10th IMEKO TC7 International Symposium
June 30–July 2, 2004, Saint-Petersburg, Russia

DIAGNOSTICS OF UPPER LAYER ON A SURFACE OF HALF-INFINITE MEDIA BY THE ULTRA-WIDEBAND VECTOR RADAR METHODS

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Abstract – In the paper, a possibility of creation the operative methods of the remote no destroy control of layered natural and artificial media is considered. The behaviour peculiarities of the reflection factors for the ultra-wideband (UWB) signals of vertical and horizontal polarization are analysed at inclined falling on the control media. Results of UWB sounding by the vertical and horizontal polarized waves at small falling corners are used for the joint determination of electrophysical and structured properties of the upper layers of spreading media. Functional relationships between electrophysical properties of structured control media elements and parameters of UWB signal are carried out.

Keywords: ultra-wideband, geo radar, dielectric media

1. INTRODUCTION

Radar methods are the perspective way of the remote diagnostics and control of the material media. The ground penetration radar system operate is based on analysis of targets of the studying media on the sounding signal. Choice of signal and method of its processing defines an efficiency of they radiophysical diagnostics. One of the perspective directions of increase of the radar methods efficiency is connected with UWB signals and their polarized processing. The interpretation of measurement results, connected with the problem of the adequate description of interaction of electromagnetic waves with sounding media is a very important and urgent problem for a stage of sounding data processing.

Improvement of methods of the reflected signals interpretation is connected with decision the problems, taking into consideration of interaction of the sounding signals with the layered media, which is described by geometrical parameters and dielectric characteristics. Method of data interpretation, based on the interaction of the plane waves with layered media at their inclined fall is widespread. At present, methods and equipment of measurement of the dielectric and structured parameters of the upper layers by underground media are well known [1,2]. These methods are effective at corners of signal fall, closed to a Brewster corner, that complicates their practical application.

In the given paper, the behaviour of reflection factors for the UWB signals of vertical and horizontal polarization is analysed at small corners of fall on the control media. Joint using the results of sounding by the vertical and horizontal polarized UWB signals allows to receive information about dielectric and structured properties of the sounding layers.

2. STATEMENT OF A PROBLEM

On layered dielectric media, characterized by complex dielectric and magnetic permeability *($\varepsilon^*=1$, $\mu^*=1$)*, from the free space the plane electromagnetic wave at various corners Θ (fig. 1) is falling. It is required to define the reflecting factor *R* from the studying media depending on corner of the falling waves of horizontal and vertical polarizations, if the dielectric layer is present on the media surface. The upper layer and spreading media have a half-infinite thickness.

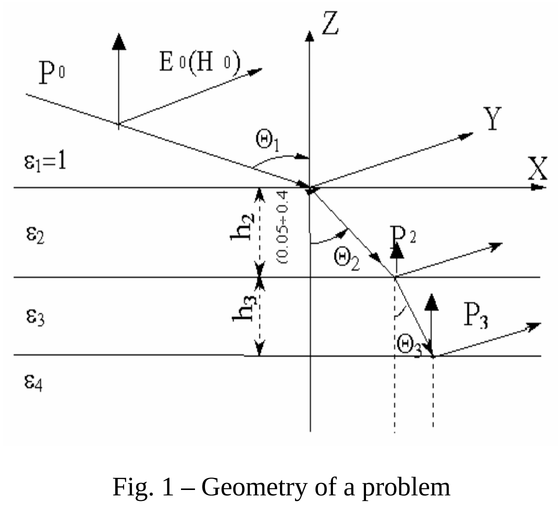

Fig. 1 – Geometry of a problem

Media is usually represented in the kind of the multi-layered system (2, 3, 4). In this case ε^* will be function of coordinate Z, and on borders between layers this function can be explosived. The dependence $\varepsilon^*(Z)$ inside each layer is set by numerical values in some points Z_i. For simplification of calculations we guess that ε^* between points Z_i and Z_{i+1} is constant and similar in X and Y directions on layers. We suppose that the sounding is carried out by UWB signals of vertical and horizontal polarization with conterminous phase centres of radiation and forming an uniform amplitude $A(\omega)$ and phase $\psi(\omega)$ spectrums. The electrical field in a falling signal E_i in a general case can be possible to present in the following kind:

$$E_i(r,t) = E_0 f\left(t - \frac{n_i, r}{c}\right), \tag{1}$$

where n_i is a single vector, determining a direction of distribution of the fall radar signal, but function (f) sets a form of the signal. For decision of the problem the signal (1) is suitable to present as a superposition of falling plane waves:

$$E_i(r,t) = E_{0i} \int_{-\infty}^{\infty} A(\omega) \times \times \exp\left[i\omega\left(t - \frac{(n_i, r)}{c}\right)\right] d\varpi \tag{2}$$

We shall similarly describe a reflected signal:

$$E_f(r,t) = E_{0f} \int_{-\infty}^{\infty} A(\omega) R(\omega) \times \times \exp\left[i\omega\left(t - \frac{(n_f, r)}{c}\right)\right] d\omega, \tag{3}$$

where n_i, n_f are the single vectors, determining a direction of distribution of the falling and reflected signals accordingly; $A(\omega)$ is amplitude-frequency spectrum of the falling signal, $R(\omega)$ is a reflection factor for the appropriate plane waves. At such statement of the problem a spectrum of reflected signal is completely determined by $R(\omega)$. The thickness of layers h_2 h_3 were chosen commensurable with wavelength, appropriate to central frequency of the signal spectrum. It is known [3-6], that the reflection factor R_{1-N} of the plane waves for multi-layered media is determined by the recurrence formula:

$$R_{1,n} = \frac{R_{1,2} + R_{2,n} \exp(-j4\pi h_2 / \lambda\sqrt{\varepsilon_2})}{1 + R_{1,2} R_{2,n} \exp(-j4\pi h_2 / \lambda\sqrt{\varepsilon_2})} \tag{4}$$

where

$$R_{i,i} = 0, \quad R_{i,i+1} = \frac{\sqrt{\varepsilon_{i+1}} - \sqrt{\varepsilon_i}}{\sqrt{\varepsilon_{i+1}} + \sqrt{\varepsilon_i}} \tag{5}$$

$$R_{i,k} = \frac{R_{i,i+1} + R_{i+1,k} \exp(-j4\pi h_{i+1} / \lambda\sqrt{\varepsilon_{i+1}})}{1 + R_{i,i+1} R_{i+1,k} \exp(-j4\pi i h_{i+1} / \lambda\sqrt{\varepsilon_{i+1}})} \tag{6}$$

where $k \neq i, \quad k \neq i+1$.

On formulas (1-6) for different conditions of media the modules and phases of reflecting factor for the plane waves, appropriate to spectral forming of pulsed signal of horizontal $|R_g|$ and vertical $|R_v|$ polarization in a frequency band from 10 up to 2000 MHz for the different corners of falling Θ on sounding media (fig. 1) were calculated. Actually we receive the media transmission amplitude-frequency characteristics (AFC) for signals of vertical and horizontal polarization.

In case of media with one thin layer on surface for the constant thickness of a thin layer ($h_2=0,5$) the various ε^*_2 thin layers and ε^*_3 for spreading media, appropriate to real conditions were chosen. Results of the numerical modelling of the reflection factors for horizontal $|R_g|$ and vertical $|R_v|$ polarizations in the frequency band were used for the finding of the polarization relation for the appropriate spectral component.

Practical realization of the inclined sounding at a small corners is connected with the choice of the inclination corner, at which the differences between vertical and horizontal polarization signals are observed. Analysis of results has shown that when at increase of the inclination corner Θ from 0 up to 10 degrees the nonlinear increase of the relation coefficient $K_{g/v}$ (fig. 2) is observed.

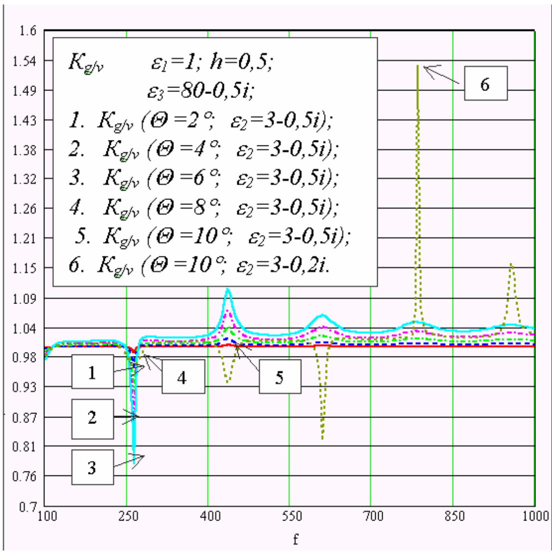

Fig. 2 – Dependence of the relation coefficient Kg/v vs. frequency and corner of wave falling (Θ from 2° up to 10°)

For further studies, a corner of 10 degrees was chosen, allowing to realize in practice a difference of antennas and giving dynamics of change of the relation coefficient $|K_{g/v}|$ sufficient for measurements. Analysis of the formulas (1-6) and diagrams on fig. 2-6 shows that modules of the reflecting factors $|R_v|$, $|R_g|$ and the relation coefficient $K_{g/v}$, as well as the arguments of these factors have periodic character of changing from frequency. Thus, lobes of $K_{g/v}$ on the diagrams are narrower, and top sharper than at $|R_v|$, $|R_g|$ (Fig. 3), that allows to determine value of frequencies in extreme points more exactly. The phase characteristics of reflection factors of R_v, R_g have small differences. Amplitudes of lobes of $|R_v|$, $|R_g|$, $|K_{g/v}|$ graphs, and their arguments depend on the image part (ε''_2) of dielectric permeability ε_2 of thin layers (fig. 5), herewith within the frequency band they are changed at the exponential law (fig. 2-6). However it is true if dependence ε''_2 from frequency is not present. For real media with the frequency dependence ε_2,, the character of changing of the amplitude spectrum envelope will be more complex. On certain frequencies the change of a sign of $K_{g/v}$ (fig. 2, diagram 6) is observed. Thus, the frequency, at which a sign of $K_{g/v}$ is changed, depends on value ε''_2. Before changing a sign of $K_{g/v}$, the exponent was increased, and then its recession is observed.

Change of the real part ε'_2 of the dielectric permeability brings in changing of a period of the lobes $|R_v|$, $|R_g|$ and $|K_{g/v}|$ and their arguments (Fig. 3, 6). In real media, having frequency dependence ε'_2, the non-uniformity in lobes distribution at the frequency band will be observed. The appropriate account of a distance between lobes in a signal spectrum allows to find the frequency dependence of ε'_2. The change of ε'_3 results changing an amplitude of $|K_{g/v}|$ and its sign (fig. 4). The sign of $|K_{g/v}|$ is determined by a condition: ε'_3 more or less ε'_2. The image part ε_3 does not impact to behaviour character of $|K_{g/v}|$.

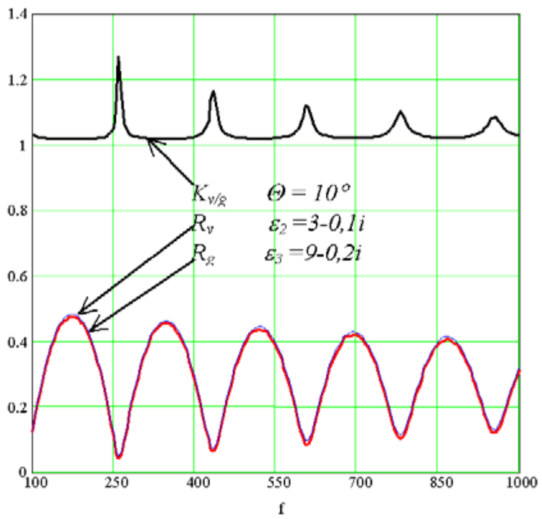

Fig. 3 – Reflection coefficient R_g , R_v , $K_{v/g}$ vs. frequency

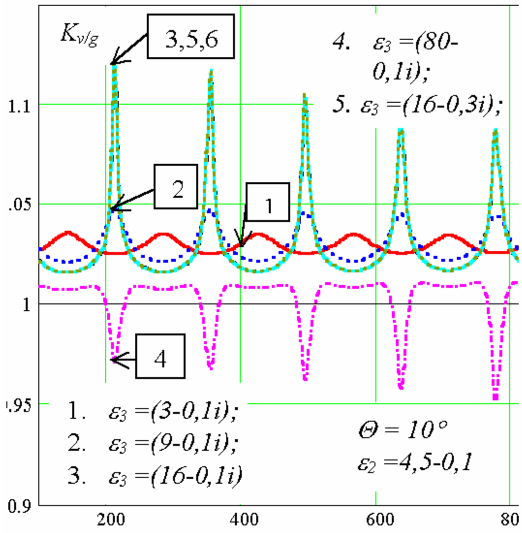

Fig. 4 – The relation coefficient $K_{v/g}$ vs. frequency for different ε_3

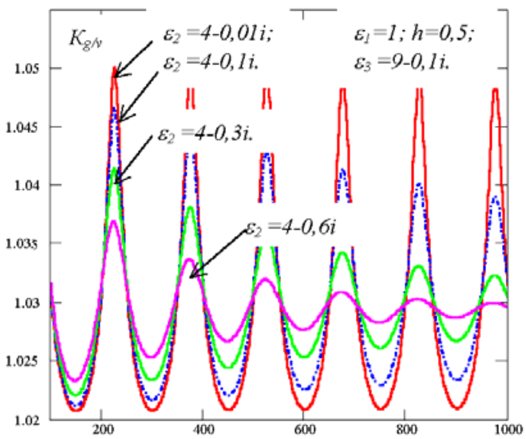

Fig. 5 – The relation coefficient $K_{g/v}$ vs. frequency for different Im(ε_2)

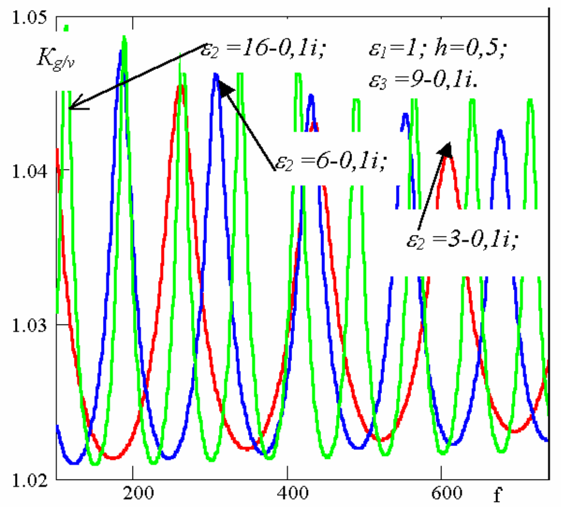

Fig. 6 – The relation coefficient $K_{g/v}$ vs. frequency for different Re(ε_2)

The modern pulse signals have a complex amplitude spectrum. Therefore it is difficult to operate with such spectrum, and information about radiate signal spectrum is required. If the attitude of signals of vertical and horizontal polarization is used, the knowledge of a radiate signal spectrum is not necessary.

Thus, analysis above has shown that for the control and diagnostics of thin layer, being on a surface of a half-infinite media, it is enough to carry out the structural analysis of transmission AFC of media. The use of the media spectral AFC relation for signals of vertical and horizontal polarization allows to exclude of the radiate signal control.

In a case of two thin constructive layers on half-space surface, transmission AFC for media has the more complex kind, and simple analysis does not allow to find a relationship between parameters of thin layers and APC parameters.

3. CONCLUSION

During studying the laws of structure of the UWB signal formation were derived. Functional relationships between parameters of signal and structured elements of layers –thickness of layers and their radiophysical properties are founded. Herewith the joint use of the horizontal and vertical polarization signals gives a certain advantage in accuracy of measurement for some parameters of thin layers.

The studies above have shown a possibility of determination of dielectric and structured properties of the upper layers of ground by inclined radio-sounding at small corners to the account of use UWB pulsed signals of vertical and horizontal polarization. It is shown that use of the spectral part relation of the horizontal and vertical polarization UWB signal (the spectral polarization attitude) allows to considerably increase the accuracy of measurements. A possibility of determination of dielectric and structured parameters of layered media, such as ground-soils, building materials etc has been described, by radio sounding at a small corners of the UWB pulse signals and it polarization processing.

The offered approach enables to create the practical ways for control of the thin layered media by geo radars, including diagnostics of auto roads, flight lines etc. Received results allow to expand fields of practical application for already known methods.

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