The Problems of Result Interpretation of Microwave Subsurface Penetration of Plane-Parallel Medium

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The influence of non-homogeneous distribution of dielectric parameters in soils on shaping an electromagnetic response of sounding microwave signals has been investigated. The study revealed that the correct interpretation requires to take into account the profile distribution of the $\varepsilon, tg\delta$ *soils parameters.*

In the paper, the reflection factor behaviour of the plane electromagnetic wave scattered by ground-soils with non-homogeneous distribution of dielectric parameters, which is caused by profile distribution of moisture, and also influence of such media on electromagnetic response formation of sounding microwave signals are analysed.

Such ground-soils radiowave characteristics as permittivity ε and dielectric loss angle $tg\delta$ are complex functions of the different parameters: moisture, temperature, type and structure of ground-soils, frequency of the electromagnetic field interacting with medium. In this case, ε and $tg\delta$ are strongly affected by soil moisture (soil solution) [1].

Fig.1,2 show the values of ground-soils $\varepsilon, tg\delta$ parameters depending on profile distribution of moisture with depth “H” and profileless distribution of radiowave parameters. In Fig.1, the curve “1” corresponds to ε’ distribution for a certain type of turf ground directly after strong thunderstorm, the curve “2” corresponds to the same ground case but 2 days after the thunderstorm, and the curve “3” corresponds to averaged ground moisture in July of long standing. Fig. 2 shows the $tg\delta$ values for the same ground; curves “1-3” denote the cases as in Fig.1 (the curves “3” in Fig.1,2 correspond to profileless distribution).

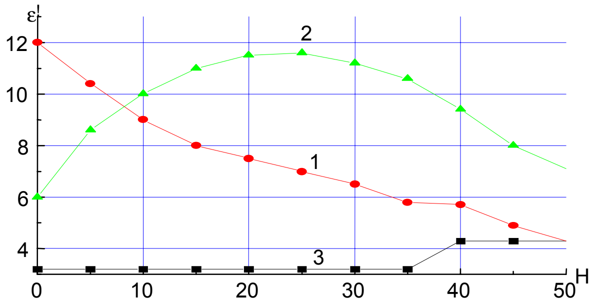

Fig.1

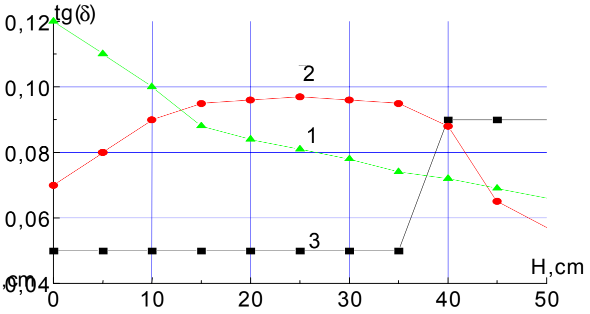

Fig.2

The medium with a spatial distribution of dielectric parameters is considered to be a multilayer system. For the sake of example clearness, we suppose the system to be homogeneous in x- and y-directions. Then $\varepsilon = \varepsilon$’(1 + jtg$\delta$) is only function of z-coordinate ($\varepsilon = \varepsilon$ (z)), where this function may have discontinuities on the boundaries between the layers. The permittivity inside the each layer is a function of moisture and temperature. Moreover, these functions depend on z-coordinate that means the ε dependence on “z” inside the each layer. Generally speaking, the moisture distribution may be nonstationary one, therefore the permittivity will be function not only of the spatial coordinates but time also. However, the temporal scales for temperature and moisture processes (hours and days) and processes of signals propagation are essentially different, so the time dependence of the ε parameter can be neglected in the given research.

As a rule, the ε-dependence on “z” inside the each layer can be numerically specify in certain points h_i. To simplify the calculations, let us suppose the ε parameter to be constant between h_i and h_{i+1} points. A number of such partitions inside the each layer is determined by the ε (z) function form. To obtain the needed calculations accuracy, it can be chosen as much as desired large. In such a case, the layer thickness must be less than wavelength with regard to dielectric parameters in a whole frequency band.

The problem can be stated as follows. Let the plane electromagnetic wave is radiated normally to layered non-homogeneous dielectric half-space with “n” layers having different thickness and permittivity values. It is required to find the reflection factor R in free half-space depending on wavelength λ when the radiowave parameters have different profile distributions. It is known [2] that the reflection factor of multilayer medium can be found with the use of recursion relation:

$$R_{1,n} = (R_{1,2}+R_{2,n}\,\mathbf{exp(-}j*4*\pi*h_2/\lambda*\sqrt{\varepsilon}_2))/(1+R_{1,2}*R_{2,n}*\mathbf{exp(-}j*4*\pi*h_2/\lambda*\sqrt{\varepsilon}_2)), \qquad (1)$$

where

$$R_{i,i}=0,\;\; R_{i,i+1}= -(\sqrt{\varepsilon}_{i+1}-\sqrt{\varepsilon}_{i})/\sqrt{\varepsilon}_{i+1}+\sqrt{\varepsilon}_{i},\;\; R_{i,k}= (R_{i,i+1}+R_{i+1,k}*\,\mathbf{exp(-j}*4*\pi*h_{i+1}/\lambda*\sqrt{\varepsilon}_{i+1}))/$$

$$/1+R_{i,i+1}*R_{i+1,k}**\mathbf{exp(-j}*4*\pi*h_{i+1}/\lambda*\sqrt{\varepsilon}_{i+1}),\;\; k\neq i,\quad k\neq i+1. \qquad (2)$$

The final expression for the reflection factor R (for our case of 11 layers with corresponding values of ε and tgδ) has the following form:

$$R=R_{1,12}=(R_{1,2}+R_{2,12}*\exp(-j*4*\pi*h_2/\lambda*\sqrt{\varepsilon}_2))/1+R_{1,2}*R_{2,12}*\exp(-j*4*\pi*h_2/\lambda*\sqrt{\varepsilon}_2), \qquad (3)$$

The used values Ri,i+1 and Ri,k are easily obtained from (2) by known hi and ε i.

The results of numerical simulation of the reflection factor modulus in 0.3-0.7 GHz band are given in Fig.3,4. The curves “1”, “2” in Fig.3 correspond to profile distributions of the $\varepsilon, tg\delta$ parameters shown in curves “1”, “2” in Fig.1,2, and curve “3” corresponds to profileless distribution of the dielectric parameters. Fig.4 shows the reflection factor modulus dependencies for some inhomogeneities buried at 15 cm depth: curve “1” - metal, curve “3” - a dielectric (permittivity 2.5) layer with 10 cm thickness; with the view of comparison, the curve “2”, which corresponds to curve “3” in Fig. 3, is given. In the case of profile distribution of the radiowave parameters, as one can see from curve “2” in Fig.1,2, the scattered signal equals nearly to zero. The curve “3” in Fig.3 demonstrates clearly expressed maxima and minima of the reflection factor. Their position on the frequency axis can determine the upper profileless layer thickness, while the curve “1” in Fig.3 does not allow to accurately evaluate the upper layer thickness.

Thus, the results presented in the given paper have shown that taking account of the profile distributions of the permittivity and dielectric loss angle is the necessary condition for correct data interpretation of subsurface sounding of artificial objects and ground-soils.

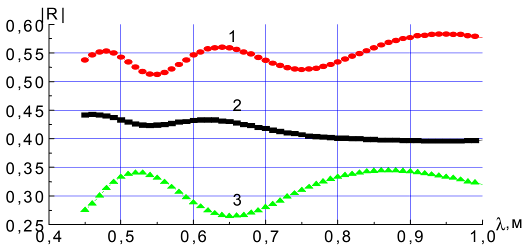

Fig.3

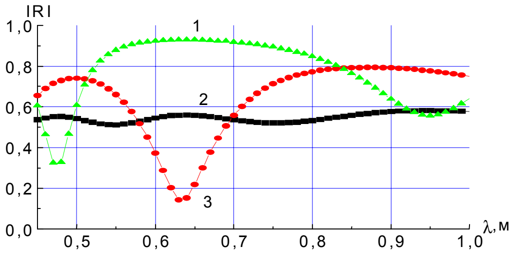

Fig.4

References

1. Shutko A.M. Microwave radiometry of water surface and ground-soils. Moscow, “Science” Publ., 1986, 190 p.

2. Radugin O.K. A theorem on relation of problems solutions concerning the vertical and horizontal dipoles field, “Izvestia VUZov, Phizika”, No.6, pp. 86-90, 1966.