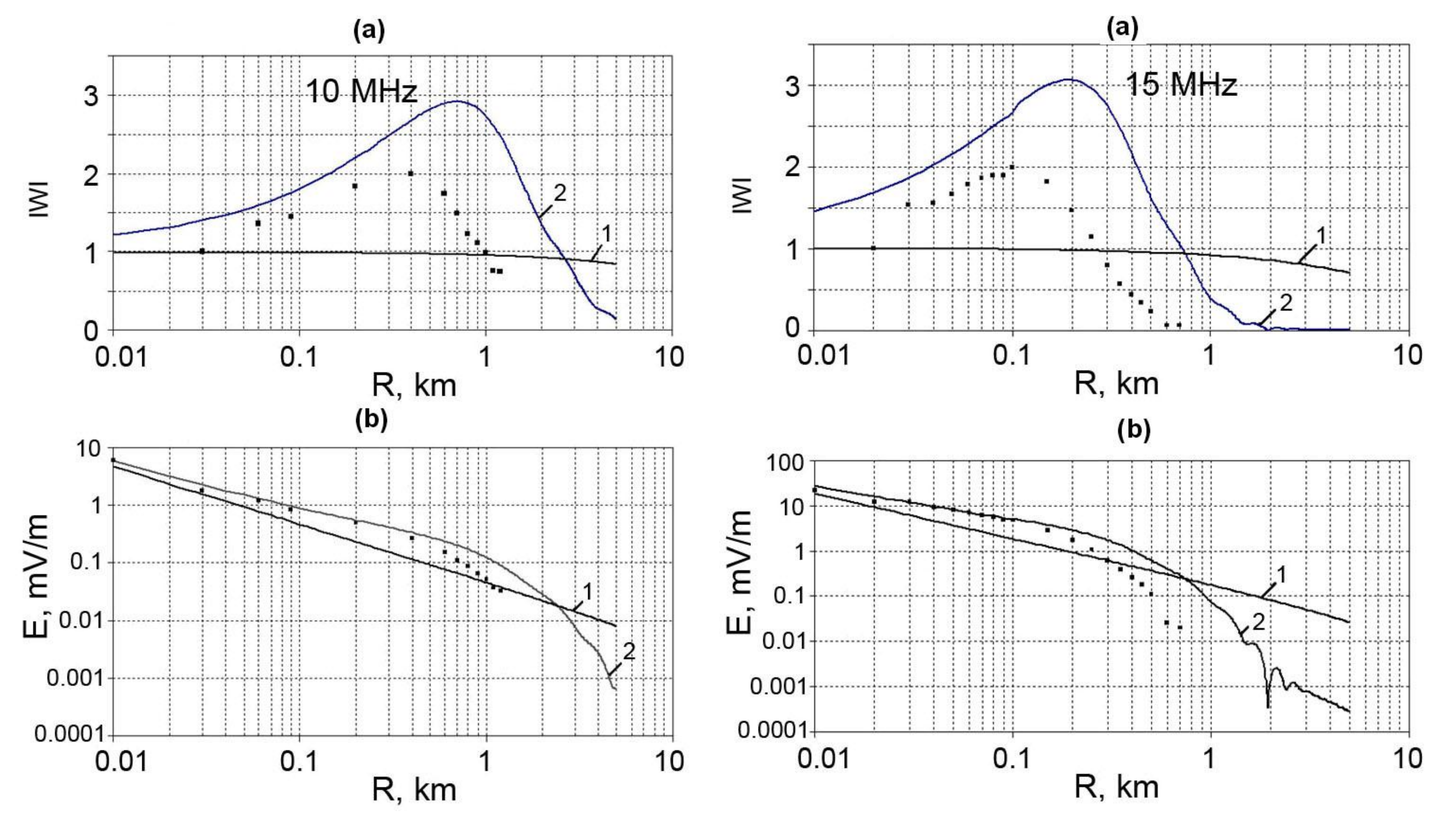
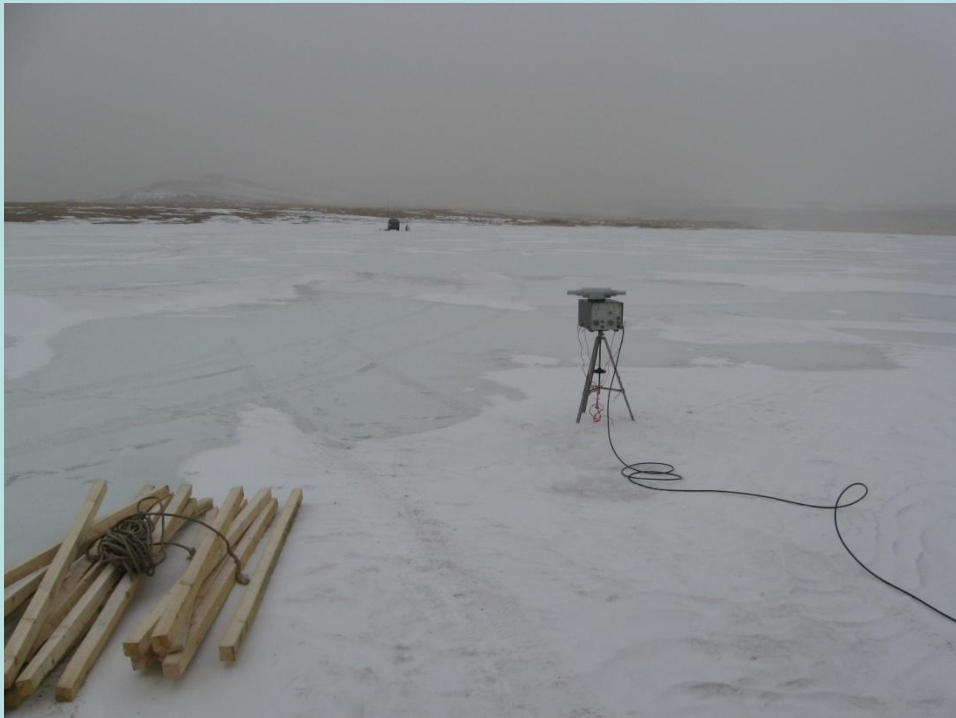


frequency	$\|\delta\|$	*arg* δ
22,2 kHz	0.002	-49^0
50 kHz	0.002	$-75{,}7^0$
164 kHz	0.005	$-77{,}6^0$
279 kHz	0.011	$-71{,}3^0$

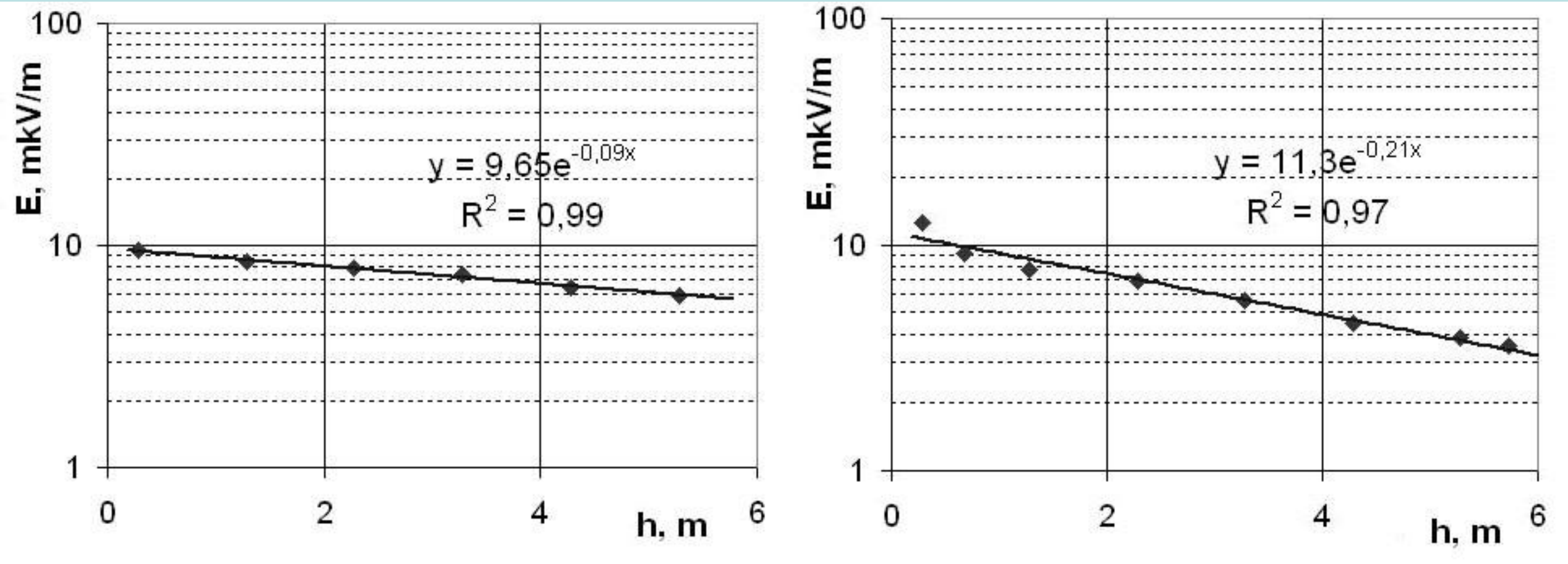
Modules of an attenuation function |*W*| (a) and field intensity *E* (b) at frequencies of 10 and 15 MHz. Solid curves are the results of calculations of the radio-wave path over salt water (1) and ice–salt water structure (2); black squares are the experimental data.





E field intensity at frequency of 10 MHz (a) and 15 MHz (b) versus height. Solid curves show the trend of the experimental data (points). Exponential equations fitting the experimental data and the values of criterion validity are shown on the charts.



Conclusions

A propagation of electromagnetic waves over real Earth's surface is considered. The layered structure of the surface sufficiently influences the character of the electromagnetic field. It is important to take into account this peculiarity in calculations of amplitude and phase of the field. The experiments on propagation of electromagnetic waves in the decameter range (10 and 15 MHz) excited by a vertical dipole above the ice-coated surface of a salt lake over a distance of up to 1.2 km reliably proved the existence of surface electromagnetic waves. Experimental data on surface electromagnetic waves agree with the results of numerical calculations of the electromagnetic field.


Thank You!