Influence of Crossover and Mutation Coefficients on GA Optimization of Ultrashort Pulse Duration by Criteria of Peak Voltage Maximization in PCB Bus

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***Abstract*—Importance of genetic algorithms (GA) usage in the investigation of an ultrashort pulse peak voltage in multiconductor structures of printed circuit boards (PCB) is highlighted. Trapezoidal ultrashort pulse propagation along the conductors of real PCB multiconductor bus was simulated. With the usage of GA, an optimization of the rise, top and fall durations of the ultrashort pulse was made by criteria of peak voltage maximization in the PCB bus. The optimization was launched with the following parameters: the number of chromosomes in population – 5; the number of populations – 26; mutation coefficients – 0.01, 0.03, 0.05 and 0.08 when the crossover coefficient was 0.5; crossover coefficients – 0.1, 0.3, 0.5 and 0.8 when the mutation coefficient was 0.1. A voltage maximum by 38% exceeding the steady state level is revealed and localized with variation of ultrashort rise, top and fall durations when the whole ultrashort pulse duration was near 1.5 ns. An influence of mutation and crossover coefficients variation on the obtained results convergence is shown.**

Keywords—ultrashort pulse; optimization; genetic algorithms; crossover coefficient; mutation coefficient; printed circuit board; peak voltage.

I. INTRODUCTION

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 printed circuit boards (PCB) are investigated insufficiently. It can be the reason of its uncontrolled propagation [2]. By revealing and localizing signal peak values, sites of possible mutual parasitic influences and interference might be determined, so it would be possible to take necessary measures in order to ensure the electromagnetic compatibility. Moreover, it can help to choose places to install sensors for control of useful signals and monitoring the interference that is also important for the improvement of the radioelectronic equipment noise immunity and reliability [3].

It is more effective to use the computer simulation in such research rather than measurements as it is necessary to obtain waveforms at multiple points along each conductor of complex structures. Besides, the signal distortion by the input impedance of a measuring probe influences on the accuracy of measurements. The quasi-static approach is widely used for the analysis of PCB interconnections, because the accuracy of the circuit analysis is often unacceptable, while the electromagnetic analysis often incurs large computation costs. The theoretical basis of the quasi-static response calculation for an arbitrary network consisting of MCTL sections are described in [4, 5]. Algorithms for the calculation of the time response based on this theory are developed in [6] and allow the calculation of current and voltage values only in network nodes.

Basic expressions and algorithm of the current and voltage values calculation, that allow improved calculation of time response at any point along each conductor of MCTL section of an arbitrary network in TALGAT software [7], are presented in [8]. This paper also contains the investigation of two-turn microstrip meander line that proves the necessity of more detailed research. For this reason, one-turn meander line in parameter range was examined [9].

Inasmuch single sections of ideal coupled lines are investigated in these papers, similar investigation of real PCB bus of autonomous navigation system [10] and ultrashort pulse maximum localization along bus conductors with a variation of boundary conditions [11] have been carried out. The bus with a variation of ultrashort pulse duration has been investigated in [12], however, only 3 fixed durations of the ultrashort pulse were considered. Meanwhile, the bus investigation with the variation of the ultrashort pulse duration is important for radioelectronic equipment performance and interference immunity increasing. Indeed, for performance increasing a duration of useful signals is decreased, while shorter interfering signals are more dangerous.

The GAs usage for electromagnetic and radio waves propagation tasks became popular due to the fact that it allows us to exclude the blind search. The number of papers devoted to this problem and published in high quoting international journals increases every year. A search in the Scopus database shows that there are 65762 conference papers and 94510 journal papers related to GAs from 1977 to 2016 [13] that is significantly exceeds the number of papers, where other evolutionary methods are used. GAs, the most popular

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evolutionary algorithms, are inspired by Darwin's natural selection. GAs can be real or binary-coded. In a binary-coded GA, each chromosome encodes a binary string [14]. The most commonly used operations are crossover, mutation, and selection. Selection operator chooses two parent chromosomes from the current population according to a selection strategy. Most popular selection strategies include roulette wheel and tournament selection. Crossover operator combines two parent chromosomes in order to produce one new child chromosome. Mutation operator is applied with a predefined mutation probability to a new child chromosome. The importance of GAs usage for the investigations with a variation of ultrashort pulse duration, and also results of an optimization of ultrashort pulse duration by maximization criteria of a peak voltage in the autonomous navigation system (ANS) PCB bus are shown in [15]. Meanwhile, in that investigation, only the number of chromosomes and the number of populations were changed. By the way, the mutation and crossover coefficients can influence on convergence speed and obtained results values.

The purpose of this work is to investigate the influence of mutation and crossover coefficients on the optimization of the ultrashort pulse duration by means of GAs based on peak voltage maximization criteria in ANS PCB bus.

II. Theory

Frequency domain equations are used for calculation of voltage and current response in MCTL section [8]:

$$\mathbf{V}(x) = \mathbf{S}_V(\mathbf{E}(x)\mathbf{C1} + \mathbf{E}(x)^{-1}\mathbf{C2}), \quad (1)$$

$$\mathbf{I}(x) = \mathbf{S}_I(\mathbf{E}(x)\mathbf{C1} - \mathbf{E}(x)^{-1}\mathbf{C2}), \quad (2)$$

where $\mathbf{S}_V$ and $\mathbf{S}_I$ are the matrixes of modal voltages and currents; $\mathbf{E}(x)$ is the diagonal matrix $\{\exp(-\gamma_1 x),\ \exp(-\gamma_2 x),\ \ldots,\ \exp(-\gamma_{N_k} x)\}$ and γ_{N_k} is the propagation constant for k-th MCTL section, N_k is a number of conductors of a k-th MCTL section, x is the coordinate along the MCTL section. Calculation of $\mathbf{S}_V$, $\mathbf{S}_I$, and $\mathbf{E}(x)$ is described in [6]. **C1**, **C2** are constant vectors calculated as

$$\begin{bmatrix}\mathbf{C1}\\ \mathbf{C2}\end{bmatrix} = \begin{bmatrix}\mathbf{S}_V & \mathbf{S}_V\\ \mathbf{S}_V\mathbf{E}(l) & \mathbf{S}_V[\mathbf{E}(l)]^{-1}\end{bmatrix}^{-1}\begin{bmatrix}\mathbf{V}(0)\\ \mathbf{V}(l)\end{bmatrix}, \quad (3)$$

where $\mathbf{E}(l)=\mathbf{E}(x)$ for $x=l$; l is the length of the MCTL section; $\mathbf{V}(0)$ and $\mathbf{V}(l)$ are constant vectors describing the voltage at the ends of the MCTL section, determined after the solution of equation for circuit with n MCTL sections with lumped elements at the ends:

$$\mathbf{V}(s) = \left(s\mathbf{W} + \mathbf{H} + \sum_{k=1}^{n}\mathbf{D}_k\mathbf{Y}(s)_k\mathbf{D}_k^t\right)^{-1}\mathbf{E}(s), \quad (4)$$

where $s=j\omega$, where ω is angular frequency; **W**, **H** are matrices of order $A\times A$ describing the lumped memory and memoryless elements of network, respectively (A is the number of parameters, which are calculated by modified node potential method); $\mathbf{D}_k = [i, j]$ with entries $l_{i,j} \in \{0, 1\}$, where $i \in \{1, \ldots, N_k\}$, $j \in \{1, \ldots, 2N_k\}$ with one nonzero value in each column, is the selector matrix that maps the terminal currents of the k-th MCTL section; $\mathbf{Y}(s)_k$ is the conductance matrix of the k-th MCTL section; $\mathbf{V}(s)$ is the vector of node voltage waveforms; $\mathbf{E}(s)$ is a constant vector with entries determined by the independent voltage and current sources.

The algorithm used for calculation of response is described in [6]. First of all, initial time domain excitation is transformed to the frequency domain by means of the forward fast Fourier transformation (FFT). The calculations of (1)–(4) are carried out then. The obtained result is transformed to the time domain by means of inverse FFT.

III. Structure under Investigation, Excitation and Optimization Parameters

ANS PCB bus investigated in [15] was taken as a structure for the investigation. PCB fragment is presented in Fig. 1.

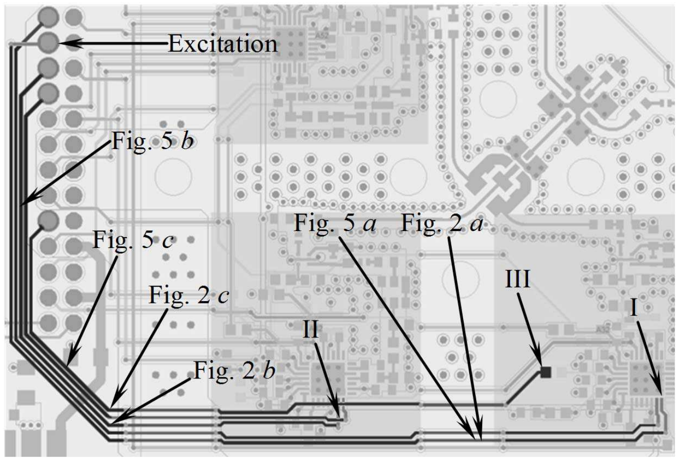

Fig. 1. Investigated bus on the PCB fragment

50 Ohm resistances are assumed at the ends of each conductor. 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.

A trapezoidal ultrashort pulse with electromotive force amplitude of 1 V and with the variation of its durations was chosen as excitation (also used in [15]). During the investigation, the rise (t_r), flat top (t_d), and fall (t_f) durations were ranged from 1 down to 0.01 ns. Such choice of excitation parameters is determined by the fact that in such way not only useful signals but interference are considered. The excitation point is shown in Fig. 1.

The simple binary-coded GA was used (a number of bits for each parameter is taken 16 as default in TALGAT software). The investigation consists of two parts: in the first part the mutation coefficient (k_m) was ranged from 0.01 up to 0.08, and in the second part the crossover coefficient (k_c) was ranged from 0.1 up to 0.8. In the first part k_c=0.5 and in the second part k_m=0.1. Three parameters: t_r, t_d, and t_f were optimized in the range from 1 ns down to 0.01 ns when the chromosome number was 5 and the number of populations was 26 (so the total GA calculation number was 130). A sum of peak voltages at the ends of the PCB bus conductors located in the points I, II and III (shown by arrows in Fig. 1) was maximized. These points are the places where the bus conductors are connected to the other PCB components. An aim of the optimization was to define the rise, flat top, and fall duration values of the ultrashort pulse, with which the sum of voltages (U_{SUM}) in the preset points will be maximal. It is important to notice that it is necessary to choose the more number of GA calculations for complete investigation. The simulation of excitation by several sources is also useful. But due to the fact that the work presents the preliminary stage of investigation only, it was decided to choose a not large number of calculations and the one source only.

IV. Simulation Results

Values of a maximum voltages sum in the preset points for the first part of the investigation are presented in Table I. The presented results are obtained with k_c=0.1 and different k_m for 10 GA runs. Signal waveforms with the highest voltage maximum value (run 3 with k_m=0.03) calculated along the investigated conductors are presented in Fig. 2, where U_b is the voltage at the beginning of the conductor, U_e – at the end, while U_{max} and U_{min} are the voltage maximum and minimum additionally revealed between the beginning and the end of the conductor. Ultrashort pulse parameters obtained for the best fitness function results from Table I are presented in Table II.

TABLE I. Values of U_{SUM}, V with Different K_M for 10 GA Runs

Run	k_m			
	0.01	0.03	0.05	0.08
1	0.50819	0.55159	0.55108	0.54131
2	0.51607	0.55122	0.55196	0.55146
3	0.54913	0.55704	0.55005	0.54974
4	0.55094	0.55081	0.55100	0.55503
5	0.50799	0.55284	0.55043	0.55127
6	0.53153	0.54920	0.55317	0.55092
7	0.52685	0.55092	0.55079	0.54232
8	0.53983	0.55271	0.55272	0.55108
9	0.54009	0.55110	0.55128	0.54909
10	0.54309	0.55132	0.55120	0.55041

TABLE II. Ultrashort Pulse Parameters for the Best U_{SUM} with Different K_M

Parameter	k_m			
	0.01	0.03	0.05	0.08
t_r, ns	0.716	0.011	0.021	0.013
t_d, ns	0.696	0.443	0.969	0.805
t_f, ns	0.010	0.014	0.011	0.013
U_{SUM}, V	0.55094	0.55704	0.55317	0.55503

GA was run 10 times for each variation of k_c and k_m. It was made in order to check the convergence of the fitness function results. Convergence diagrams for the best fitness function results obtained at different runs are shown in Fig. 3 *a*, where N_C is the calculation number, and N_R is the run number. The presented results are obtained when k_m=0.03 because with such k_m the U_{max} in Table I is the highest. Convergence diagrams of the arithmetic average of 10 runs with different k_m are shown in Fig. 3 *b*.

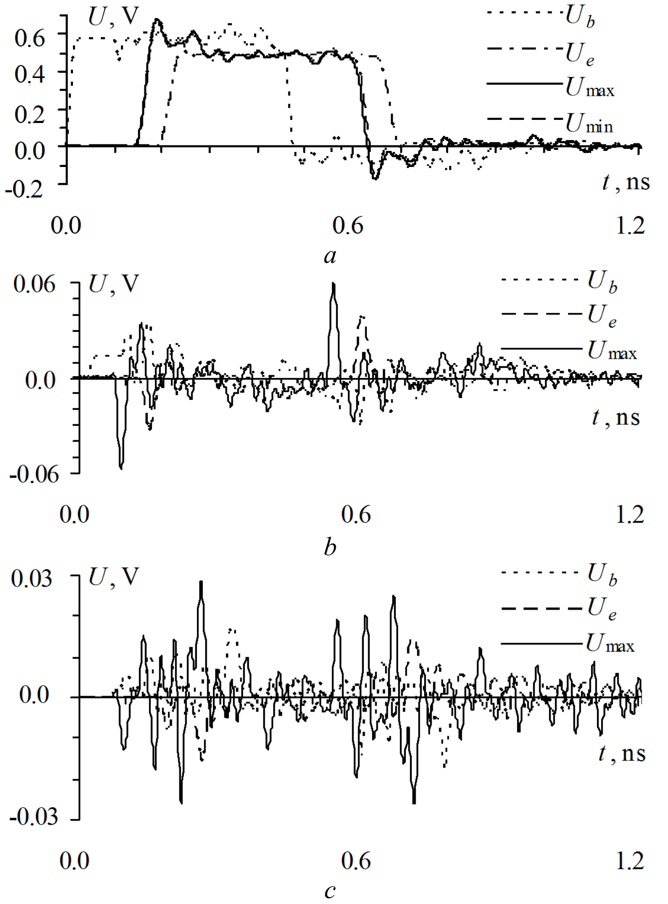

Fig. 2. Signal waveforms for the best U_{SUM} value from Table I obtained along the active (*a*), center passive (*b*), and edge passive (*c*) conductors

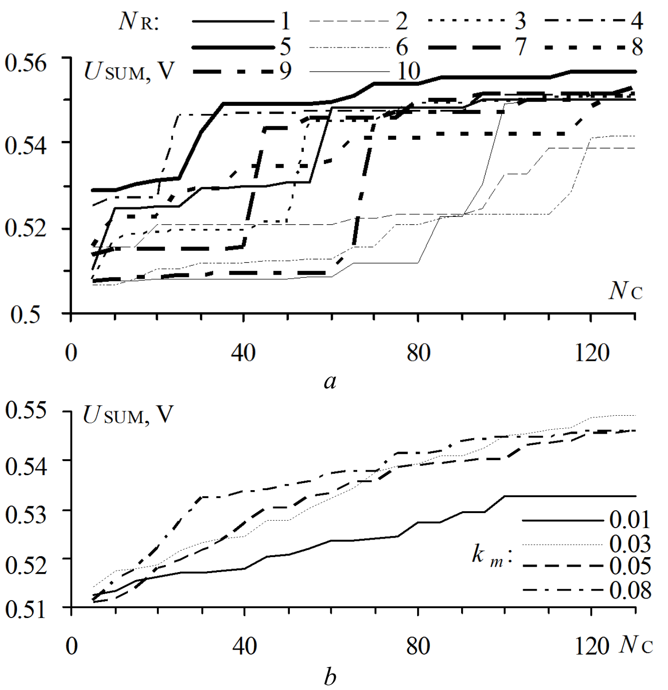

Fig. 3. Convergence diagrams of the fitness function values for each run with k_m=0.03 (*a*) and arithmetic average of runs with different k_m (*b*)

Signal waveforms, calculated after the optimization in I, II, and III points for different k_m are shown in Fig. 4.

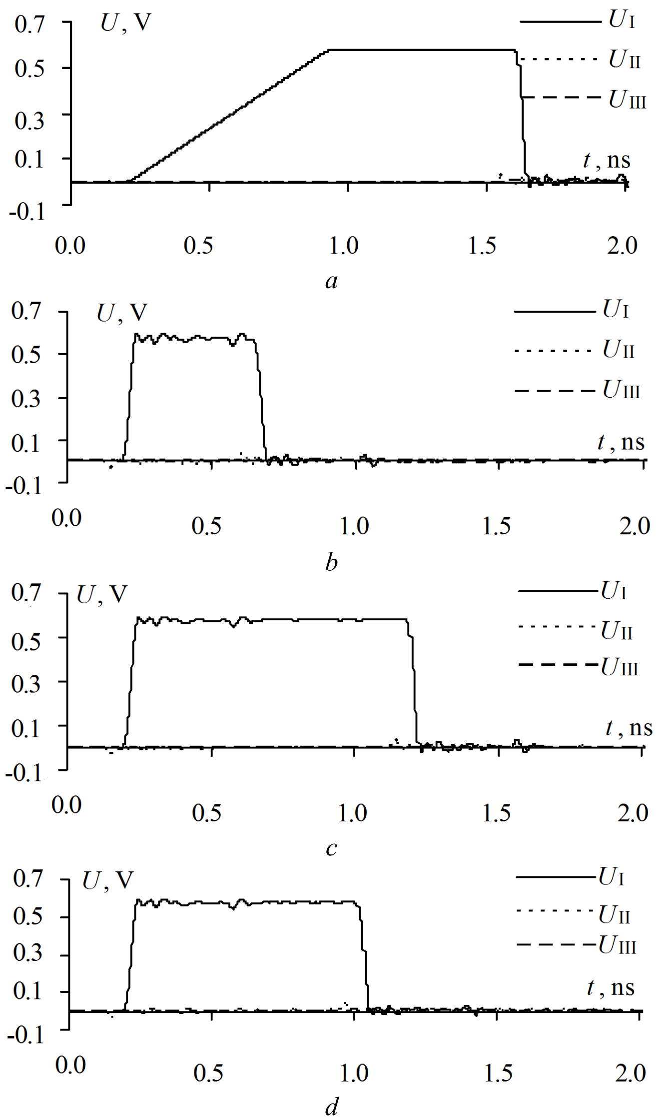

Fig. 4. Signal waveforms obtained in I, II, III points when k_m=0.01 (*a*), 0.03 (*b*), 0.05 (*c*), and 0.08 (*d*)

GA run results of the second part of the investigation (a sum of maximum voltages at I, II, and III points when k_m=0.1 and k_c is different) are presented in Table III. The signal waveforms for the highest value of the voltages sum (run 7 with k_c=0.8) calculated along the investigated conductors are shown in Fig. 5. Convergence diagrams for the best fitness function results obtained at different runs are shown in Fig. 6 *a*. The presented results are obtained when k_c=0.8 because with such k_c the U_{max} in Table III is the highest. Convergence diagrams of the arithmetic average of 10 runs with different k_c are shown in Fig. 6 *b*. The ultrashort pulse parameters obtained for the best fitness function results from Table III are presented in Table IV. Signal waveforms at I, II, and III points calculated after the optimization with different k_c are shown in Fig. 7.

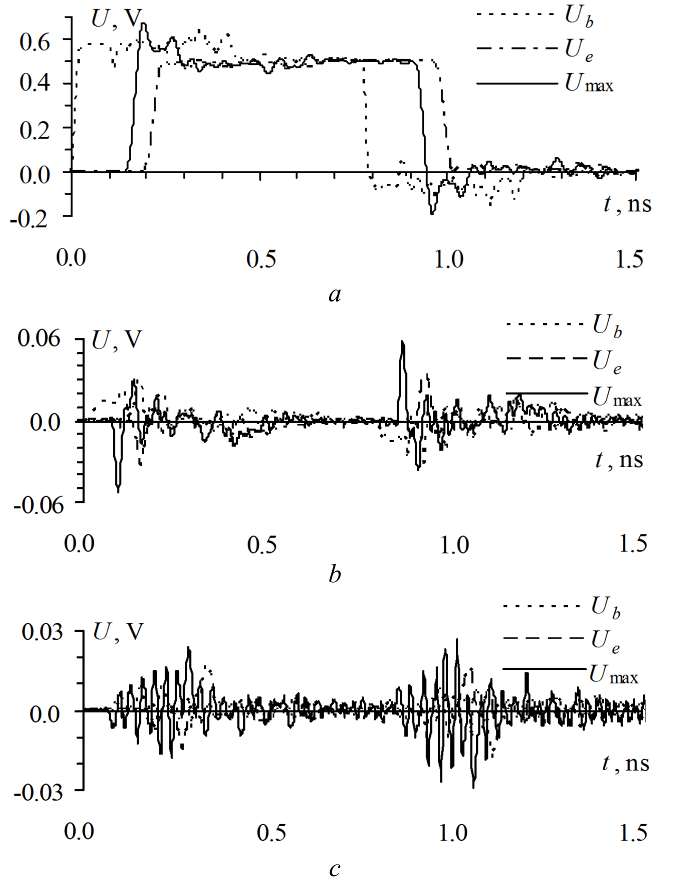

Fig. 5. Signal waveforms for the best U_{SUM} value from Table III obtained along the active (*a*), center passive (*b*), and edge passive (*c*) conductors

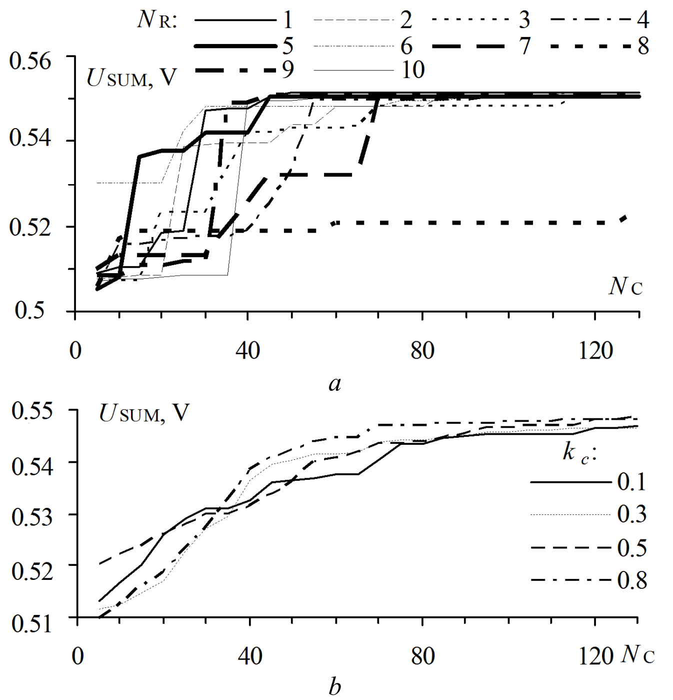

Fig. 6. Convergence diagrams of the fitness function values for each run with k_c=0.8 (*a*) and arithmetic average of runs with different k_c (*b*)

TABLE III. U_{SUM}, V VALUES WITH DIFFERENT K_C FOR 10 GA RUNS

Run	k_c			
	0.1	**0.3**	**0.5**	**0.8**
1	0.55444	0.55214	0.55166	0.55072
2	0.53083	0.55013	0.55177	0.55128
3	0.55169	0.54860	0.55027	0.55167
4	0.55041	0.54996	0.55092	0.52187
5	0.55279	0.54988	0.55121	0.55254
6	0.55102	0.55165	0.55180	0.55118
7	0.55150	0.55182	0.54766	0.55448
8	0.55120	0.55060	0.55040	0.55024
9	0.55191	0.55052	0.55122	0.55142
10	0.55058	0.55116	0.55173	0.55012

TABLE IV. ULTRASHORT PULSE PARAMETERS FOR THE BEST U_{SUM} WITH DIFFERENT K_C

Parameter	k_c			
	0.1	**0.3**	**0.5**	**0.8**
t_r, ns	0.011	0.035	0.015	0.016
t_d, ns	0.264	0.901	0.909	0.754
t_f, ns	0.011	0.01	0.015	0.011
U_{SUM}, V	0.55444	0.55214	0.5518	0.55448

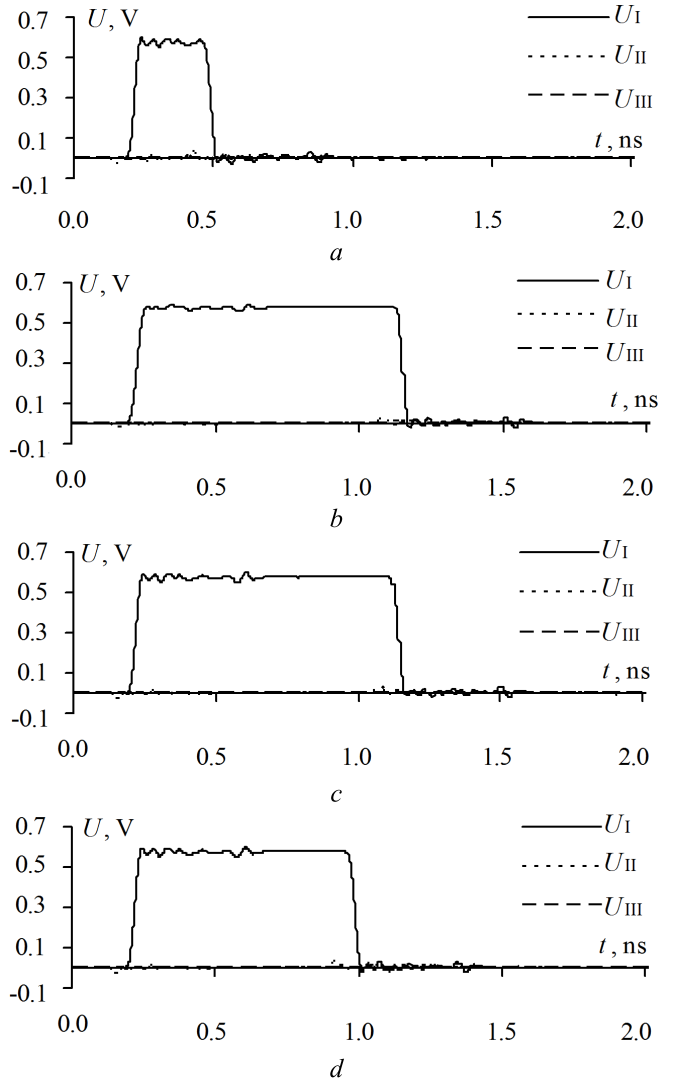

Fig. 7. Signal waveforms obtained at I, II, III points when k_c=0.1 (*a*), 0.3 (*b*), 0.5 (*c*), and 0.8 (*d*)

V. DISCUSSION OF RESULTS

Let us consider the results of the first part of the investigation. They show that in dependence on mutation coefficient the obtained signal waveforms are changing. Indeed, when k_m=0.01 the rise and flat top durations are much longer than the fall one and are 0.71, 0.69, and 0.01 respectively (Fig. 3 *a*). However, with k_m increasing the waveform of obtained pulses become much the same. Short fronts and a long flat top are observed, in particular, the differences are in flat top durations only. For example, the longest flat top duration is observed for k_m=0.05 (Fig. 3 *c*). What about the best fitness function result, the all obtained values are similar and differ in the third decimal place. By the way, the highest result (0.55704 V) is obtained with k_m=0.03 (Table II).

Let us consider the signal waveforms with peak voltages obtained after the optimization. The voltage maximum in the active conductor is 0.69 V (Fig. 2 *a*) that is by 38% higher than the steady state level of 0.5 V. The voltage minimum in the active conductor is minus 0.18 V. The voltage maximum and minimum are located in segment 16 and 17 respectively (the location point for the maximum only is shown in Fig. 1). The crosstalk maximum in the central passive conductor is 60 mV (Fig. 2 *b*) that is 12% of steady state level. It is located in segment 3 (also shown in Fig. 1). The crosstalk maximum in the edge passive conductor is 29 mV (Fig. 2 *c*) that is 5.8% of steady state level. It is located in segment 2 (shown in Fig. 1)

Let us consider the convergence diagrams of results for the each GA run when k_m=0.03 (Fig. 4 *a*). They show that the results significantly differ from each other even with the same parameters. Indeed, the best fitness function result that is achieved at the 115th calculation is obtained at run 5. Let us examine the convergence diagrams of the arithmetic average of fitness function values with a variation of k_m (Fig. 4 *b*). The diagrams for k_m=0.03, 0.05, 0.08 are located nearby to each other for all calculations. Besides, the convergence for k_m=0.08 is achieved faster than for others. However, the results for k_m=0.01 differ and the best fitness function value is not achieved (the highest average U_{max} is 0.53 V).

Let us consider the results of the second part of the investigation. The obtained signal waveforms differ by flat top durations only. For k_c=0.3 and 0.5, the durations are almost the same and equal to 0.9 ns (Table IV and Fig. 7) in particular. What about the best fitness function result, the situation is the same as for the first part of the investigation: all obtained results are similar and differ in the third decimal place only. Meanwhile, the highest result is 0.55448 V (obtained with k_c=0.8).

Let us consider the signal waveforms with peak voltages obtained after the optimization. The voltage maximum in the active conductor is 0.67 V (Fig. 5 *a*) that is by 34% higher than the steady state level. It is located in segment 12 (Fig. 1). The voltage minimum in the active conductor is minus 0.19 V (is shown in Fig. 5 as U_{max} because they are located in the same segment). The crosstalk maximum in the central passive conductor is 60 mV (Fig. 5 *b*) that is 12% of steady state level (segment 15). The crosstalk maximum in the edge passive conductor is 29 mV (Fig. 5 *c*) that is 5.8% of steady state level (segment 8).

Therefore, the mutation and crossover coefficients variation almost does not influence on voltage maximum and minimum values. This situation is the same for the ultrashort pulse in active conductor and for crosstalk in the passive ones.

Let us consider the convergence diagrams of results for the each GA run when k_c=0.8 (Fig. 6 *a*). The convergence is observed at the 70th calculation in all runs, but the run 8 is absolutely different. It has appeared, most probably, due to the fact that GA has revealed the local maximum and failed to exit it. Let us examine the convergence diagrams of the arithmetic average of fitness function values with a variation of k_c (Fig. 6 *b*). The diagrams for all k_c are located nearby to each other for all calculations. Besides, the convergence for k_{m}=0.8 is achieved faster than for others. Therefore with variation of crossover coefficient the convergence is achieved faster than with variation of mutation coefficient.

VI. Conclusion

The investigation shows the importance of an optimization with GAs usage for revelation and localization of signal peak values or sum of several signals under the excitation of the ultrashort pulses with different durations. For instance, as we can see from Table I and II, the highest fitness function value with variation either mutation or crossover coefficients is near 0.55 V, in Table I it is 0.55132 V, and in Table II it is 0.55173 V.

It is obtained that the mutation coefficient variation strongly influences on the results convergence. Indeed, with variation of mutation coefficient the convergence decelerates and the diagrams broken out of the general group are observed. The crossover coefficient variation gives us the fastest convergence (with k_c=0.8 it is at the 70th calculation). However, these coefficient variations do not almost influence on the revealed peak voltages of the ultrashort pulse and crosstalk. The obtained peak voltages have the similar amplitudes.

This paper considers the variation in range of 3 parameters for one excitation in trapezoidal form. But it is easy to consider using such approach any other excitations, for example, electrostatic discharge, Gaussian pulse, etc. The results of GA 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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