The influence of the underlying terrain on the directional characteristics of the HF-range antennas

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Abstract. The results of modeling the antennas directional characteristics in the HF range are presented. In the process of modeling, the radiophysical characteristics of the underlying surface measured under laboratory conditions were taken into account. The simulation results are compared with the results of field measurements of the antennas radiation patterns.

1. Dielectric characterization of soil

It is known that the directional properties of the radiating systems are determined not only by their design features, but also by the radiophysical characteristics of the surface on which they are located [1]. Thus, the type of radiation pattern (RP) of decameter waves (HF) antennas deployed on the soil surface of natural composition, measuring tens and hundreds of meters and located near the ground, will depend on the radiophysical characteristics of the underlying terrain. Soils of natural composition can be considered as a dispersed mixture of the following components: fragments of minerals, organic substances, air, water and / or ice. The magnetic permeability of these components of the soil is close to unity. For this reason, the nature of the interaction of the electromagnetic field with a similar structure is determined by the value of its complex dielectric permittivity (CDP). The size of the CDP soil depends on the volume fraction and CDP each of the components that make up the soil. Currently known models of CDP mixtures are empirical and semi-empirical in nature; a rigorous theory of the interaction of the electric field with a dielectric has not been created.

All known models have significant limitations when calculating CDP values. For example, matrix dielectric models of mixtures give satisfactory results of calculating the CDP in the case when a small fraction of the dielectric impurities (dispersed phase) is included in the main dielectric medium.
(matrix). Refractive dielectric models of mixtures give satisfactory results of calculating the CDP in a limited frequency range. So, the CDP soil values in the HF range, measured under laboratory conditions and calculated according to the model given in the “Recommendations of the International Telecommunication Union (ITU)” [2] are substantially different (Figure 1). The fact of using methods recognized in the world scientific community [3] testifies to the reliability of the data on the CDP obtained in the process of laboratory measurements. In the process of laboratory measurements CDP soil sample was placed in a coaxial cell. At frequencies corresponding to the HF range, the cell was included in the gap of the central conductor of a segment of a larger cross-section line. The dimension of the sample CDP was determined from the measured values of the component of the scattering matrix (complex transfer coefficient and scattering) [3]. In the future, the CDP values measured in the laboratory were reference when modeling the directional properties of antennas.

![Figure 1.](image)

Thus, it can be argued that the currently accepted ITU model of the CDP of soils is not consistent with the data of laboratory measurements in the HF wave range. For this reason, a model and field study of the directional properties of a HF antenna with the use of correct CDP values of the underlying terrain is relevant.

2. Electrodynamic modeling of antenna properties

We investigated the directional characteristics of two antennas. One of them is “Broad-band Vertical Radiator” (hereinafter referred to as BVR), which is distinguished by relatively small dimensions for HF $10 \times 10 \times 10$ m (Figure 2).
Figure 2. Schematic view of the BVR antenna: 1 – mast; 2 – upper collecting ring; 3 – irradiator; 4 – safety lock; 5 – dielectric spacers; 6 – lower collecting ring; 7 – antenna base; 8 – delays; 9 – radial balancing weight

This size of the antenna can significantly reduce the area for its placement, make it mobile. In addition, there are no dissipative elements in the design of the BVR antenna [4]. The antenna is characterized by a sufficiently uniform gain and omnidirectional radiation pattern in the azimuthal plane in the frequency range 3–30 MHz.

Second is aperiodic antenna (AA) VH 60/12 (Figure 3). Antenna is a system of current-carrying conductors placed at a certain height above the ground, loaded with a resistance equal to the iterative impedance of the emitter. Terminal resistors – unbalanced single-ended surface antenna W1 and W2, in the form of Archimedean spiral with a radius of 10 meters (number of turns – 4, spiral pitch – 2 meters). The length of the emitter – 60 m, the height of mast device – 12 meters. Ground antennas are connected at one end of the radiating wire to the lower end of the radiator of the VH 60/12 antenna, the second ends are free. Connection of terminal loads AA is carried out according to the so-called Neumann circuit. According to the scheme, part of the signal power, which is usually dissipated in the resistive load, is supplied to the input of the additional antenna through a segment of the transmission line [5].

Figure 3. Schematic view of the VH 60/12 antenna with terminal loads in the form of asymmetric single-wire surface antennas W1 and W2

Impact assessment of the effect of the underlying surface on the input characteristics of the antennas was carried out by means of electrodynamic analysis of antenna models, using an application
package that implements the finite element method (FEM) [6]. The essence of the finite element method is that all the studied space is divided into elements in the form of tetrahedron (for three-dimensional space). At the same time, the size of the tetrahedron must be small enough to describe the field in order for a simple function or a system of functions with unknown coefficients that can be found from the Maxwell equations and boundary conditions. As a result, the electrodynamic problem is reduced to a system of linear algebraic equations for these coefficients, and the chosen method of representing the antenna by a piecewise-linear structure is suitable for its solution.

In the process of modeling, the dielectric characteristics of the soils, calculated using the model presented in the “ITU Recommendations” [2], and measured in laboratory conditions were used. The results of the model calculation for the soil, which, according to the classification of the International Society of Soil Science (SSSA), silty loam, and laboratory data for the soil, according to the classification of N. A Kachinskiy, which is a loam, is listed in Table 1. Laboratory CDC measurements were carried out for a soil sample characteristic of the south Omsk Region.

In more detail, the results of measuring the CDC are described in [7]. Despite the differences in name, due to different boundary values in the classification of mechanical elements adopted abroad and in Russia, these soils are similar in grain size and should be similar in dielectric characteristics. The observed differences in dielectric characteristics are due to the incorrectness of the model given in the ITU.

Table 2 shows the values of the gain (G) of the BVR antenna obtained as a result of the simulation at different volumetric moisture content and CDC of the underlying terrain – loam and silty loam.

| Type of soil | Frequency, MHz | Real part of CDC | Conductance, mS/m |
|--------------|----------------|------------------|-------------------|
|              |                | Soil moisture    | Soil moisture     |
|              | 10 %           | 26 %             | 33 %              |
| Silty loam   | 5              | 4.8              | 12.7              |
|              | 20             | 12.4             | 25.9              |
|              | 33 %           | 16.7             | 30.9              |
| Loam         | 12.8           | 25.9             | 30.9              |

Table 2. The G values of the BVR antenna

| Type of soil | Zenith angle, degree | Frequency, MHz | G, dB |
|--------------|----------------------|----------------|-------|
|              | 10 %                 | 26 %           | 33 %  |
| Silty loam   | 5                    | –0.3           | 0.4   |
|              | 60                   | 0.6            | 1.9   |
| Loam         | 20                   | 2.6            | 3.2   |
|              | 3.5                  | 4.1            | 4.3   |
| Silty loam   | 5                    | –2.6           | –1.8  |
|              | 80                   | –0.8           | 1.1   |
| Loam         | 20                   | –8.7           | –7.7  |
|              | 80                   | –6.9           | –7.0  |

As can be seen from Table 2, the gain (G) of a BVR antenna for different observation angles and soil moisture differs by 0.7–2.9 dB in a larger direction when using experimental data, rather than ITU recommendations. Examples of the RP antenna pattern obtained as a result of the simulation are shown in Figure 4. The diagrams show the zenith angle values.
Figure 4. The radiation patterns of the BVR antenna, obtained as a result of modeling for a radiation frequency of 20 MHz, the volume moisture of the soil is 10% (a) and 26% (b)

Obtained in simulating the antenna pattern of the BVR antenna in the azimuth plane confirm the uniformity of the gain and the omni-directionality of the RP in the frequency range 3–30 MHz with an irregularity of 0.2–0.4 dB for specific KDP values, as stated by the developers. The asymmetry of the reduced diagrams is explained by the influence of the power feeder introduced into the BVR antenna model. The influence of the underlying surface on the directional characteristics of the BVR antenna was insignificant. The reason for this is the shade effect of the balancing weight.

To check the reliability of the data obtained using electrodynamic modeling of the antenna under study, a comparison was made with its full-scale measurements using an unmanned aerial vehicle. Calculations and comparisons were performed for frequencies from 3 to 30 MHz, RPs are given for frequencies 5 and 20 MHz. In Figure 5 shows the results of field measurements of the BVR antenna. The underlying terrain at the site is a loam, the radiophysical characteristics of which are presented earlier. The volumetric moisture content of the underlying terrain was uneven and varied from 20 to 25% with a change in depth from 0 to 50 cm.

Figure 5. Measurements of the BVR antenna radiation pattern measured in the field experiment: radiation frequencies 5 MHz (a) and 20 MHz (b), the underlying terrain is loam

The comparison patterns obtained during the simulation (Figure 4) and the field experiment (Figure 5) show the qualitative agreement of the results. At the same time, differences in the values of volumetric moisture load do not allow us to compare the directional characteristics quantitatively. The
actual condition of conductors, insulators, balances and other antenna elements can also have an effect on the directional properties of the antenna. Below are the results of the electrodynamic analysis of the VH 60/12 antenna for a moisture content of 10 and 33% according to the CDC values for clay loam, the model given in ITU. The value of G was calculated for the maximum of the RP antenna (Figure 6).

![Figure 6. VH 60/12 antenna radiation patterns obtained as a result of modeling for radiation frequencies of (a) 5 and (b) 20 MHz, volumetric humidity of clay loam at (1) 10% and (2) 33%](image)

From the data given in the graph, it can be seen that the RP type of VH antenna significantly depended on both the frequency and the type of underlying surface.

3. Results and discussion

Analyzing the data of Table 1, we can conclude that the radiophysical characteristics of the underlying surface have a noticeable effect on the directional characteristics of the BVR antenna. It can be noted that with an increase in the conductivity of the underlying surface, the energy gain in the gain slightly increases. However, the change in G for a fixed zenith angle with a change in the dielectric characteristics of the underlying surface is small and comparable with the modeling error.

The change in directional characteristics of the VH 60/12 antenna with a change in the value of the CDP of the underlying manifests itself to a more noticeable degree. This fact indicates a noticeable effect of the underlying surface on the directional characteristics of the HF antennas of the range that do not have elements that shield the underlying surface in their design.

The antenna gain difference shown when taking into account CDPs defined in different ways can significantly change as a result of antenna modeling placed on layered or other types of soil at negative temperatures (frozen - thawed soil, snow - frozen soil). In the future we plan to consider the effect on the directional properties of the antennas of the gradient change in soil moisture.

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