RECONSTRUCTION OF THE ROADWAY COVERAGE PARAMETERS FROM RADAR SUBSURFACE PROBING DATA

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This work is focused on the development of approach to the inverse problem of subsurface radar sounding solution in frequency domain. The genetic algorithm is used for search of global minimum of aim functional.

To improve accuracy of parameters reconstruction with the use of genetic algorithm it is necessary correctly to choose the values of arguments for aim function and parameters of genetic algorithm. We propose value of threshold in aim functional was set with the use of middle power of spectral constituents, used for the calculation of aim functional. Conditions are certain numeral calculations for the automatic calculation of threshold value

Reconstruction of parameters for model roadway coverage is executed with the use of different of selection methods of genetic algorithm. Statistical estimations of the reconstruction of parameters under various conditions are received.

Keywords: *radar, radar monitoring, inverse problem, genetic algorithm, reconstruction of parameters*

1. Introduction

Radar subsurface probing is widely used for performing of scientific and practical researches at present. It allows to find out the hidden objects as well as to determine their geometrical and physical characteristics. In spite of substantial achievements in research and development of the radar probing methods, some problems exist in an improving of quantitive interpretation of radar probing data.

The interpretation of radar measurements in form estimation of electrical and physical properties of the explored object is an inverse problem of radar probing, which is in general ill-posed. When a problem is ill-posed, attempt should made to regularize the problem.

For radar monitoring of roadway coverage the regularization is possible when appropriate model of the explored object as well as a priori information about geometry and range of electrical properties changing for partial layers are used [1]. The electromagnetic model of roadway coverage may be conceived as homogeneous horizontal layers of h_2 and h_3 thickness between medium 1 (air) and medium 4 with thickness $h_1, h_4 \to \infty$, as it is shown in [3].

Electrical properties of each model medium be described by relative dielectric constants ε_i and conductivity σ_i (for upper medium ε_1=1 and σ_1=0). For formalization of inverse problem vector of parameters $\vec{P} = \{p_1, p_2, ..., p_n\}$ was entered, which component p_i determines a great number of legitimate values of parameters for model vector $\vec{P}_{mod} \subseteq \vec{P}_{lim}$.

The model -based approach for radar monitoring data inversion of roadway coverage is presented in Fig.1.

The approach utilizes comparison of direct problem solutions for a roadway coverage two-layer model with the measured data in frequency domain in a range where inverse problem has a single stable solution [3].

Results of the reflected signal spectrum calculations compare with these for model signal spectrum, which is calculated for all search range of data on electrical properties of probing object. The end of the calculations will be when meetings the condition:

$$A = \sum_{i=1}^{L} \left(\left| \dot{S}_{refl}\left(\omega_i, \vec{P}\right) \right| - \left| \dot{S}_{mod}\left(\omega_i, \vec{P}_{mod}\right) \right| \right)^2 < \alpha , \qquad (1)$$

where: $\left| \dot{S}_{refl}\left(\omega_i, \vec{P}\right) \right|$ – a module of the reflected signal spectral density for estimated vector $\vec{P}$;

$\left| \dot{S}_{mod}\left(\omega_i, \vec{P}_{mod}\right) \right|$ – a module of the model signal spectral density for model vector;

α – value of threshold, which is limited by a permissible absolute error of the parameter estimations.

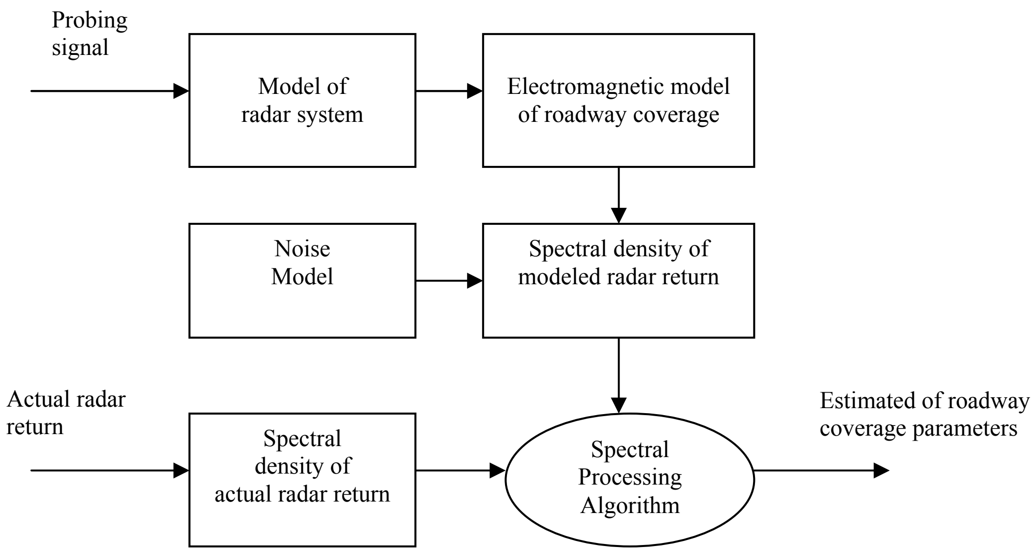

Fig. 1. The model -based approach for radar monitoring data inversion

Simplified flow diagram of calculation procedure for this case is shown in Fig.2.

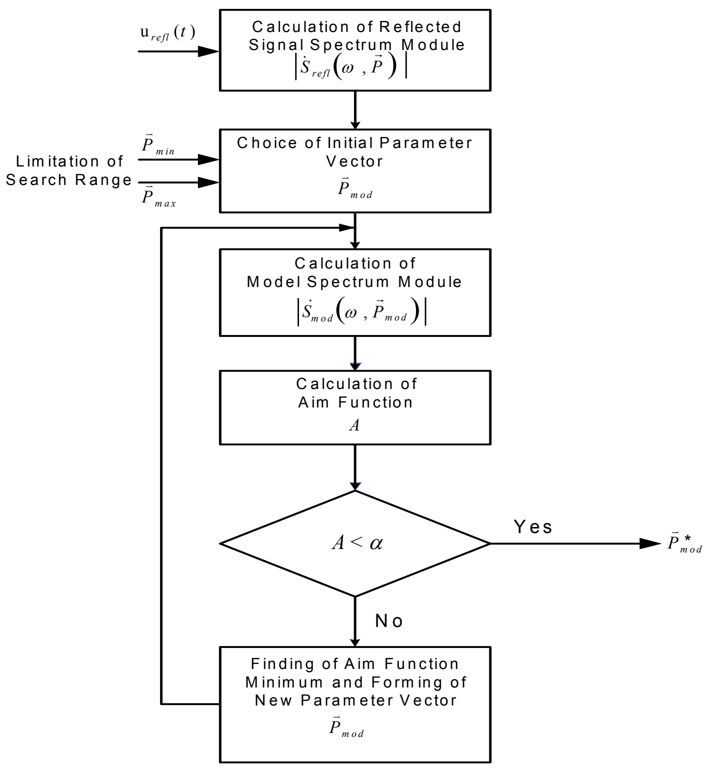

Fig. 2. Simplified flow diagram of procedure to solve radar inverse problem in the frequency-domain

Electrical properties of medium of roadway coverage (ε_i and σ_i) can be expected with the use of models, in which influence of physical and chemical parameters of medium is taken into account on these electrical properties [3]. The reflected signal forming channel model is offered in [3] also. The basic element of this model is the antennas system which executed as two identical linear vibrators are located near-by the border of mediums.

The inverse problem is investigated numerically [1, 3], using simulation of reflected signal forming channel model for shock exitation of transmitting antenna.

Genetic algorithm was used for search of global minimum of aim functional A. The results of investigations show that the considered algorithm of inverse structural problem is available for practical application. However, one can increase accuracy of reconstruction of parameters of road coverage using the genetic algorithm only by a correct choice of values of arguments of the aim functional A and of the parameters of the genetic algorithm.

2. The Features of Solving of the Inverse Problem Using the Genetic Algorithm

As it is known from technical literature [4], one from three conditions is necessary for completing the data processing by genetic algorithm. These are:

- Appropriate quality of solution is received (for radar subsurface inspection of road covers it means that parameters of object are estimated with an enough accuracy);
- Local extremity was found but algorithm can't come out from this state;
- Maximal number of population into generation is formed but appropriate quality of solution is not received.

In expression (1) one can see that the aim function A depends on a great number of its arguments in a complicated way. These arguments are as follows:

- vector of model parameters $\vec{P}_{\text{mod}}$;
- the number of the spectral components L used for calculation of the aim functional;
- the frequency range containing these spectral components; values of parameters for model vector;
- the range of changing of parameters for model vector $\vec{P}_{\text{lim}}$.

Along with a global minimum aim functional A has a great number of local minimums.

The genetic algorithms use the aim function for estimating the quality of the optimization problem solution. Therefore, value of threshold α has a substantial influence on inverse problem solution at the use of genetic algorithm. Use of an eventual value of threshold α does not allow to reconstruct the electrophysical parameters of roadway coverage with enough accuracy. Diminishing of threshold α increases time of decision of inverse problem substantially[3].

From expression (1) it is evidently, that threshold α is a power parameter. Because value of threshold α may be calculated with the use of mean power of spectral constituents of $\left|\dot{S}_{\text{mod}}\left(\omega_i, \vec{P}_{\text{mod}}\right)\right|$, used for the calculation of aim functional A:

$$P_{\text{m}} = \frac{1}{L}\sum_{i=1}^{L}\left|\dot{S}_{\text{mod}}\left(\omega_i, \vec{P}_{\text{mod}}\right)\right|^2 , \tag{2}$$

but it is possible to expect threshold α as follows:

$$\alpha = \frac{P_{\text{m}}}{k} , \tag{3}$$

where k is a dimensionless coefficient.

Using such approach for calculating α , one gets condition (1) like this:

$$A = \frac{1}{L}\sum_{i=1}^{L}\left\|\dot{S}_{\text{refl}}\left(\omega_i, \vec{P}\ \right)\right| - \left|\dot{S}_{\text{mod}}\left(\omega_i, \vec{P}_{\text{mod}}\right)\right\|^2 < \frac{P_{\text{m}}}{k} . \tag{4}$$

Condition (4) makes choice of the threshold value of the decision making easier, because the preliminary analysis of the values of the aim functional A is not necessary. Nevertheless, the value of k must be chosen so that the specified accuracy of reconstruction of parameters of roadway coverage is taken into account.

3. Results of Reconstruction of Parameters of Roadway Coverage

We have investigated inverse problem numerically, using model of roadway coverage, as it shown in [3].

Fixed values of parameters $\vec{P}_{\text{mod}}$, which are presented in Table 1, were chosen for electromagnetic model of the roadway coverage.

Table 1. The values of parameters for model vector

Number of medium	Parameters of medium		
	ε'	σ	h,m
2	2.6	0.0015	0.3
3	7.0	0.001	0.4
4	15.0	0.05	∞

The module of the model reflected signal spectral density $\left|\dot{S}_{\text{mod}}\left(\omega_i, \vec{P}_{\text{mod}}\right)\right|$, which was received with help parameters presented in Table 1, is shown on Fig. 3. This spectrum was used as a model spectrum in expression (1) at investigation of inverse problem. The model reflected signal is shown in a Fig. 4.

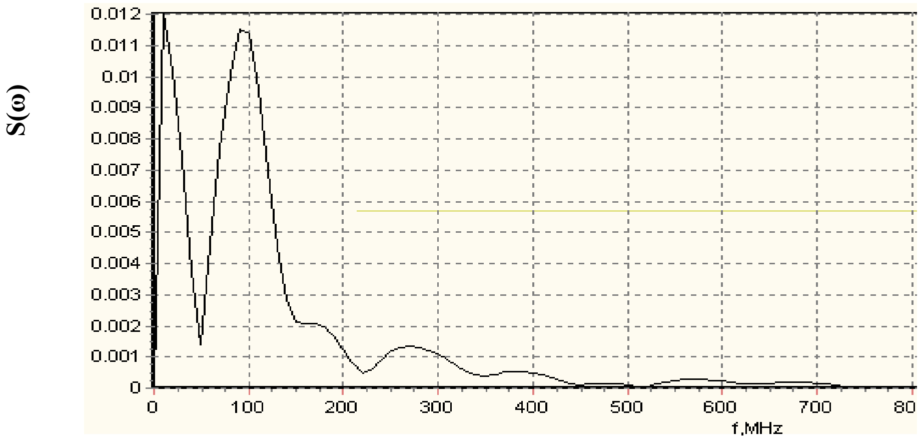

Fig. 3. Model spectrum of reflected signal on output of receiving antenna

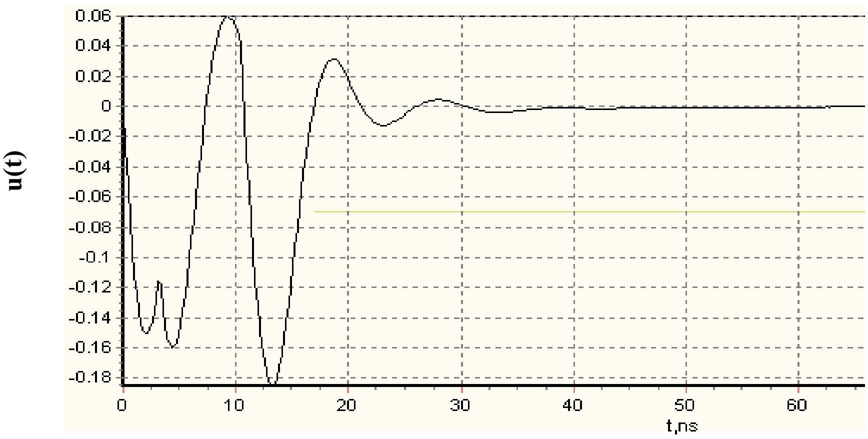

Fig. 4. Model reflected signal on output of receiving antenna

For searching the global minimum of aim functional A genetic algorithm was used with the following characteristics:

- Maximal number of generations 50;
- Coding alphabet of an estimated parameters.....................binary;
- Number of bit per parameter 6;
- Probability of crossingover 0,9;
- Probability of mutation...0,05;
- Method of selection..roulette;
- Admitted number of population into generation for the aim functional means improving............................500.

We investigated influencing of some factors on accuracy of reconstruction of the model parameters, but maximal frequency of analysis $F_{\max}$ was chosen equally 500 MHz, that L was equal 50. The error of reconstruction of model parameter was determined as relative mean quadratic deviation of the recovered values of model parameter. 100 recovered values were used for this purpose

The influence coefficient k ***and search range d.*** Joint influence of these two parameters on the relative error of reconstruction of model parameters was explored. The followings values were set to k: 10, 20 and 50. The parameters of the first layer (ε'_2, σ_2 and h_2) were chosen as the explored parameters. The got dependences are shown in Fig. 5–7.

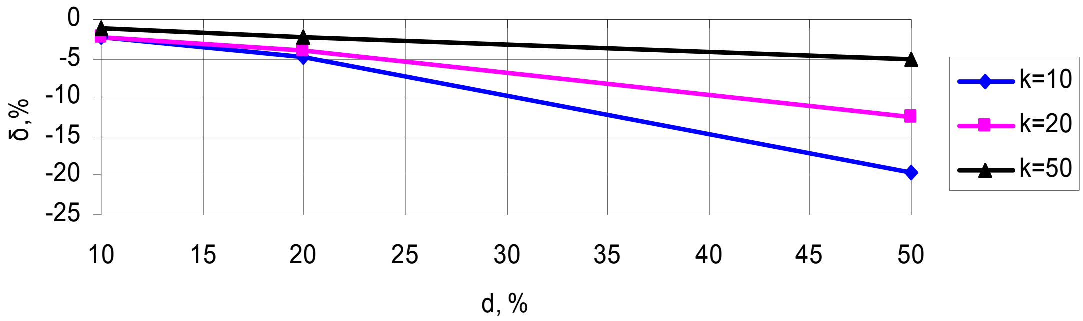

Fig. 5. Joint influence of coefficient k and search range d on the relative error of reconstruction of ε'_2

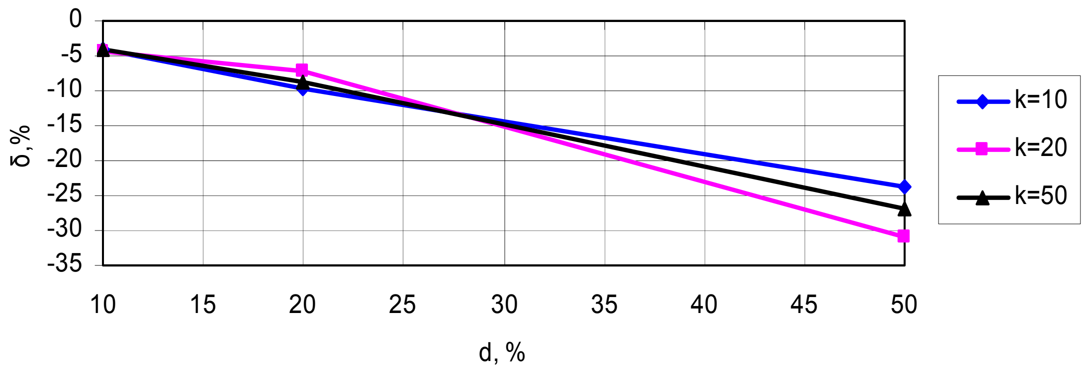

Fig. 6. Joint influence of coefficient k and search range d on the relative error of reconstruction of σ_2

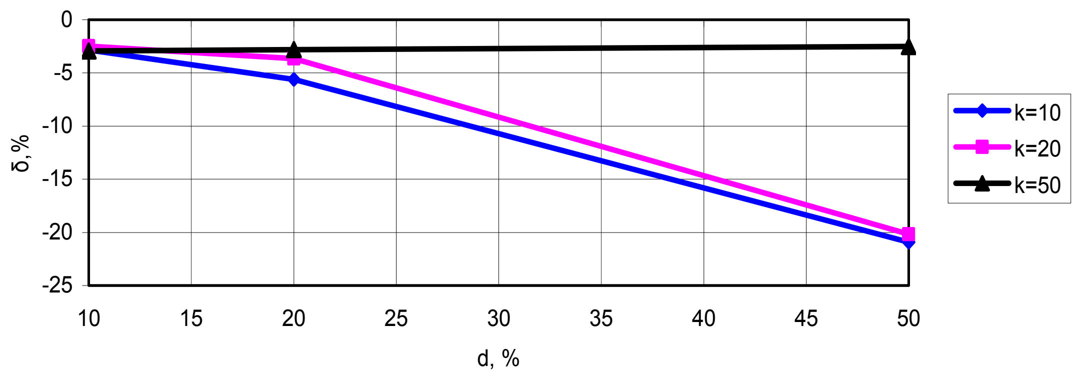

Fig. 7. Joint influence of coefficient k and search range d on the relative error of reconstruction of h_2

Dependences show that the relative range of search of model parameters *d* influences on the value of relative error of reconstruction of parameters more. Multiplying a coefficient k is gives by a considerable diminishing of error of reconstruction of ε'_2 and h_2 at the large values of *d*. It is possible to draw a conclusion that choice of *k* value depends on quality of a priori information.

Reconstruction of parameters of model roadway coverage in the presence of noise. Aggregate of factors, causing the errors of reconstruction of parameters of the probed object, it is possible to examine as additive noise, operating in the output of receiver. In our investigations for the modeling of additive noise the model of white noise was used. The relation of energies of the reflected signal and noise (S/N) was set for the frequency range ($0\ldots F_{\max}$) in all experiments.

The reflected model signal without noise and reflected model signal with noise at S/N=10 are shown in Fig. 8, and the spectrum modules of these signals are shown in Fig. 9, for example.

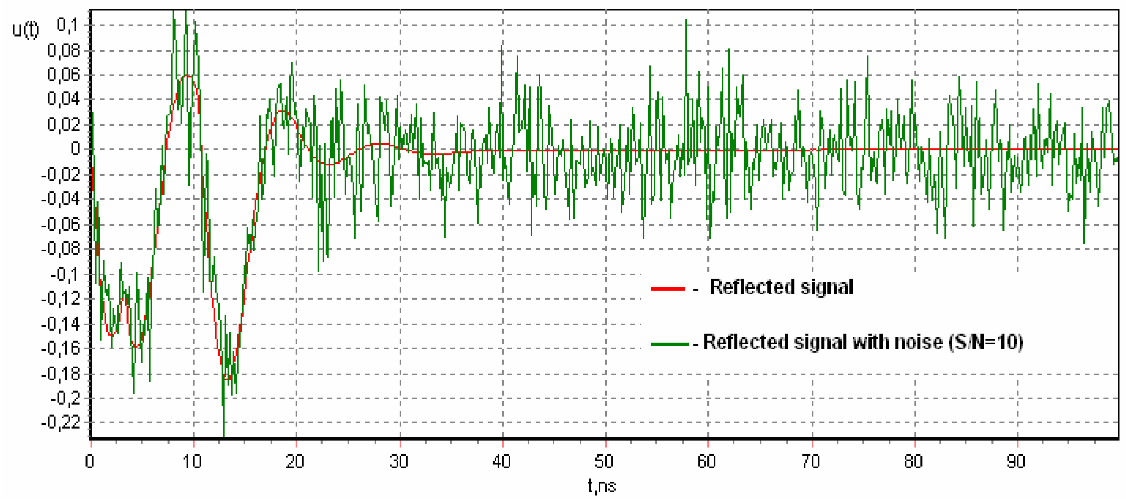

Fig. 8. Model reflected signals with and without noise

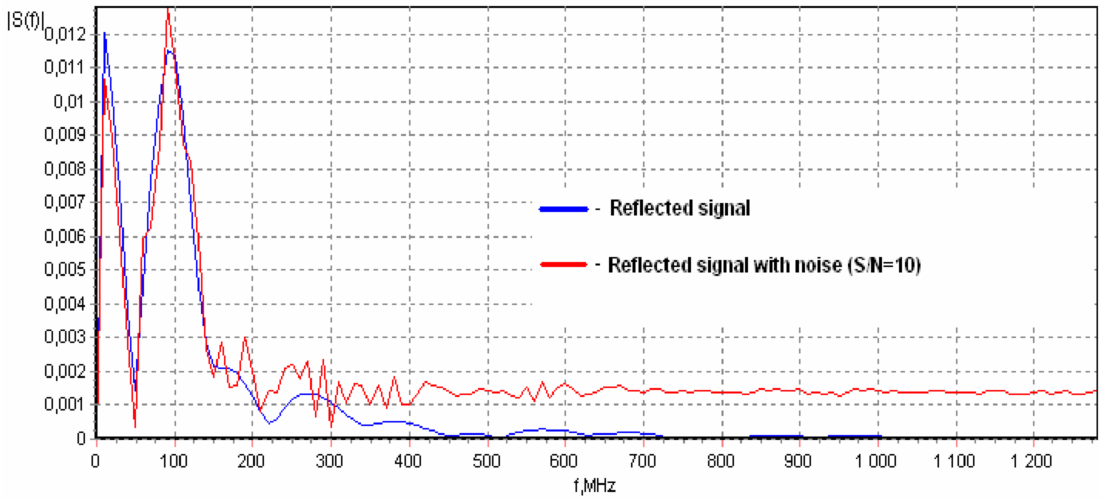

Fig. 9. Spectrums of model reflected signals with and without noise

The spectrum of the reflected signal with noise was used in expression (1) for the solution of inverse problem as $\left|\dot{S}_{\mathrm{ref}}\left(\omega_i, \bar{P}\right)\right|$.R reconstructed parameters at the use of spectrum of the reflected signal with noise, presented in Fig. 9, at k=10 and d=10% were used for reconstruction (calculation) of the reflected signal and it's spectrum. The spectrum module of reflected signal without noise and module of the recovered spectrum are presented in Fig. 10, and signals, proper them, are shown in Fig. 11.

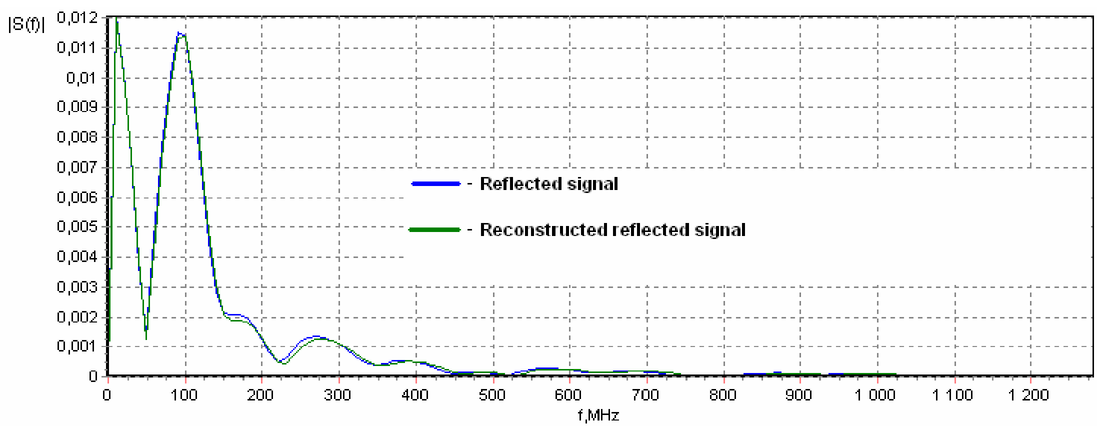

Fig. 10. Spectrums of model reflected signal and reconstructed reflected signal

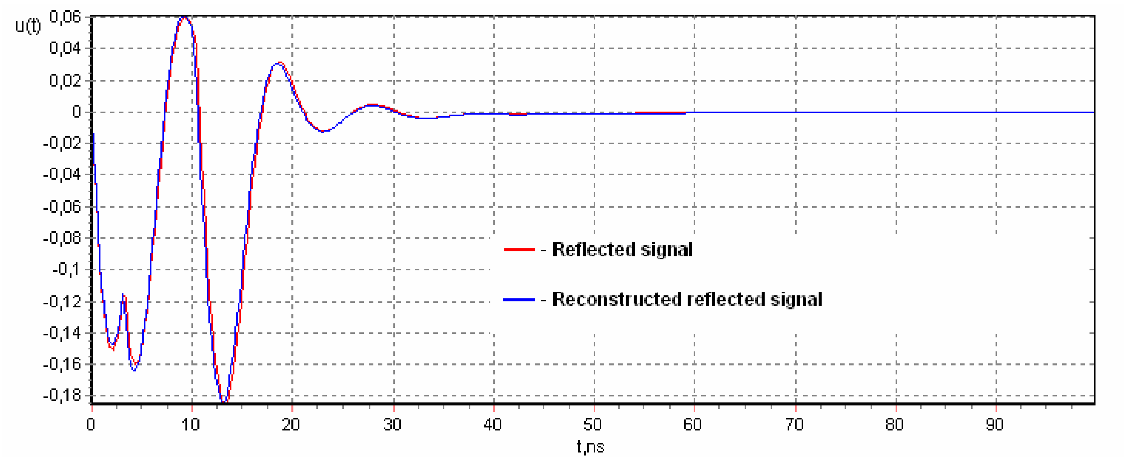

Fig. 11. Model reflected signal and reconstructed reflected signal

Dependences of relative errors of reconstruction of ε'$_2$, σ_2 и h_2 on relation signal/noise (S/N) for k=10 and k=50, at the search range d=50% are shown in a Fig. 12–14.

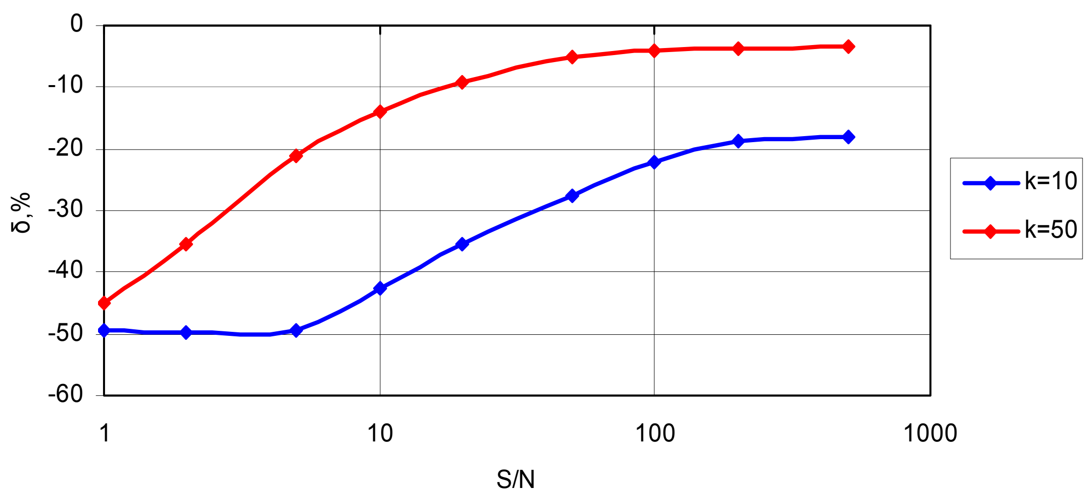

Fig. 12. Influencing of relation signal/noise on the relative error of reconstruction ε'$_2$

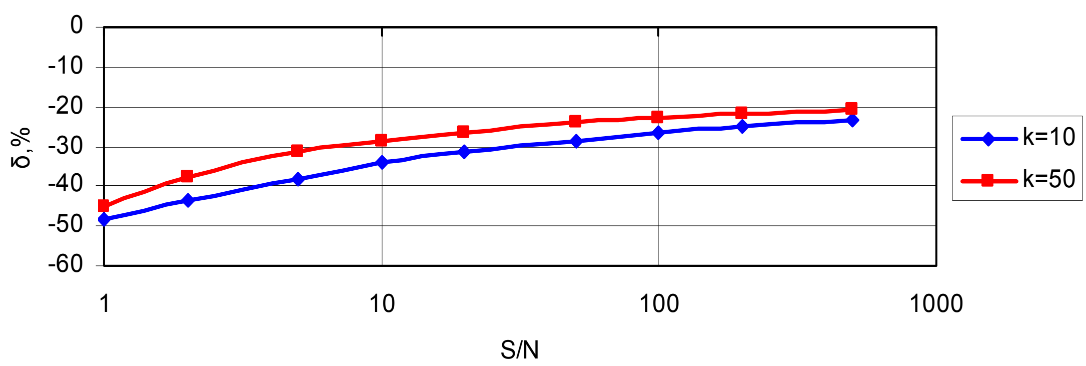

Fig. 13. Influencing of relation signal/noise on the relative error of reconstruction σ_2

Evidently, that there are large values of relative errors of reconstruction of parameters at small relations signal/noise. At a relation signal/noise more than 20 the relative errors of reconstruction of parameters approach values which were got at reconstruction of parameters in default of noise and at the same terms of reconstruction of parameters. At an increase of k the relative errors of reconstruction of parameters of ε'_2 and h_2 diminish substantially. This effect is observed and at reconstruction of parameters in default of noise.

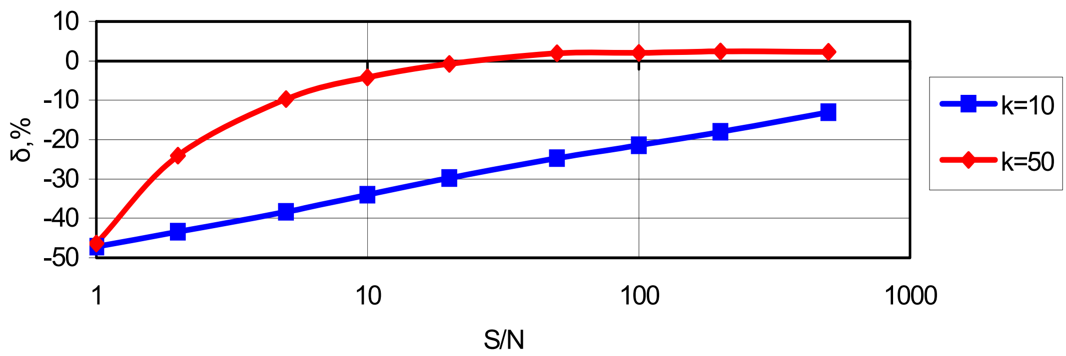

Fig. 14. Influencing of relation signal/noise on the relative error of reconstruction h_2

Influencing of selection method. All above-mentioned results were obtained at the use of one selection method of genetic algorithm - method of roulette. However at the use of this selection method the relative errors of reconstruction of parameters can achieve a few tens of percent. Therefore for reconstruction of parameters two selection methods were used additionally: tournament method and method of « roulette+ tournament ».In this experiment the errors of reconstruction of parameters of the first layer (ε'_2, σ_2 и h_2) of model roadway coverage (Fig. 1) were obtained for 3 selection methods at identical terms, listed above.

At the small search range of model parameters (d=10%) and large coefficient k (k=50) for every parameter the relative error of reconstruction does not exceed a few percent and does not depend on the selection method (Fig.15).

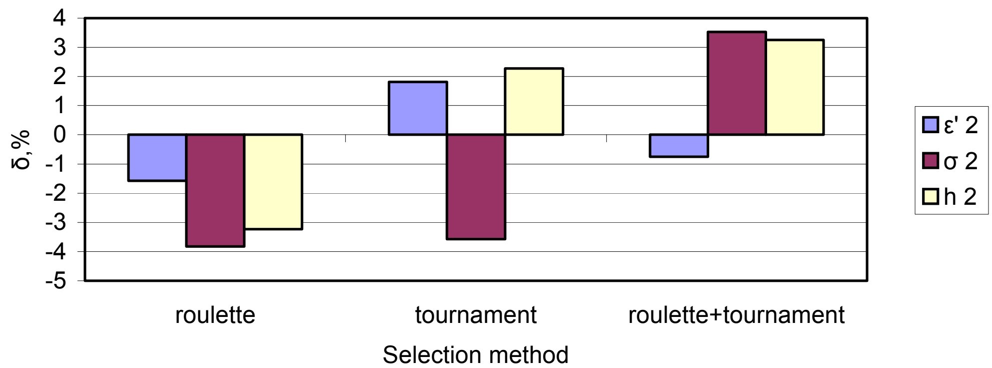

Fig. 15. Dependences of relative errors of reconstruction of first layer parameters on the selection method (k=50, d=10%)

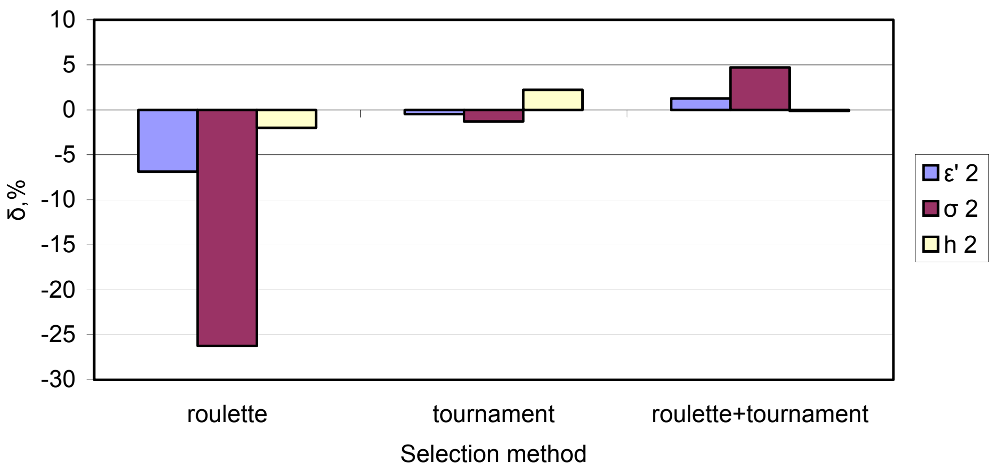

Fig. 16. Dependences of relative errors of reconstruction of first layer parameters on the selection method (k=50, d=50%)

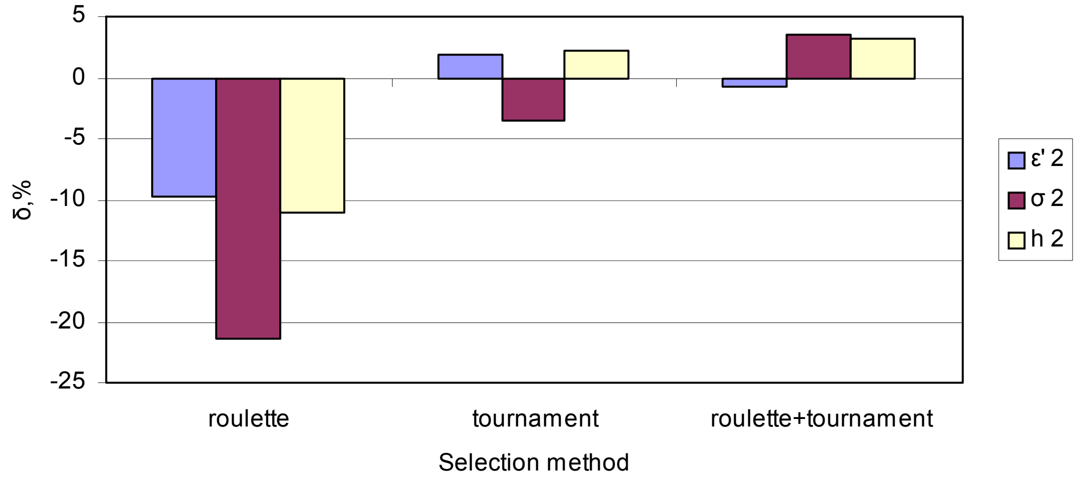

Fig. 17. Dependences of relative errors of reconstruction of first layer parameters on the selection method (k=10, d=50%)

At the large search range of model parameters (d=50%) advantage of tournament method and method of «roulette + tournament» is visible (Fig.16-17). Value of coefficient *k* does not influence the results of reconstruction of parameters at the use of these selection methods. It is necessary to mark that relative error of reconstruction of h_2 is less than 1% at the use of method of « roulette+ tournament », k=50 and d=50%.

Conclusions

The main results of these experiments are following:

- the value of threshold α can be automatically expected, defining energy of spectral constituents, used for the inverse problem solution;
- finding of mean value of results of reconstructed electrophysical parameters of roadway coverage at the set value of threshold α diminishes the error of reconstruction of parameter once or twice;
- the choice of spectral constituents, determining basic energy of the reflected signal, for the calculation of aim functional A, allows to decrease influence of noise on the error of reconstruction of parameters of the sounded object;
- the amount of population into generation practically does not influence on the error of reconstruction of parameters of roadway coverage;
- The use of tournament selection method allows to promote accuracy of reconstruction of electrophysical parameters of roadway coverage.

References

1. Krainyukov, A., Kutev, V. Intelligent system for radar monitoring of transport communications. In: *Proceedings of the 7th International Conference "Reliability and Statistics in Transportation and Communication (RelStat'07), 25–27 October 2007, Riga, Latvia"*, Transport and Telecommunication Institute, 2007, pp. 312-320.
2. Krainyukov, A., Kutev, V. Simulation of Reflected Signal Track Formation in Subsurface Radar Probing Problems. *RAU Transactions*. Riga: RAU, 1995, pp.17-23. (In Russian)
3. Krainyukov, A., Kutev, V. Model-based results of inverse problem solution for radar monitoring of roadway coverage. In: *Proceedings of the International Conference „Modelling of business, industrial and transport systems", 07–10 May 2008, Riga, Latvia"*, Transport and Telecommunication Institute, 2008, pp. 169-176.
4. Gladkov, L.A., Kureichik, V.V., Kureichik, V.M. *Genetic Algorithms*. / Edited by Kureichik, V.M., 2nd ed. Moscow: FIZMAZIT, 2006. 320 p. (In Russian)