Use of Evolution Strategy in Identifying the Worst Case Effects of Ultrashort Pulse Propagation in PCB Bus of Spacecraft Autonomous Navigation System

Ruslan R. Gazizov, Rustam R. Gazizov, Talgat R. Gazizov

***Abstract*—The paper highlights the importance of using evolution strategy (ES) in investigating ultrashort pulse peak voltages in multiconductor structures of printed circuit boards (PCB). Trapezoidal ultrashort pulse propagation along the conductors of a real PCB multiconductor bus was simulated and, with ES, the whole ultrashort pulse duration was optimized using the criterion of peak voltage maximization in the PCB bus in order to identify the worst-case effects. The ES optimization was launched 10 times with different initial solutions (*IS*) – 3 ns, 300 ps, 30 ps. It is shown that changing the *IS* does not influence the optimization results. The voltage maximum exceeding the signal amplitude at the input by 20% and the crosstalk maximum exceeding that of the steady state level in the active conductor by 14% are detected and localized.**

***Keywords*—optimization, evolution strategy, ultrashort pulse, PCB, localization, voltage peak values, quasistatic analysis.**

I. Introduction

THE growing complexity of the devices to be developed and the processes appearing in them make mathematical simulation increasingly important. It happens due to the fact, that full-scale simulation often becomes too expensive. Radioelectronic equipment, which is very popular in our life, needs to be simulated particularly accurately.

It is necessary to consider all possible desired and interfering signals to investigate complex printed circuit boards (PCB). To study the bus with various ultrashort pulse (USP) durations is important in order to increase the performance and interference immunity of radioelectronic equipment. Since for increasing the performance of EE the duration of desired signals and interfering signals is decreased, the research into varying the duration of USP is becoming relevant. Such electric signal propagation in multiconductor transmission lines (MCTL) is properly studied [1]. However, particular aspects of the ultrashort pulse propagation along conductors of high-density PCB are investigated insufficiently. It can be the reason of their uncontrolled propagation [2]. The localization of signal peak values in MCTL and in autonomous navigation system (ANS) PCB is investigated in [3–7]. Moreover, the problem of how ultrashort pulse duration influences the localization of its peak values is investigated in [8, 9]. The same problem is also explored with use of genetic algorithm (GA) optimization in [10, 11]. However, despite their (GAs) wide-spread application in various scientific spheres, other optimization methods are actively used too [12]. Therefore, it is worth considering how the problem of identifying and localizing the signal peak values in ANS PCB bus can be solved with a different optimization method, namely, an evolution strategy (ES). Due to the fact that ES, unlike GA, has a parameter of initial solution (IS), it is useful to investigate the influence of the IS of ES on the signal peak value in a given node of the ANS PCB bus.

The purpose of this paper is to investigate the influence of ISs in ES in identifying the worst-case effects of the ultrashort pulse propagation in PCB bus of a spacecraft ANS.

II. Theory

The theoretical principles and algorithms to calculate the quasistatic response along each conductor of each MCTL section are given in [13–15] and are not presented here.

A. Structure under Investigation

As a structure under investigation we took the ANS PCB bus explored in [8–11]. The PCB fragment and its circuit diagram are shown in Fig. 1 and Fig. 2, respectively.

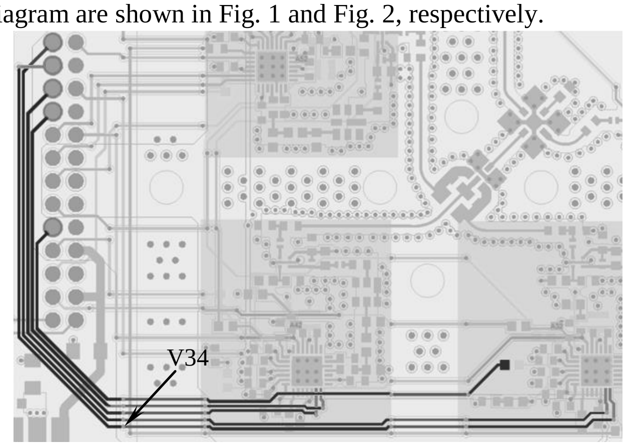

Fig. 1. The bus under investigation on the PCB fragment

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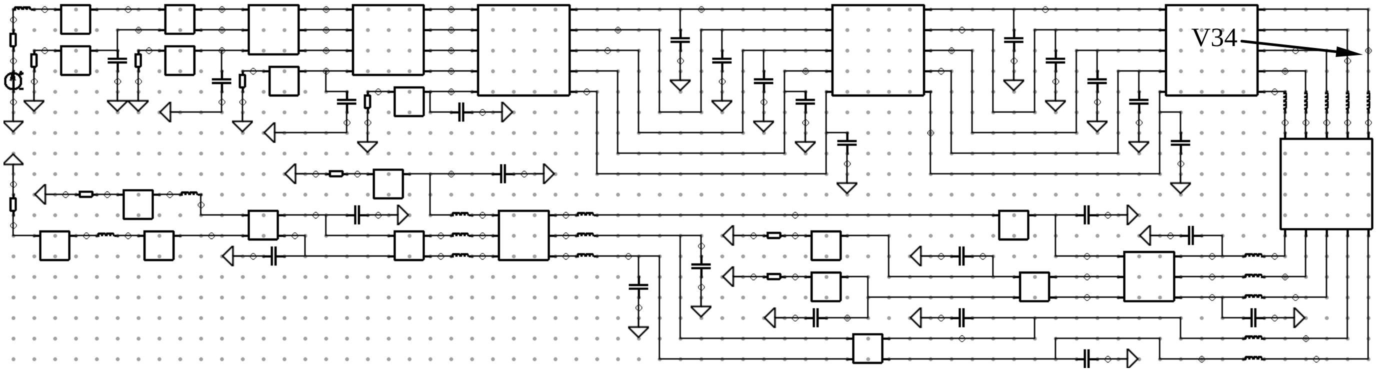

Fig. 2. ANS PCB bus circuit diagram in TALGAT software

The resistances at the ends of each conductor were assumed to be 50 Ohm. The conductor band and via were approximately modeled as a parallel capacitance of 1 pF and series inductance of 1 nH, respectively. The cross sections of each MCTL section were modeled and **L** and **C** matrices were calculated according to PCB stack parameters. The calculations were made without regard to losses.

B. Optimization Algorithm and Parameters

The ES algorithm in general view can be formulated as [16]:

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:

- Select (randomly) $\boldsymbol{\rho}$ parents from $\mathbf{P}_\mu$ (if $\boldsymbol{\rho} = \boldsymbol{\mu}$ take all parental individuals instead).
- Recombine the $\boldsymbol{\rho}$ selected parents to form a recombinant individual **r**.
- Mutate the strategy parameter set ***s*** of the recombinant **r**.
- Mutate 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. The 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 the termination criterion is fulfilled.

To implement optimization we used the barecmaes2.py library [17] built in TALGAT software [18]. The whole ultrashort pulse duration was optimized in order to get the highest peak voltage in V34 node (shown in Fig. 1 and 2). The sigma of the ES algorithm was 10 ps. The ES was 10 times run for each *IS* (3 ns, 300 ps, 30 ps). The aim of the optimization was to get the parameters of the whole ultrashort pulse duration which will allow for the highest peak voltage in V34 node.

C. Excitation Parameters

As excitation we chose a trapezoidal ultrashort pulse with electromotive force amplitude of 1 V and with the variation of its duration (as in [8]). Durations (U_1, U_2, U_3) for each *IS* of ES are shown in Fig. 3. During the research, the whole ultrashort pulse duration was ranged from 3 down to 0.03 ns. Such choice of excitation parameters was determined by the fact that this way allows us to consider not only desired signals but interference as well.

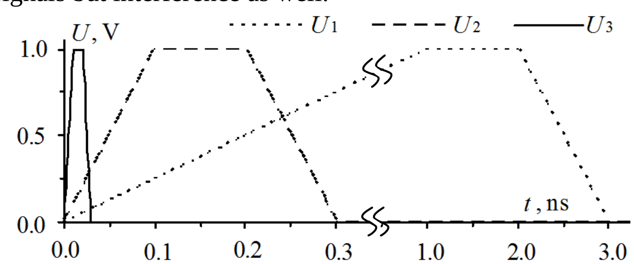

Fig. 3. Excitation pulse EMF waveforms

III. Simulation Results

The results of the ES application are shown in Table I. The peak voltages (U_{max}) at a given node (for 10 ES runs) with different *IS* of ES are shown in the table along with the best solutions of ES for the U_{max}. The cells of the table with the highest U_{max} for each *IS* are colored in grey. Signal waveforms calculated with *IS*=3, 0.3, 0.03 ns for the highest U_{max} are shown in Fig. 4.

TABLE I. U_{MAX} Values for 10 Runs of ES with Different *IS*

ES Run	***IS*, ns**		
	3	0.3	0.03
1	0.59792	0.59787	0.59789
2	0.59789	0.59784	0.59785
3	0.59787	0.59759	0.59786
4	0.59768	0.59760	0.59786
5	0.59775	0.59755	0.59788
6	0.59786	0.59774	0.59785
7	0.59780	0.59774	0.59783
8	0.59779	0.59773	0.59759
9	0.59785	0.59774	0.59770
10	0.59791	0.59768	0.59784
The best solution	325.53 ps	330.06 ps	325.59 ps

The U_{max} arithmetic means (of 10 runs) for the *IS*=3, 0.3, 0.03 ns depending on ES iteration number (N_I) are shown in

Fig. 5–7 respectively. Further, it is necessary to check where signal peaks will appear along the whole conductor using excitation parameters which were obtained after the optimization.

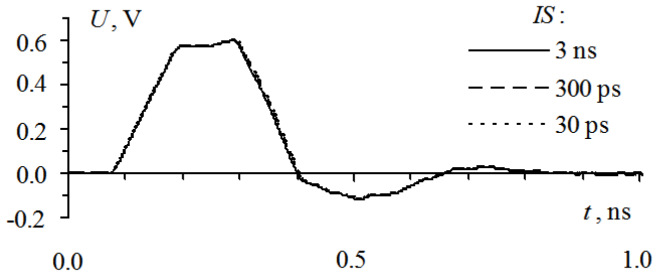

Fig. 4. Voltage waveforms for the U_{max} with different *IS*

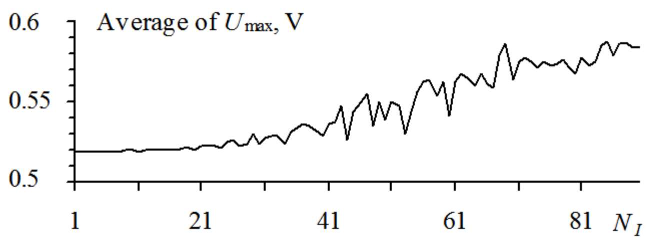

Fig. 5. Dependence of the U_{max} arithmetic mean on N_I for *IS*=3 ns

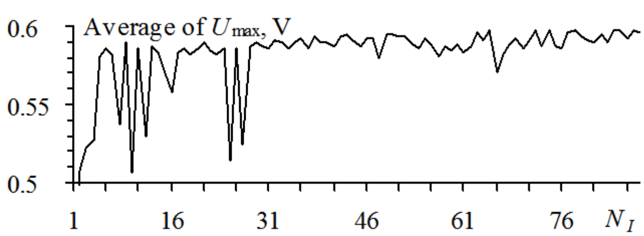

Fig. 6. Dependence of the U_{max} arithmetic mean on N_I for *IS*=300 ps

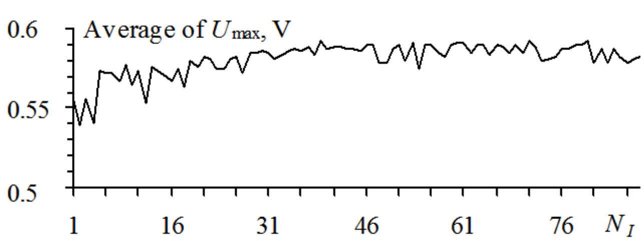

Fig. 7. Dependence of the U_{max} arithmetic mean on N_I for *IS*=30 ps

Fig. 8 *a* shows voltage waveforms along the active conductor where U_b is the waveform at the input, U_e is the one at the end, U_{max} is the one with the highest peak voltage. The localization of the voltage maximum is shown in Fig. 8 *b*. Fig. 9 illustrates the voltage waveforms along the passive (nearest to the active) conductor with the highest crosstalk amplitude and the localization of its maximum.

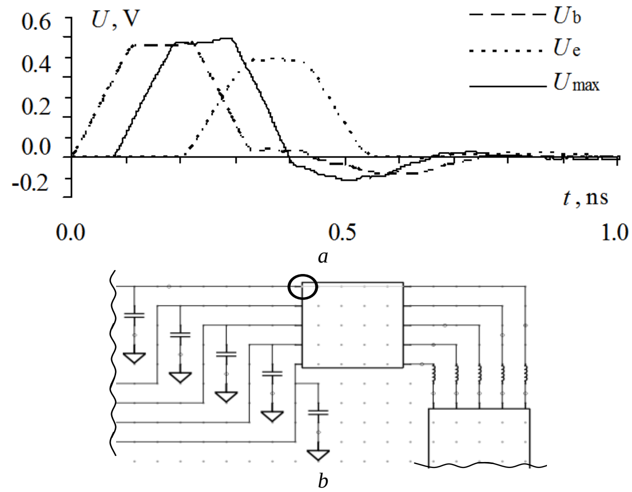

Fig. 8. Voltage waveforms along the active conductor (*a*) and the localization of voltage maximum (*b*)

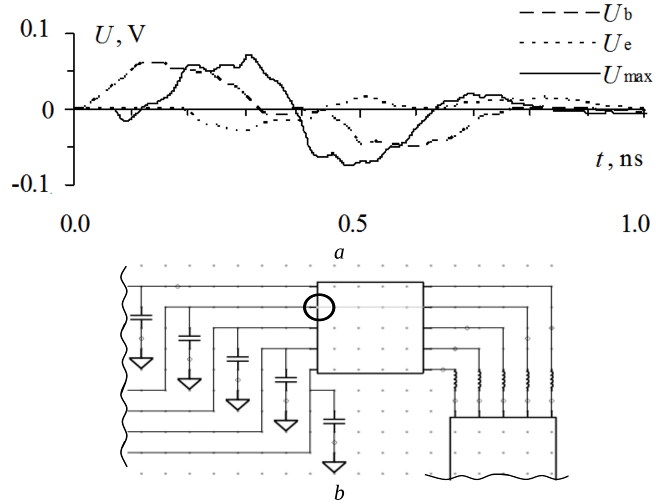

Fig. 9. Voltage waveforms along the passive conductor (*a*) and the localization of its maximum (*b*)

IV. Discussion of Results

Let us consider the optimization results in Table I. They show that all U_{max} values are very similar and only differ in the fourth decimal place. The same situation is observed with the best solutions obtained after each ES cycle – the differences are near 5 ps. The highest U_{max} is obtained in the first ES run for all *IS*. The small differences in the obtained results hardly change the voltage waveforms calculated in V34 node. As we can see from Fig. 4 the signal waveforms coincide.

Let us consider the U_{max} arithmetic mean for each *IS*. The strongest change of U_{max} is observed when *IS*=300 ps, starting from 0.5 V (Fig. 6). However, after 30th calculation, it becomes almost the highest and other changes are within the bounds of 30 mV. Before the 30th calculation, U_{max} change has sharp surges possibly caused by a serious mutation of an offspring. When *IS*=30 ps (Fig. 5) the U_{max} arithmetic mean has a smooth rising character without sharp surges (lies in the range up to 30 mV). Starting at 0.52 V it reaches the maximum value in the 69th calculation. When

IS=30 ps (Fig. 7) $U_{\max}$ changes least of all – starting at 0.55 mV reaches its maximum in the 39th calculation.

Let us consider the voltage waveforms with localized maximums. The maximum is localized in the first segment of the same MCTL section both in the active (Fig. 8) and passive (Fig. 9) conductors. The ultrashort pulse maximum in the active conductor is 598 mV that is 20% higher than the steady state level. The maximum in the passive conductor is 70 mV that is 14% of the steady state level in the active conductor.

V. Conclusion

The research done shows the importance of optimization with ES in order to identify and localize signal peak values under the excitation of the ultrashort pulse with different durations. The highest peak level of active conductor 20% higher than the steady state level and the crosstalk of 14% of the steady state level are detected for 325 ps ultrashort pulse. It is also shown that the change of *IS* by an order of the best solution does not influence the optimization results.

This paper considers the investigation when the *IS* variation is close to the best one. Moreover, the sigma of ES was constant. Further, it is useful to investigate how the change of sigma influences the ES optimization and also the situations when *IS* is far from the best solution choice. In addition, it is interesting to compare the GA and ES optimization results.

The results of using ES show the possibility 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 you to minimize the interference effect and to exclude the upsets of integrated circuits in spacecraft critical devices.

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