A GEO-RADAR INTENDED FOR DETECTION, CONTROL AND DIAGNOSTICS OF SUBSURFACE OBJECTS STATE

S.P. Lukianov, O.V. Stoukatch, V.E. Semenchuk, A.S. Karaush, R.V. Potemin

Tomsk State University of Control Systems and Radioelectronics,
TUCSR, 40 Lenin Avenue, Tomsk, 634050, Russia.
Fax: +7-3822-223262, E-mail: ird@tusur.ru

1. Fundamental scientific problem

The paper addresses to investigations of influence of phase and structural variations of components in non-homogeneous semi-conducting media of complex structure (like rocks, soils, grounds) on propagation of radiated ultra-wideband (UWB) pulse radio-signals and their scattering by inhomogeneities of the media.

During the last years, such new scientific and engineering trend as remote sensing of objects and media with electromagnetic short-pulses has been forming in radioelectronics, geology, building, municipal services, ecology, etc. This diagnostics and control technique is based on analysis of the investigated medium response caused by probing pulse with wide spectrum. The pulse impact leads to exciting all possible eigen-modes of the object or medium that allows to significantly increase information content of the diagnostics. In this connection, engineering systems for diagnostics and control of subsurface media and objects have become qualitatively new class of searching-prospecting multi-purpose equipment. The methods of electromagnetic subsurface diagnostics and control are only possible means (or much more effective ones in comparison with others known methods) for solving such important tasks as detection of dielectric mines, reliable predicting and control of disturbances in the following natural and technogeneous media: rock workings, mines, coal-field sections, landslide structures, ground of building sites, foundations, bridges, tunnels, road and airfield coverings, subsoil waters distribution, spillings of liquid poison and polluting components, underground buryings of poison substances, oil spillings, industrial discharges, etc.

The georadar methods are based on analysis of subsurface medium (object) response caused by UWB electromagnetic radiation. The width of used signals spectra equals to hundreds of MHz (or more), therefore the UWB-signal impact leads to excitation of all possible modes of investigated medium (object). It essentially increases informative ability of radar diagnostics and control of disturbances in natural and technogeneous media.

In the most of practical tasks, the georadar methods are only possible means for reaching the needed purposes, or much more effective ones in comparison with others methods. For example, the known location systems with using the acoustic waves do not allow to detect objects and inhomogeneities of interest, which dimensions are less than a few meters, in loose grounds and alluvial soils. In addition, such acoustic systems require a good contact of radiating and receiving sensors with medium surface.

The paper goal is to improve searching-prospecting performance of georadar systems under detecting objects of interest in different media, and also to manufacture a georadar prototype intended for the use in practice.

The electromagnetic response of sounded media is directly connected with manifestation of such physical effects as reflection, scattering, refraction and attenuation of UWB-radiation, and also with changing of its propagation phase velocity. The characteristics of the electromagnetic response (amplitude, duration and form) of the received UWB-signal result from the united impact of the effects above. Moreover, all mentioned characteristics are considerably influenced by changing in conditions of the signal radiation: instability of performance of transmitting and receiving channels of a georadar, spatial instability of the georadar searching element when scanning over underlying medium, essential spatial variability of the electrical characteristics of the medium being radiated, etc. A large number of unsupervised factors considerably obstructs the reliable detection of the signals caused by objects being prospected. To successfully solve the detection and discrimination problems, one needs to find a set of invariant signatures (parameters) of the signals and determine conditions, in which the signatures (parameters) invariance will be preserved.

Some of the factors limiting the potential of available georadar systems have been studied insufficiently. Such factors are the following:

- influence of the medium electrophysical characteristics on the signal level;
- influence of the transmitting and receiving antenna patterns on accuracy performance of UWB-georadar systems;
- influence of the electrophysical characteristics of different underlying media on parameters used in available algorithms of the signals processing, intended for decision making applied to assignment of the given medium (object) to a certain class by a set of classification signatures.

Therefore at present the investigate mechanisms and regularities which change the electrodynamic parameters of different semiconducting substances under impact of internal and external factors, to simulate and calculate time-

domain changes of the electrodynamic parameters' volume distribution in capillary-porous semiconducting substances (like rocks and grounds) under impact of humidity and temperature, to investigate response of heterogeneous semiconducting media on radiated electromagnetic radiation under phase and structural changes of constituent components are urgent.

2. Present state-of-art

Theoretical and experimental investigations in the field of subsurface radar systems designing, which were carried out in Siberian Physical and Technical Institute (SPTI) and Tomsk University of Control Systems and Radioelectronics (TUSUR) during last years, have shown good prospects of sub-nanosecond radar methods for searching, detection and recognition of small-sized, low-contrast dielectric inhomogeneities in subsurface media.

Results of patent search have shown that we obtain principally new scientific and technical results. The efficiency increasing of the short-pulse radar equipment being designed can be reached due to the use of models which connect spatial-temporal structure of the signals with radiophysical (radiowave) properties of subsurface media, as well as dimensions and spatial location of the objects of interest.

In this connection, advancement of subsurface radar methods for monitoring the natural water media and ground-soils is directly connected with solution of the following tasks:

- development of a model describing spatial-temporal dependencies of the electrodynamic parameters in ground-soils and water media under influence of real external climatic and technogeneous factors;
- development of solution method of direct and inverse electrodynamic problems of UWB-signals propagation in complex natural media.

High information content of the radiophysical methods of investigations has lead to their intensive use for solution of a wide range of fundamental and applied problems. Once an engineering possibility to radiate high-amplitude UWB-signals has been acquired, the radiophysical probing of semi-conducting media has become one of the efficient methods of investigation of natural processes in different media and objects. In this case, the general problem consists not only in a formal solution of the corresponding Maxwell's equations, but as well as in the determination of macroscopic properties of a medium, which are characterized by parameters in the main electrodynamic equations. In turn, the medium properties are significantly influenced by a set of different factors, including the impact of the radiated UWB-signal itself.

The most strong changes of the electrodynamic characteristics of non-homogeneous, semi-conducting media with a complex composition are observed when components with high electrical conductance suffer phase or structural transformations caused by influence either of the factors. For example, the permittivity change of free water in ground-soils and some biological objects at low-temperature impact reaches 20 times. The similar situation is observed when free water is linked by a chemical admixture or vaporized under action of high temperature. Practically in all cases above, the structural transformations have nonstationary nature. It leads to necessity to know spatial-temporal distribution of the medium's electrodynamic characteristics.

At present, there is not reliable data concerning behaviour of electrodynamic characteristics of non-homogeneous, semi-conducting media (in which liquid component with high electrical conductance suffers phase conversions) in wide frequency range of electromagnetic waves. Moreover, even in microwave band properties of linked water in ground-soils have been studied insufficiently. The medium models, which are often used in problems of radiophysical sensing of the terrestrial covers, have phenomenological descriptive nature and give results with acceptable accuracy only under uniform moisturising. One of the effective analysis methods of macroscopic features of complex composition mixtures, suffering the phase conversions of components, is a mathematical theory of flowing.

The reasons of that the fundamental properties of such media were investigated insufficiently can be explained by the absence of comprehensive studies with using the radiophysical, electrophysical, thermophysical and hydrodynamic methods of the analysis. This approach was used earlier and has shown a high efficiency.

3. Development background

During the last years, the authors has accumulated a large experience connected with investigations of electrophysical characteristics of multi-component semi-conducting materials in the wide frequency range of electromagnetic radiation - from near zero up to 10 GHz. For the first time, methods of the flowing theory were used for description of concentration and temperature dependencies of dielectric parameters and conductance. It was also proved the appropriateness of their use for a wide class of capillary-porous materials. In the framework of the stuff activities, modern algorithms for solution of electrodynamic and heat-humidity problems have been applied for the problems connected with the electrophysical and structural parameters of semi-conducting materials.

To date, sufficient theoretical and practical experience for designing both individual functional units, and transmitting-receiving devices of georadar systems has been accumulated. Principles of designing antennas, videopulse generators were studied, receiving and

processing designs of reflected signals were approved. Preliminary investigations of the microwave power limiters were carried out. Alternates of logarithmic amplifiers and digital processing units were designed and manufactured.

An exploratory prototype of the georadar system including dual-channel antenna, dual-channel stroboscopic receiver, synchronizer and microprocessor unit for data processing has been designed. The microprocessor unit ensures the control and diagnostics, the synchronization of the receiver and transmitter modes, data acquisition, pre-processing and storage, the data transferring with the use of sequential communication channel. The most of units are original ones.

Unique measuring installations and techniques for experimental investigations of the electrodynamic characteristics of semi-conducting materials under impact of temperature fields in the wide frequency range were created. A large volume of the investigations results concerning the electrodynamic characteristics of ground-soils, building materials and products, biological objects has been accumulated.

There is a significant theoretical and practical margin regarding the UWB subsurface radar systems.

The developed package of the problem-oriented programs includes investigations data of the electrodynamic characteristics of natural and technogeneous media and their components in the wide frequency range of electromagnetic radiations (from near zero up to 10 GHz).

To describe the concentration and temperature dependencies of the dielectric parameters and conductance, the methods of the flowing theory are used. The modern algorithms for solution of electrodynamic and heat-humidity problems regarding the electrophysical and structural parameters of semi-conducting materials, which form the subsurface media and objects of control, are used.

4. Expected results of the investigations

The further investigations direction will be connected with complex (experimental and theoretical) studies of the influence which is rendered by the permittivity and conductivity of such complex composition and structure media as mountain rocks, grounds and soils, building materials, on the characteristics of geo-radar system as an engineering tool for prospecting subsurface objects and media of interest.

It is expected that the developed algorithms of data processing will ensure a high efficiency of subsurface objects (which are embedded in dielectric and semi-conducting media) prospecting by the geo-radar as at detection and discrimination stages. The system being developed for diagnostics and control of subsurface media will allow to improve the efficiency of spatial-temporal resolution, detection and identification (due to increasing the informative ability) of small-sized and low-conrast objects (with dimensions of order 7-30 cm) at several (2-5 m) meters depth under surface.

The geo-radar system developed to date has a special purpose. Now it is planned to develop a geo-radar intended for detection, identification and recognition of subsurface natural and man-made objects with enhanced image quality. The efficiency increase of the system being developed in comparison with the known analogues is achieved by using the models connecting the spatial-temporal structure of the ultrawideband (UWB) signals with radiophysical properties of subsurface medium and objects, namely their dimensions and spatial location. Advancement of such approach will allow to use the subsurface radar methods as for well-known practical tasks (measuring the thickness, state and properties of extended objects in different media), and for a wide class of new problems connected with detection and identification of objects (including small-sized and low-contrast ones) in different dielectric media. The UWB-signals processing algorithms in geo-radar systems, which are based on the invariance of their informative signatures, will allow to detect and discriminate low-contrast subsurface objects in real-time.