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INFLUENCE OF SOIL HUMIDITY CHANGING TO COEFFICIENT OF REMOVING OF ELECTROMAGNETIC WAVES

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The change of soil humidity on changing of permittivity, and correspondent on coefficients of electromagnetic waves is investigated theoretically. Complex reflection coefficients for perpendicular and parallel polarization from layered semi-space are determinate by impedance method. Elaborated method of solution gives the opportunity of practical determination of soils' humidity and structure with help of the radiometry, and can be used in the systems of fine agriculture also.

Dielectric permittivity, reflection coefficients of electromagnetic waves, soil humidity, system of fine agriculture.

Presence of water in soils changes them physics and mechanics descriptions, and, in particular, them inductivity. It is related to that the complex inductivity of water in the highfrequences region of radioexitation substantially differs from the inductivity of soils, and that is why the effective inductivity of water-wet soil will differ from corresponding description of dry soils. This change, in particular, will influence on the coefficient of removing of electromagnetic wave from the surface of soil. As measuring of coefficient of beating back is an investigational experimental task [6], then it, in principle, allows after the change of coefficient beating back to nose after a change to the amount of moisture being in soil. In connection with distribution of the systems of exact agriculture of realization of such researches is actual.

Being of water in soils changes them the inductivity of layers of that depends on the amount of water in a layer and his structure. For determination of inductivity of layers of soil the methodology of determination of effective dielectric function of porous environments worked out before is used [2−5]. Coefficients of removing of hertzian wave from stratified half-space is calculated by means of impendens method [1].

An aim of researches − is an analysis of influence of change of humidity of soil on the coefficient of removing of electromagnetic wave from the surface of soil for finding out of possibility of application of noncontact radiolocation methods of sounding at determination of structure and humidity of soils in the system of exact agriculture. Therefore, this direction of scientific researches is actual and perspective.

Results of researches 1. Being of coefficient of removing of electromagnetic radiation is from stratified on half-space. Will design soil stratified half-space and will consider a flat harmonious electromagnetic wave with the electric vector of E and aclinic line of H accordingly, that spreads in overhead half-space and falls on the limit of division of two half-spaces

$$\mathrm{E} = \mathrm{E}_0 e^{i(\mathrm{kr} - \omega t)};\ \mathrm{H} = (c / \mu\omega)[\mathrm{k} \cdot \mathrm{E}] \tag{1}$$

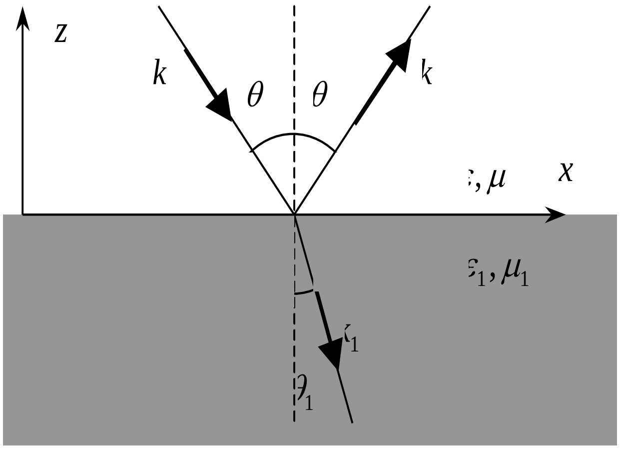
In a formula(1) $\mathrm{k} = \{\mathrm{k}_\xi, \mathrm{k}_\psi, \mathrm{k}_\zeta\}$ − wavevector; $r = \{x,y,z\}$ − a radius-vector of arbitrary point overhead half-space; ω − frequency; t − time; c − speed of light; μ − permeance of overhead half-space.

The module of wavevector is here determined after a formula:

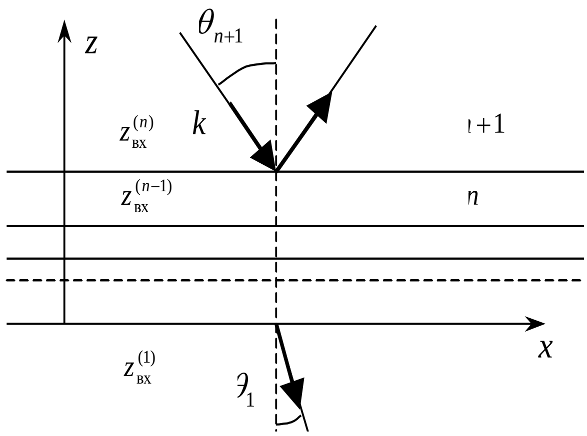
$$k = (\omega / c)\sqrt{\varepsilon\mu} = (2\pi / \lambda)\sqrt{\varepsilon\mu}, \tag{2}$$

where λ − a wave-length is; $\varepsilon = \varepsilon' + i\varepsilon'' = \varepsilon'(1 + itg\delta)$ − complex inductivity; ε', ε'' − actual and imaginary parts; $tg\delta$ − tangent of corner of dielectric losses, that is determined by correlation $tg\delta = \varepsilon'' / \varepsilon'$.

At first will consider the case of homogeneous lower environment. Will designate complex dielectric and magnetic to permeability in overhead and lower environments accordingly through ε, μ and ε_1, μ_1. Will choose the rectangular system of coordinates so that plane xy coincided with the plane of division of two environments, and plane xz – with the plane of falling of flat wave. Angle of incidence of wave, id est a corner between a wavevector and plane of division will designate through ϑ, corner of refraction through ϑ_1 (rice.1).



Rice.1. Removing of flat wave is from the stratified half-space



Rice.2. Removing of flat wave is from the limit of division of two half-spaces

As known, any flat electromagnetic wave can be presented as a superpositions of two waves. For one of them a vector of electric constituent of E is perpendicular to the plane of falling (perpendicular polarization), and for other lies in this plane (parallel polarization).

The electric field in an overhead environment can be written down in a kind

$$E = E_y = E_0 e^{i(k_x x - k_z z)} + V E_0 e^{i(k_x x + k_z z)}, \qquad (3)$$

where the first element shows a soba a falling wave, and second - the removed wave. Amplitude of falling wave marks through E_0, and coefficient of removing of - V ($V_\perp$ − for to the athwart polarized wave, $V_{||}$ − for to the wave polarized in parallel). Components of wavevector here $k_x = k\, sin\, \vartheta$, $k_z = k\, cos\, \vartheta$.

In a lower environment the electric field

$$, \qquad E_1 = E_{1y} = WE_0 e^{i(k_{1x}x - k_{1z}z)} \tag{4}$$

where W –coefficient of transparency between($W_\perp$ – for the athwart polarized wave, $W_{||}$ – for the wave polarized in parallel), and

$$k_{1x} = k_1 \sin\vartheta_1 ,\ k_{1z} = k_1 \cos\vartheta_1 ,\ k_1 = k(\varepsilon_1\mu_1 / \varepsilon\mu)^{1/2} . \tag{5}$$

To steel, V, W, and also corner of refraction determined from maximum terms that provide continuity of tangential constituents of E, H for different. In future it comfortably to enter the concept of iimpedance. For over head and lower half-spaces iimpedance equal accordingly

$$Z = E / H_x ;\ Z_1 = E_1 / H_{1x} , \tag{6}$$

and after the record of maximum terms through impedance get expressions for the calculation of coefficient of beating back in the cases of perpendicular and parallel polarizations :

$$V_\perp = \frac{Z_1^0 / \cos\vartheta_1 - Z^0 / \cos\vartheta}{Z_1^0 / \cos\vartheta_1 + Z^0 / \cos\vartheta} , \tag{7}$$

$$V_{||} = \frac{Z_1^0 \cos\vartheta_1 - Z^0 \cos\vartheta}{Z_1^0 \cos\vartheta_1 + Z^0 \cos\vartheta} , \tag{8}$$

where $Z^0 = (\mu / \varepsilon)^{1/2}$, $Z_1^0 = (\mu_1 / \varepsilon_1)^{1/2}$- wave supports of overhead and lower environments accordingly.

The angles of incidence and refraction for both polarizations are bound by correlation of law of refraction

$$k_x = k_{1x} \Rightarrow k \sin\vartheta = k_1 \sin\vartheta_1 . \tag{9}$$

The concept of entrance impedance allows to get a recurrent formula for the calculation of coefficient of beating back for the system of layers that divide two environments (rice. 2). An entrance impedance is calculated recurrently [1]:

$$Z_{вх}^{(n)} = \frac{Z_{вх}^{(n-1)} - iZ_n tgk_{nz} d_n}{Z_n - iZ_{вх}^{(n-1)} tgk_{nz} d_n} Z_n, \quad (10)$$

where d_n − thickness of n-layer.

Have consistently:

$$Z_{вх}^{(1)} = Z_1,\ d_n = d_2;\ Z_{вх}^{(2)} = \frac{Z_{вх}^{(1)} - iZ_2 tgk_{2z} d_2}{Z_2 - iZ_{вх}^{(1)} tgk_{2z} d_2} Z_2 = \frac{Z_1 - iZ_2 tgk_{2z} d_2}{Z_2 - iZ_1 tgk_{2z} d_2} Z_2$$

but so farther.

For *n* layers the coefficient of beating back can be calculated on a formula:

$$V = \frac{Z_{вх}^{(n)} - Z_{n+1}}{Z_{вх}^{(n)} + Z_{n+1\ 2}}, \quad (11)$$

where impedance of layers it is resulted by expressions:

$$Z_j = Z_j^0 / \cos\vartheta_j,\ Z_j = Z_j^0 \cos\vartheta_j, \quad (12)$$

accordingly for perpendicular and parallel polarizations. Thus through $Z_j^0 = (\mu_j / \varepsilon_j)^{1/2}$ the impendance of *j* layer marks.

Will notice that for complex dielectric проникностей glowed the coefficient of beating back too will be an imaginary. Therefore usually enter the coefficient of beating back after power, that is determined by correlation

$$|R|^2 = VV^*, \quad (13)$$

where V^* − conjugating number.

The brought formulas over allow fully to untie a task about establishment of dependence of coefficient of removing of flat wave from the stratified environment from her length, angle of incidence and polarization. In case of the normal falling the coefficients of beating back coincide for both polarizations.

2. Determination of effective inductivity of soils. Design soils porous environments. Wave-length λ in a highfrequences range considerably anymore sizes of characteristic formations of porous environment, that is why the effective inductivity of water-wet soils $\varepsilon = \varepsilon(\omega)$ is determined by means of model of double-base porous environment [2− 5] from equalization:

$$\int_0^1 \frac{\varepsilon_c(\omega,\varphi)-\varepsilon(\omega)}{\varepsilon_c(\omega,\varphi)+2\varepsilon(\omega)}\lambda(\varphi)\mu(\varphi)d\varphi + \int_0^1 \frac{\varepsilon_B(\omega,\varphi)-\varepsilon(\omega)}{\varepsilon_B(\omega,\varphi)+2\varepsilon(\omega)}[1-\lambda(\varphi)]\mu(\varphi)d\varphi = 0, \quad (14)$$

where $\varepsilon_B = \varepsilon_B(\omega)$; $\varepsilon_C = \varepsilon_C(\omega)$– dielectric to permeability, that characterize skeletal and percolation parts of the chosen cell of characteristic size and calculated after formulas:

$$\varepsilon_B = \varepsilon_R \frac{2\varepsilon_R + \varepsilon_R - 2(\varepsilon_R - \varepsilon_w)\varphi}{2\varepsilon_R + \varepsilon_R + 2(\varepsilon_R - \varepsilon_w)\varphi}, \quad (15)$$

$$\varepsilon_C = \varepsilon_W \frac{\varepsilon_R + (2/3)(\varepsilon_R - \varepsilon_w)\varphi}{\varepsilon_W - (1/3)(\varepsilon_w - \varepsilon_R)\varphi}. \quad (16)$$

In turn $\varepsilon_R, \varepsilon_W$ − it dielectric to permeability to the skeleton and including accordingly. All dielectric to permeability are complex sizes.

A function $\mu(\varphi)$ determines the closeness of distribution of probability of sizes of porous, and function $\lambda(\varphi)$ – closeness of distribution of length of constrained inter the porous (percolation constituent of porous environments). A function $\mu(\varphi)$ can be certain experimentally after treatment of photos of cuts of standards, but for a function $\lambda(\varphi)$ it is possible to get some theoretical estimations only [7]. To this work the model of homogeneously constrained porous is driven, for that $\lambda(\varphi) = const = p$ [2,5,7], and the function of distribution of porous after sizes is described by distribution of beta, that at the defined values of parameters degenerates in a piece-permanent function. As well as before [2,4], accept, that

$$\mu(\varphi) = \begin{cases} 4, & 0 \le \varphi \le 0{,}2 \\ 0, & 0{,}2 \le \varphi \end{cases} \quad (17)$$

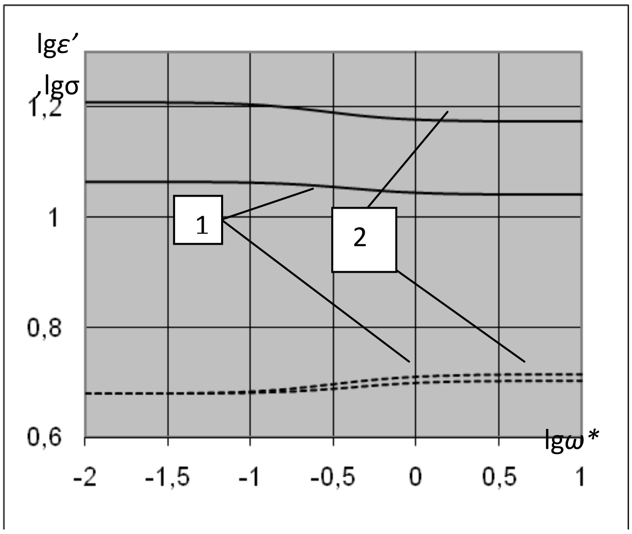
A formula(14) allows to calculate an effective inductivity at known of skeleton and liquid that fills pores, and functions of distribution $\mu(\varphi)$, $\lambda(\varphi)$. For this purpose it is needed at the fixed value of frequency to untie equalization(14) that can be given in a kind : $F(\varepsilon;\lambda,\varphi) = 0$ relatively $\varepsilon = \varepsilon(\omega)$. It is expedient to use the method of

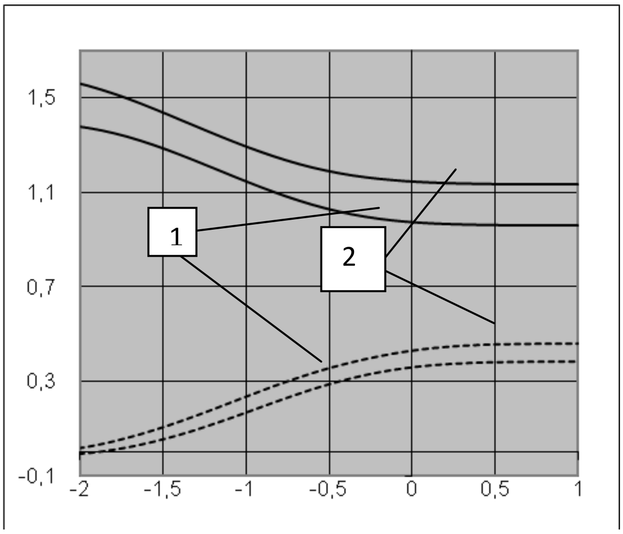
Newton, that spreads to the function of complex argument. Then an unknown value of inductivity is ітеративно after a formula

$$\varepsilon_{k+1} = \varepsilon_k - F(\varepsilon_k) / F'_\varepsilon(\varepsilon_k). \tag{18}$$

The initial approaching it comfortably to accept mean arithmetic value of dielectric проникностей skeleton and including. On physical considerations obviously, that a process will always coincide. Application of formula(18) according to(14) it is related to the calculation of values of function the argument of that enters under the sign of certain integrals as parameter. These integrals at the fixed values are numeral.

As an example, will consider water-wet soil with two values of actual part of inductivity of material of skeleton $\varepsilon_R{}' = 5$ та $\varepsilon_R{}' = 10$, and for water will accept $\varepsilon_W{}' = 79$ and conductivity $\sigma_W = \varepsilon_W$. At a task to the percolation function in the model of homogeneously constrained porous will take on two values $p = 1{,}0$ and $p = 0{,}5$. Dependences of actual part of inductivity and conductivity of such porous are environments from dimensionless frequency $\omega^* = \omega / \omega_0$ for these cases it is brought around to rice. 3,4, where $\omega_0 = 1/(\varepsilon_0 \varepsilon'_W) = 1{,}43 ГГц$ – it is frequency of relaxation of water, and $\varepsilon_0 = 8{,}8452 \cdot 10^{12} Ф/м$.





Rice. 3. Frequency dependence of actual part of inductivity and conductivity for the model of homogeneously constrained porous at $\lambda = 1$

ε′, --------- ——— **-** σ;

Rice. 4. Frequency dependence of actual part of inductivity and conductivity for the model of homogeneously constrained porous at $\lambda = 0{,}5$

$1 - \varepsilon_R = 5$, $2 - \varepsilon_R = 10$

Calculations were executed in a range $0{,}03\omega_0 \le \omega \le \omega_0$. On graphic arts double logarithmic scales are used with tithe basis, continuous lines are show curves for effective actual part of inductivity, and by a stroke − for effective conductivity.

From the brought data over swims out, that increase of inductivity of skeleton and increase inductivity of porous environment and his conductivity. Substantial influence has перколяційна constituent that changes effective descriptions not only, and also notedly influences on their frequency dependence. Thus there is a certain range of frequencies at, id est range , in that dielectric description keep a permanent value practically. This circumstance is substantial enough, as it allows to use devices that work in the centimetre range of waves.

Conclusions

The offered methodology allowed to link dielectric descriptions of soils that are with the use of offered earlier the model of porous environments, with such description, as a coefficient of removing of electromagnetic wave from the surface of soil that is determined by means of exact decision of equalizations of Maxwell for the stratified half-space with application of impedance method. The turn-down of coefficient of beating back, that in theory grounds possibility of the use of noncontact radiolocation methods of sounding at determination of humidity and underlying structure of soils in the system of fine agriculture, is certain.

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