Use of Genetic Algorithm and Evolution Strategy when Revealing the Worst Case Effects of Crosstalk Propagation in PCB Bus of Spacecraft Autonomous Navigation System

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Abstract – **Importance of the genetic algorithm (GA) and evolution strategy (ES) usage in the investigation of an ultrashort pulse peak voltage in a printed circuit board (PCB) bus of autonomous navigation system (ANS) is highlighted. Trapezoidal ultrashort pulse propagation along the conductors of the PCB bus was optimized. The optimization was made by maximization criteria of maximum crosstalk amplitude at the preset point. The two methods were used for the optimization, which results are compared. The ES optimization was run 20 times when the initial solution was 300 ps. The GA optimization was run 10 times with the parameters: the number of chromosomes – 5, 10; the number of populations – 5, 7, 10, 15; mutation coefficient – 0.1; crossover coefficient – 0.5. After the ES and GA optimizations the crosstalk maximums of 32% and 78% of steady state level in the active conductors respectively were revealed and localized.**

Index Terms – **optimization, genetic algorithm, evolution strategy, ultrashort pulse, printed circuit board, peak voltage.**

I. INTRODUCTION

INCREASING complexity of developed devices and appearing in them processes make the mathematical simulation increasingly important. It happens due to the fact, that full-scale modeling often becomes too expensive. Radioelectronic equipment which is very popular in our life demands accurate simulation.

It is necessary to consider the all possible useful and interference signals for complex printed circuit boards (PCBs) investigation. The bus investigation with a variation of ultrashort pulse duration is important for radioelectronic equipment performance and interference immunity increasing. In practice a duration of useful signals and interfering signals is decreased. Such electric signal propagation in multiconductor transmission lines (MCTL) is properly studied [1]. However, particular aspects of the ultrashort pulses propagation along conductors of high-density PCB are investigated insufficiently. It can be the reason of its uncontrolled propagation [2]. The signal peak values localization in MCTL and in autonomous navigation system (ANS) PCB is investigated in [3, 4]. Also, the problem of ultrashort pulse duration influence on the localization of its peak values is investigated in [5, 6]. This problem is investigated with use of genetic algorithms (GA) optimization in [7, 8]. However, despite its popular usage in various scientific spheres, other optimization methods are used too [9]. Therefore it is useful to consider, how the problem of the signal peak values revealing and localization in ANS PCB bus can be solved by a different optimization method, for example, an evolution strategy (ES).

The purpose of this paper is to investigate use of ES when revealing the worst case effects of the crosstalk propagation in PCB bus of spacecraft ANS and compare its results with the GA results.

II. THEORY

The theoretical bases and algorithms of quasistatic response calculation along each conductor of each MCTL section are given in [10, 11] and are omitted here.

A. Structure under Investigation

The ANS PCB bus investigated in [5–8] was taken as a structure under investigation. The PCB fragment is shown in Fig. 1 and its circuit diagram is in Fig. 2. Resistances of 50 Ω are assumed at the ends of each conductor.

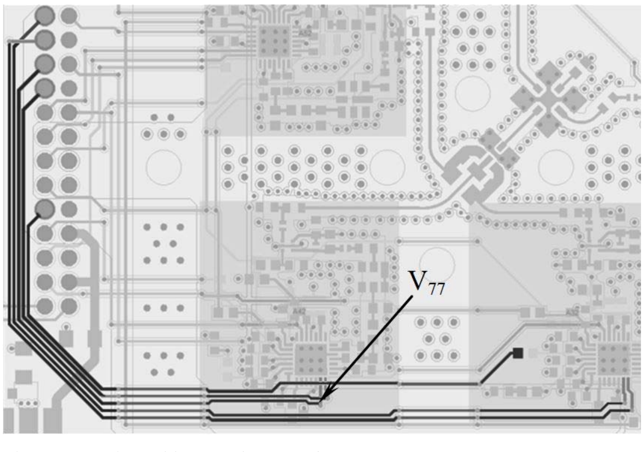


Fig. 1. Investigated bus on the PCB fragment

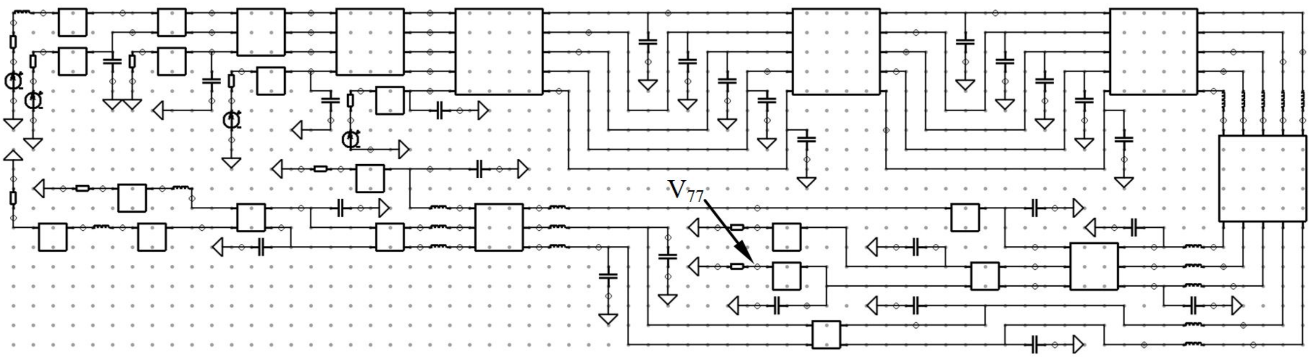


Fig. 2. ANS PCB bus circuit diagram in TALGAT software

Conductor bend and via are approximately modeled as a parallel capacitance of 1 pF and series inductance of 1 nH, respectively. Cross sections of each MCTL section are modeled and **L** and **C** matrixes are calculated according to PCB stack parameters. The calculation is made without losses.

B. Optimization Algorithms and Its Parameters

A trapezoidal ultrashort pulse with electromotive force amplitude of 1 V and with the variation of its duration was chosen as excitation. During the investigation, the whole ultrashort pulse duration was optimized in range from 3 down to 0.03 ns. Such choice of excitation parameters is determined by the fact that in such way not only useful signals but interference are considered.

The two optimization algorithms (GA and ES) were used in the investigation.

The ES algorithm in general view can be formulated as [12]:

1. The initialization of a population $\mathbf{P}_\mu = \{\mathbf{a}_1, \ldots, \mathbf{a}_\mu\}$ with usage of $\boldsymbol{\mu}$ parent chromosomes.

2. The generation of $\boldsymbol{\lambda}$ offspring $\hat{\mathbf{a}}$ forming the offspring population $\hat{\mathbf{P}}_\lambda = \{\hat{\mathbf{a}}_1, \ldots, \hat{\mathbf{a}}_\lambda\}$ where each offspring $\hat{\mathbf{a}}$ is generated by:

- Selecting (randomly) $\boldsymbol{\rho}$ parents from $\mathbf{P}_\mu$ (if $\boldsymbol{\rho}=\boldsymbol{\mu}$ take all parental individuals instead).

- Recombining the $\boldsymbol{\rho}$ selected parents to form a recombinant individual **r**.

- Mutating the strategy parameter set *s* of the recombinant **r**.

- Mutating the objective parameter set **y** of the recombinant **r** using the mutated strategy parameter set to control the statistical properties of the object parameter mutation.

3. Selection of new parent population (using deterministic truncation selection) from either the offspring population $\hat{\mathbf{P}}_\lambda$ (this is referred to as comma-selection, usually denoted as "(μ,λ)-selection"), or the offspring $\hat{\mathbf{P}}_\lambda$ and parent $\mathbf{P}_\mu$ population (this is referred to as plus-selection, usually denoted as "(μ+λ)-selection").

4. Go to 2 until termination criterion fulfilled.

The barecmaes2.py module [13] was used with TALGAT software [14] for optimization implementation. The sigma of the ES algorithm was 10 ps. The ES was run 20 times when the initial solution of the strategy was 300 ps.

The binary-coded GA was run with the following parameters: mutation coefficient – 0.1 and crossover coefficient – 0.5. The number of chromosomes was 5, and 10, and the number of populations was 5, 7, 10, and 15.

The whole ultrashort pulse duration was optimized in order to get the highest crosstalk amplitude in V_{77} node (shown in Fig. 1 and 2). This node is supposed to be a critical in the bus, when other conductors are active. The aim of the optimization was to get such parameters of the whole ultrashort pulse duration with which the crosstalk amplitude in V_{77} node will be the highest.

Four conductors were under the excitation as it shown in the circuit diagram, and the central one was passive.

III. SIMULATION RESULTS

The results of ES runs are shown in Table I, where N_R is a number of a run, and N is a number of a fitness function calculations.

The GA operation results ($U_{\max}$ – the maximum crosstalk voltage amplitude at V_{77} node) with the different runs and the numbers of the fitness function calculations are presented in Table II. The number of the fitness function calculations (in case with GA) is defined by the multiplication of a number of chromosomes and the number of populations. The GA was run 10 times for each combination of the chromosomes number and the population number. It was made in order to check the convergence of the fitness function results.

The $U_{\max}$ values in dependence on N_R of ES are shown in Fig. 3. The $U_{\max}$ values for 10 runs of the GA with different N are shown in Fig. 4. The durations obtained after the optimization are shown in Fig. 5. It is interesting to check the appearance of crosstalk peaks along the whole conductor with the usage of these excitation parameters. The 20 voltage waveforms were calculated in the each segment along each conductor of each MCTL section from

Fig. 2 with the obtained results for the best fitness function result of GA and ES. But only waveforms at the conductor beginning (U_b), end (U_e), and also with voltage maximum ($U_{\max}$) values are presented.

The crosstalk waveforms along the passive conductor after the ES optimization are shown in Fig. 6 *a*, and its maximum location is shown in Fig. 6 *b*. The similar results for the GA optimization are shown in Fig. 7.

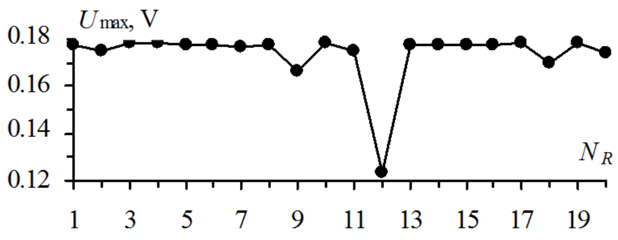


Fig.3. Dependences of the crosstalk maximum values on N_R of the ES

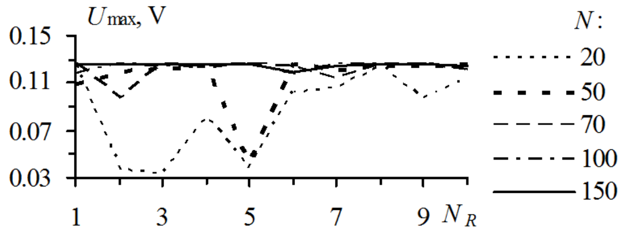


Fig.4. The $U_{\max}$ values for 10 runs of the GA with different N

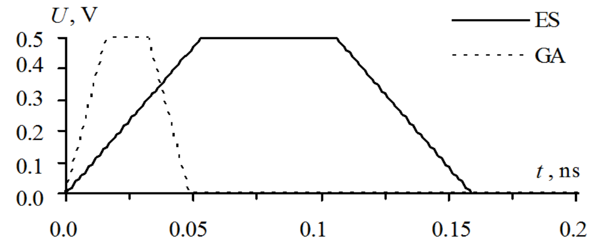
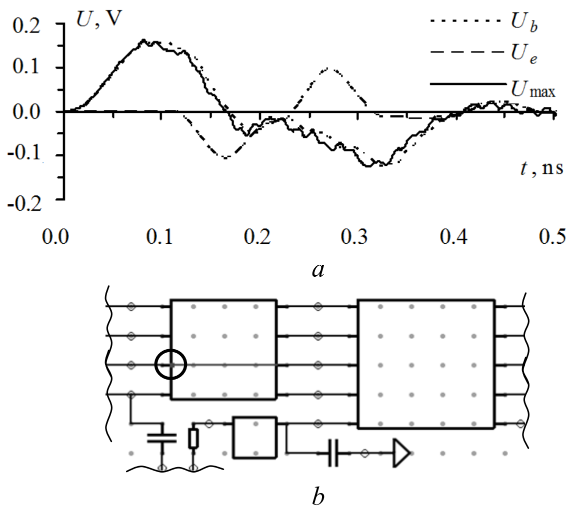


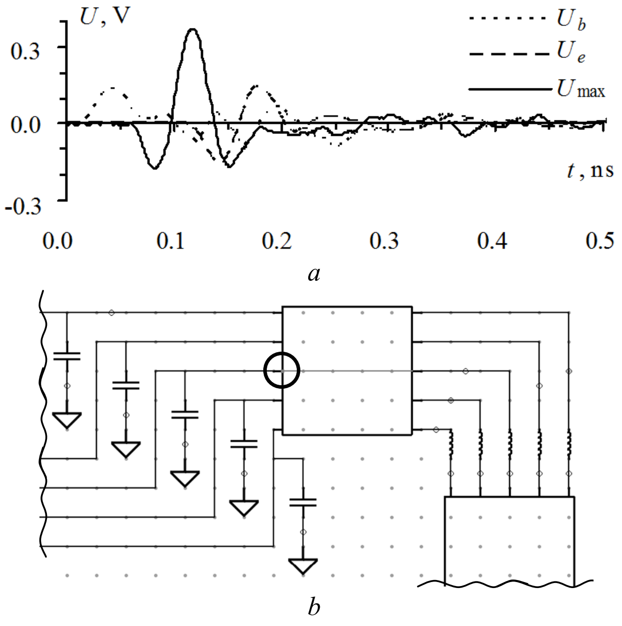
Fig.5. Durations of the ultrashort pulse optimized by ES and GA



a

b

Fig. 6. Crosstalk waveforms (*a*) and its maximum location (*b*) after the ES optimization



a

b

Fig.7. Crosstalk waveforms (*a*) and its maximum location (*b*) after the GA optimization

IV. DISCUSSION OF RESULTS

Let us consider the ES optimization results from Table I. They show that fitness function results are almost the same (around 0.177 V) at each ES run. There is only one run when the fitness function result was as low as 0.1235 V. The best solution at that moment was 54 ps, but all other were in the range 150–160 ps. The highest fitness function result was obtained when the best solution was 159.33 ps.

TABLE I
THE RESULTS OF ES RUNS

N_R	$U_{\max}$	N
1	0.1774	56
2	0.1751	48
3	0.1779	44
4	0.1779	76
5	0.1778	60
6	0.1773	68
7	0.1770	52
8	0.1772	44
9	0.1662	64
10	0.1779	52
11	0.1749	60
12	0.1235	40
13	0.1773	44
14	0.1777	100
15	0.1778	52
16	0.1777	48
17	0.1779	76
18	0.1693	52
19	0.1779	44
20	0.1737	68
The best ES solution	159.33 ps	

TABLE II

THE U_{MAX}, V FOR DIFFERENT N_R AND N OF GA

N_R	N				
	20	**50**	**70**	**100**	**150**
1	0.1256	0.1092	0.1261	0.1177	0.1256
2	0.0373	0.1188	0.0964	0.1255	0.1265
3	0.0331	0.1218	0.1254	0.1250	0.1262
4	0.0817	0.1249	0.1249	0.1220	0.1259
5	0.0378	0.0415	0.1264	0.1259	0.1259
6	0.1027	0.1261	0.1250	0.1173	0.1194
7	0.1047	0.1216	0.1135	0.1252	0.1249
8	0.1242	0.1244	0.1261	0.1256	0.1255
9	0.0974	0.1248	0.1252	0.1256	0.1258
10	0.1148	0.1266	0.1216	0.1216	0.1239
The best GA solution	47.49 ps				

Let us consider the GA optimization results from Table II. They show that with increasing the number of calculations the result becomes better. The highest fitness function result (0.12 V) was obtained when the N was 50 and the best solution was 47.49 ps. It should be mentioned that all GA results are smaller than the ES ones.

Let us consider the crosstalk waveforms calculated after the optimization. After the ES optimization the highest crosstalk amplitude is 0.16 V that is 32% of steady state level in the active conductors. The maximum is located in the first segment of the MCTL section. After the GA optimization the crosstalk peak value is higher than the previous one and it is 0.39 V. This crosstalk maximum is 78% of steady state level in the active conductors.

V. CONCLUSION

The investigation shows the importance of the optimization with different methods for revelation and localization of crosstalk maximums in a complex structure. In spite of the fact that results of GA optimization are smaller than the ES one, the crosstalk maximum amplitude of GA is higher. So we can make a decision that GA solves the problem of crosstalk maximum revelation and localization better than the ES one.

The results of optimization usage show the ability to discard the blind search and to solve more complex optimization tasks, for example, the influence of ultrashort pulse durations on the voltage peak values along the active and the passive conductors of the whole PCB. Such approach will allow to minimize the interference influence and to exclude the upsets of integrated circuits of spacecraft critical devices.

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