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Optimization of PCB Bus Loads with Usage of Genetic Algorithms by Criteria of Peak Voltage Minimization

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***Abstract*—Importance of the genetic algorithms (GA) 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 simulated. Using GA an optimization of the 10 parameters for loads at the ends of the bus conductors was made. The optimization was made by minimization criteria for a peak voltage sum at preset points. The optimization was run 10 times with the parameters: the number of chromosomes – 3, 5, 7, 10; the number of populations – 6, 8, 11, 26; mutation coefficient – 0.1; crossover coefficient – 0.5. Using of the optimization has allowed us by 30 times decreasing the signal amplitude in the active conductor. Herewith, the signal maximums revealed along the bus conductors don't exceed the values, obtained before the optimization. A good convergence of the obtained results is shown.**

Keywords—ultrashort pulse; printed circuit board; optimization; genetic algorithms; electromagnetic compatibility; 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 cause 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 of 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 voltage amplitude measurements. The quasi-static approach is widely used for the analysis of PCB interconnections, because the accuracy of the circuit analysis is often inacceptable, while the electromagnetic analysis often incurs large computation costs. The theoretical basis of the quasi-static response calculation for an arbitrary network 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, are implemented in [7, 8]. These papers also contain results of the investigations for one and two-turn microstrip meander lines. Inasmuch single sections of ideal coupled lines are investigated in these papers, similar investigation of real PCB bus of the autonomous navigation system (ANS) [9] and ultrashort pulse maximum localization along bus conductors with a variation of boundary conditions [10] have been carried out. The bus with a fixed variation of the ultrashort pulse duration has been investigated in [11] and with the using of an optimization by genetic algorithms (GAs) in [12]. Ultrashort pulse parameters are also obtained in [12]. The using of these parameters gives us the greatest peak voltage value in the PCB bus. However, it is interesting to find with usage of GA such load parameters at the conductor ends, when this peak voltage will be the minimal. It is important, because a PCB developer has some degree of variance of load parameters choice. Therefore, it is important to use this possibility not only for the useful signals, but for decreasing the interference at various PCB points.

The purpose of this paper is to carry out an optimization of load parameters at the conductor ends of the ANS PCB bus with usage of GA by minimization criteria for sum of peak voltage at the points of bus connection to the other PCB components.

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II. Theory

A. Response Calculation

Frequency domain equations are used for calculation of voltage and current response in MCTL section [7]:

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

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

where $\mathbf{S}_V$ and $\mathbf{S}_I$ are the matrixes of modal voltages and currents; $\mathbf{E}(x)$ is the diagonal matrix $\{\exp(-\gamma_1 x), \exp(-\gamma_2 x)$, …, $\exp(-\gamma_{N_k} x)\}$ 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 $i \in \{1, …, N_k\}$, $j \in \{1, …, 2N_k\}$ 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). Then calculations of (1)–(4) are carried out. The obtained result is transformed to the time domain by means of inverse FFT.

B. Structure under Simulation

The ANS PCB bus from [12] was taken as a structure for the investigation. The PCB fragment is presented in Fig. 1, and its circuit diagram in Fig. 2. Resistances are connected to the ends of each bus conductors. Conductor bend and via are approximately modeled as a capacitance of 1 pF and 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 the accounting for losses.

A trapezoidal ultrashort pulse with electromotive force amplitude of 1 V obtained in [12] was chosen as excitation. The rise (t_r) time was 12.3 ps, flat top (t_d) time was 0.549 ns, and fall (t_f) time was 12.14 ps.

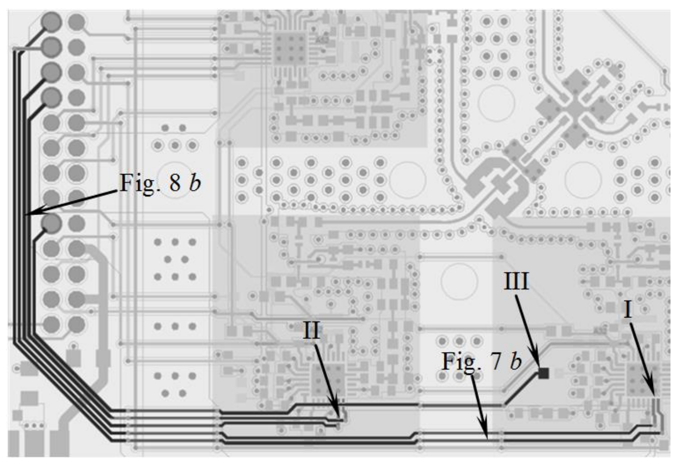

Fig. 1. Investigated bus on the ANS PCB fragment

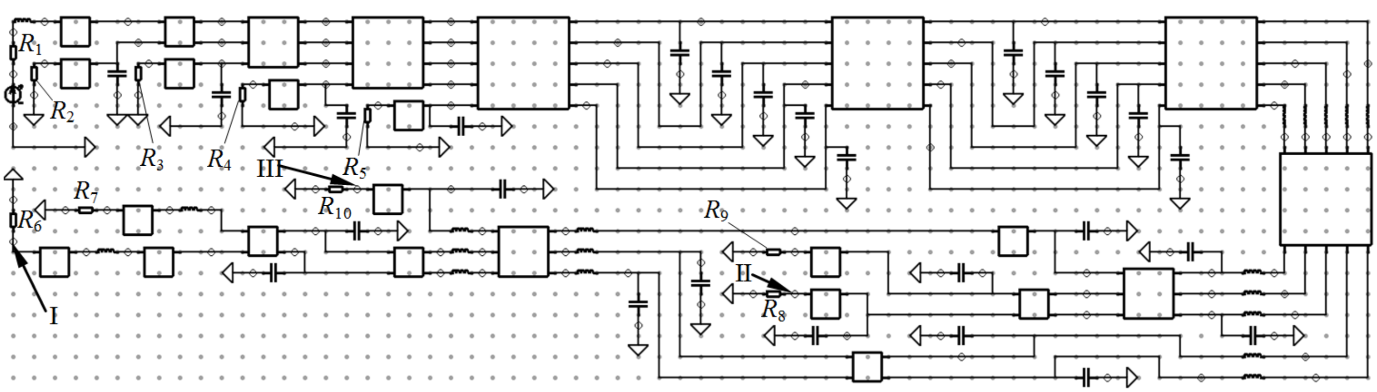

Fig. 2. Circuit diagram of ANS PCB bus

C. Optimization Parameters

GAs, the most popular 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 [13]. 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 GA usage let us exclude the blind search. The binary-coded GA was run with the following parameters: mutation coefficient – 0.1 and crossover coefficient – 0.5. The 10 parameters – resistances were optimized in the range from 1 to 200 Ω, the number of chromosomes was 3, 5, 7, and 10, and the number of populations was 6, 8, 11, and 26. A maximum sum of the peak voltage values at preset points of the ANS PCB bus was minimized. These points are the connection places of bus conductors with the other PCB components. Therefore, an aim of the optimization was to determine such resistance parameters, with which the sum of the peak voltages at I, II, and III points (shown in Fig. 1 and 2) will be the minimal.

III. Simulation Results

The GA operation results (U_{min} – the minimum value of the peak voltages sum at I, II, and III points) with the different runs and the numbers of the fitness function calculations are presented in Table I, where N_R is a number of a run, and n is a number of a fitness function calculations. The number of the fitness function calculations 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. A diagram of the U_{min} values convergence with a different n is shown in Fig. 3. Dependences of the minimum voltage values on the n are shown in Fig. 4.

TABLE I. U_{MIN}, MV FOR DIFFERENT N_R AND N

N_R	n							
	18	**30**	**33**	**55**	**56**	**60**	**110**	**260**
1	428	61	53	50	77	45	44	41
2	82	87	283	52	154	47	765	35
3	584	170	78	47	94	46	84	23
4	120	234	59	52	72	187	59	22
5	356	180	46	44	86	82	62	35
6	105	236	47	59	143	52	44	26
7	130	77	44	31	60	88	47	28
8	115	132	52	54	71	51	59	18
9	413	49	187	88	54	76	60	16
10	122	144	154	37	38	72	54	35

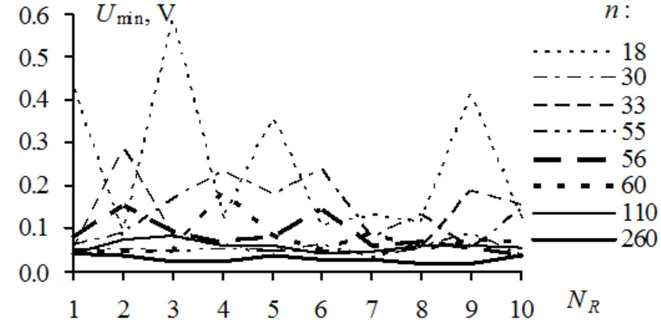

Fig. 3. The U_{min} values for 10 runs with different n

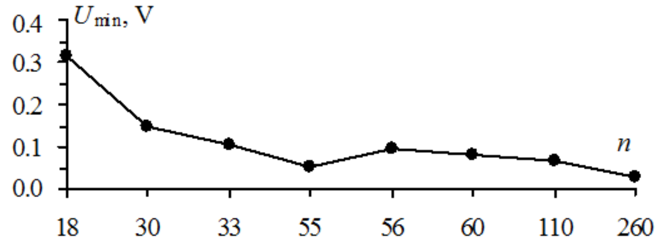

Fig. 4. Dependences of the U_{min} on n

Resistance values, obtained for the best fitness function result (run 9 from Table I when n was 260), are presented in Table II. A signal waveform is calculated in the preset points with using of these parameters (Fig. 5). Moreover, the signal waveforms also calculated in these points before using the optimization are presented in Fig. 6.

It is interesting to know what will happen with the signal along the whole conductor with using the obtained 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. But only waveforms at the conductor beginning (U_b), end (U_e), and also with voltage maximum (U_{max}) values are presented. Presented results are only for an active and one passive conductor with the highest amplitude of the crosstalk. The voltage waveforms along the active conductor are shown in Fig. 7 *a*, and the ultrashort pulse maximum location is shown in Fig. 7 *b*. The similar results for the crosstalk are shown in Fig. 8.

TABLE II. RESISTANCE VALUES FOR THE BEST FITNESS FUNCTION RESULT

Resistance	**Value, Ω**
R_1	123.345
R_2	131.854
R_3	101.057
R_4	59.0162
R_5	30.9100
R_6	1.01822
R_7	74.8943
R_8	2.69743
R_9	174.438
R_{10}	3.61447

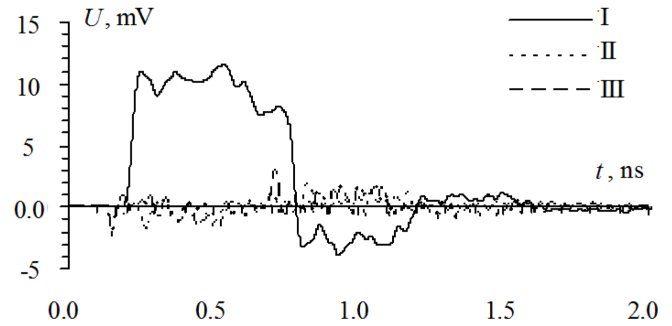

Fig. 5. Signal waveforms for the best fitness function result at I, II, and III points

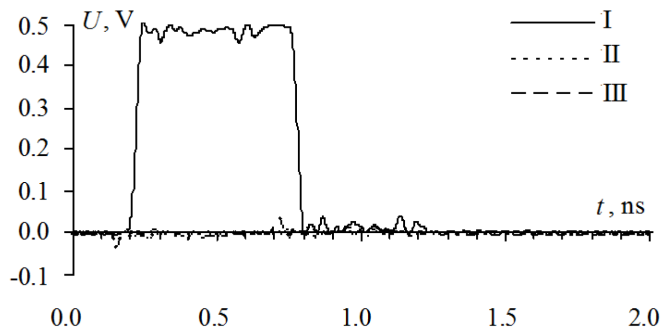

Fig. 6. Signal waveforms at I, II, and III points before using the optimization

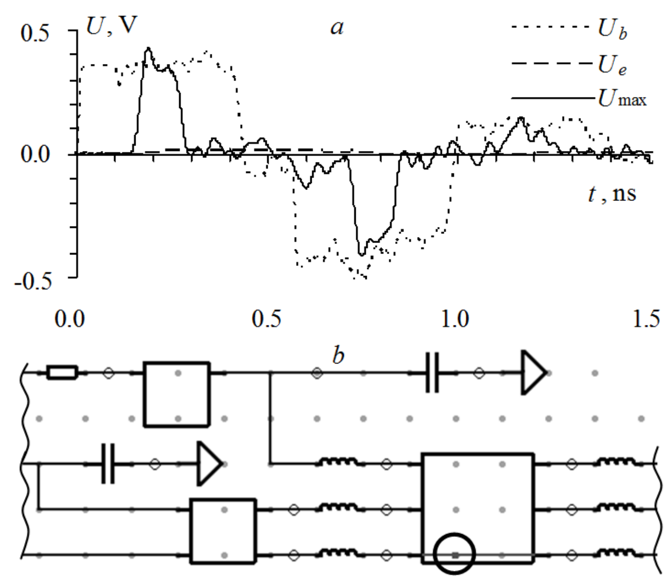

Fig. 7. Voltage waveforms along the active conductor (*a*) and the voltage maximum location (*b*)

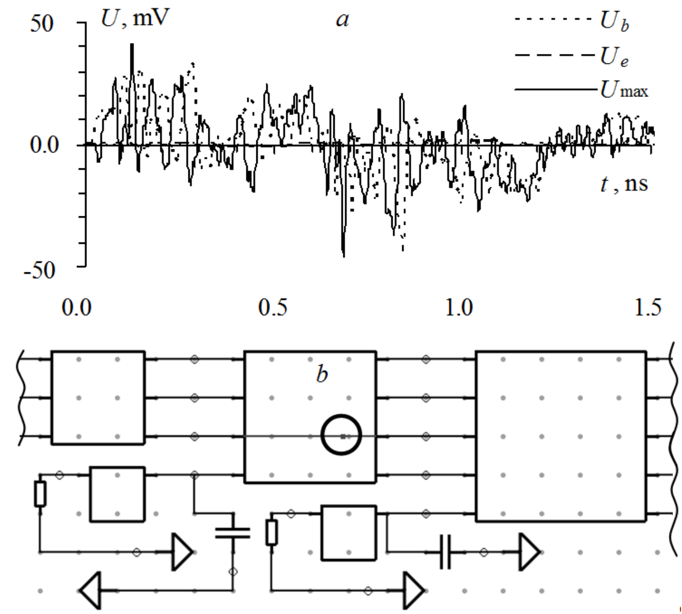

Fig. 8. Voltage waveforms along the passive conductor (*a*) and the crosstalk maximum location (*b*)

IV. Discussion of Results

Let us consider the optimization results from Table I. They show that with the increasing number of calculations, the fitness function value decreases (that is also shown in Fig. 4). The fitness function results show a good convergence when the number of calculations is 110 and more (Fig. 3). With the maximal number of calculations, the summarized peak voltage value is 16 mV (run 9 from Table I) that is 30 times smaller than the signal amplitude (0.5 V) in the active conductor before using the optimization (Fig. 6).

Let us consider the waveforms changing along the bus conductors. It is seen that the voltage maximum in the active conductor is located in the segment 15 of the bus from the other layer. However, the signal amplitude is 0.48 V that does not exceed the steady state level of 0.5 V (before the optimization). Moreover, that essential negative voltage has appeared in this conductor after using the optimization. The negative voltage is 0.41 V. A crosstalk maximum is revealed and localized in the segment 14. The crosstalk is 50 mV that is 10% of the steady state level in the active conductor (before the optimization).

V. Conclusion

The investigation shows the importance of the optimization with GAs usage for revelation and localization of the sum of several signals peak values with variation of load parameters. For instance, the optimization usage has allowed us to decrease the sum of peak values by 30 times.

The results of GAs 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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