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Differential mode pulse minimization by using the genetic algorithm in the bus

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Abstract. The article considers an optimization of a spacecraft component. The choice of length of the power supply was carried out using a genetic algorithm. The main purpose was decreasing the maximum voltage amplitude in the power supply bus. As an excitation we used a differential excitation of a trapezoidal pulse. Comparison of the results of signal simulation after optimization for two approaches is presented, that differed by various numbers of chromosomes and populations. It was found that the two approaches are not differ significantly in the simulation results. We decreased the maximum voltage amplitude by 270 times with using the genetic algorithm.

1. Introduction

The preliminary analysis of the structure being developed is a necessary stage in the process of developing modern radioelectronic devices as it can check their structures and features faster and correct the dangerous errors. Besides, it requires less time and financial costs than a testing with a finished product. It is important to consider possible of various interference that appear between conductors of high-precision radioelectronic devices. It is important to study in detail all the features of the connections in the equipment [1]. Doing a lot of research on materials and design methods rises the success of a quality product. This also applies to printed circuit boards (PCB) where vulnerabilities may be present [2]. High precision simulation will prevent the influence of electromagnetic interference (EMI) on electronic equipment [3, 4]. Dangerous signals include electrostatic discharge (ESD) [5], ultrashort pulses [6] and ultra-wideband pulses. Therefore, when investigating, it is needful to take into account both useful and interfering signals. This issue is especially important in high-precision technologies, for example, in aircraft construction, where an error in one unit may be worth the failure of an entire aircraft [7, 8].

The space industry is constantly improving. Every year, trends towards miniaturization and increasing of useful signals become more and more popular. If relatively recently the satellites were large enough and the number of satellites launched into space was very small, now we can see, for example, the Starlink project from the SpaceX Company founded by Elon Musk, which launched more

55 satellites by one rocket firing [9]. It proves that miniaturization has achieved the level when we are speaking about not centimeters but millimeters [10, 11]. Such level of miniaturization became possible with the varied types optimization actively used in the development of similar devices for different goals, for example, for prototyping of spacecraft [12], new internal structures [13], and others. On the other hand, with close arrangement of components tightening is required to assure electromagnetic compatibility of similar devices.

Earlier, mathematic models, modeling techniques, algorithms, and software have been developed for calculating the time response of the multi-conductor transmission line (MCTL) networks of arbitrary complexity [14]. These methods have been used to improve the elements of the spacecraft [15] and a power supply (PS) bus [16]. Besides, a large amount of work has been carried out on the study of signal propagation using various optimization: genetic algorithm (GA) and evolution strategy (ES) [17]. However, there are many unresolved issues in the optimization of a PS bus. Patricianly, it is reasonable to optimize the differential-mode excitation propagation in devices to be used in space.

The aim of this paper is to optimize the length of MCTL sections of a PS bus to minimize the voltage maximum, and to investigate the influence of the number of chromosomes and populations of GA on the results of optimization. It is necessary to keep in mind that this work has more scientific interest concerning the methodology than the practical search of best parameter values of equipment parts, the failure of which can greatly affect the performance of the entire system.

2. Theory

For scientific research we took a spacecraft PS bus. The photo of the bus experimental model is shown in figure 1. Central and side branches conductors are indicated by full black arrows, while the PS is bus indicated by black dotted arrow. The branches extending from the center of the rectangular shell to the left and right are the central branch conductors. The circuit diagram of the bus is shown in figure 2

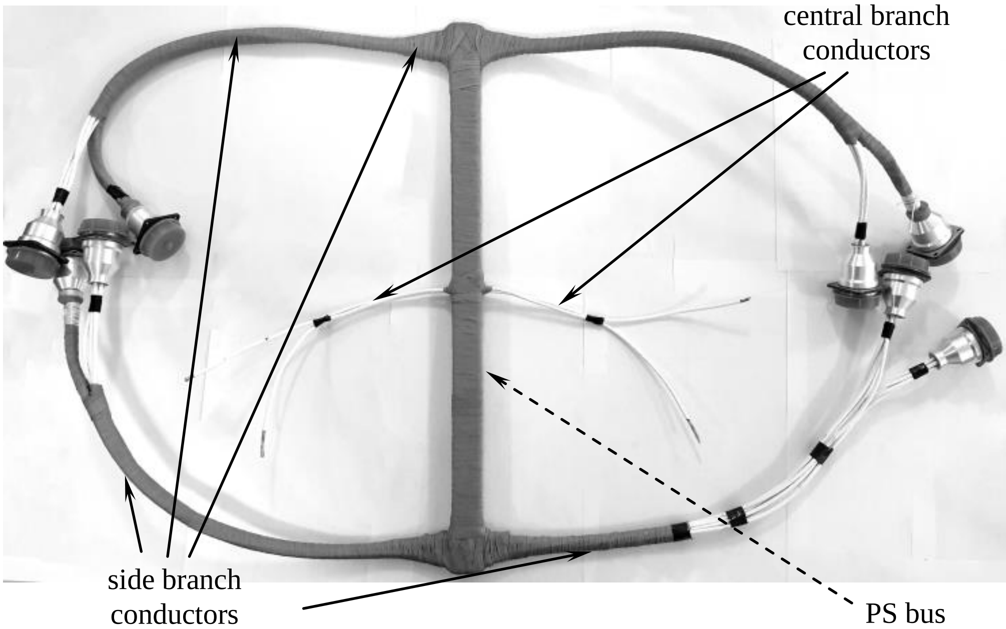

Figure 1. The photo of the experimental model.

The MCTL sections 7–12 of the PS bus without branch conductors are marked by a rectangle. The lengths of sections 1, 2, 13, 14, 5, 6, 17, 18 are equal to 0.5 m and sections 3, 4, 15, 16 – 0.25 m. The lengths of sections 7–12 were changed with GA and will be described in the next subsection. All resistors (R_1–R_{12}) were supposed equal to 50 Ohm. The cross-sections of the structure under the investigation are presented in figures 2 and 3, respectively. The version of the PS bus under study was modified and has the LMAMS shielding layer. The part of the PS bus where it is connected with the side branch conductors has a big cross-section (figure 2 *a*) and in the other parts – small (figure 2 *b*). The detailed structure parameters are shown in table I, while the relative dielectric permittivity of isolating material of the wire was taken «2» for wires and «1» for the shielding conductor.

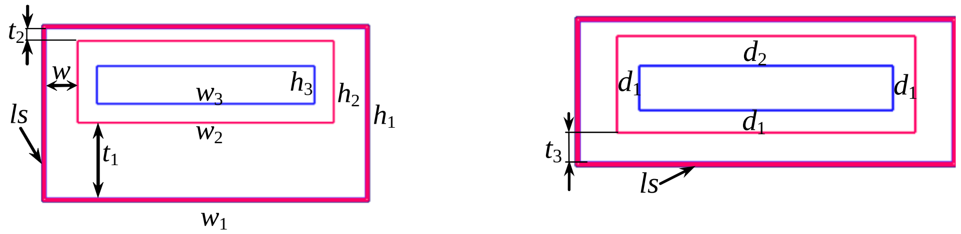

Figure 2. The cross-sections of big part (sections 7 and 12 – *a*) and the small part (sections 8–11 – *b*) of the PS bus.

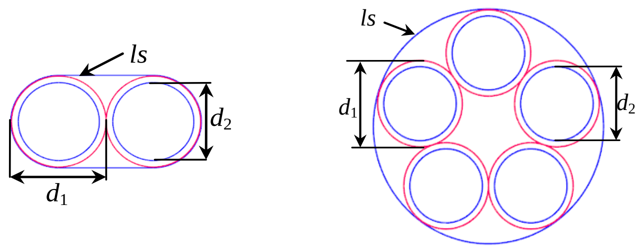

Figure 3. The cross-sections of central (sections 3, 4, 15, 16 – *a*) and side (sections 1, 2, 5, 6, 13, 14, 17, 18– *b*) branches.

The coefficient matrices of the electrostatic (**C**, pF/m) and the electromagnetic (**L**, nH/m) inductions for the side branches:

$$\mathbf{C}=\begin{bmatrix} 241.92 & -53.92 & -1.35 & -1.35 & -53.65 \\ -53.92 & 243.02 & -53.92 & -1.34 & -1.34 \\ -1.36 & -53.92 & 241.92 & -53.65 & -1.35 \\ -1.35 & -1.34 & -53.65 & 243.03 & -53.75 \\ -53.65 & -1.34 & -1.35 & -53.75 & 243.03 \end{bmatrix}, \quad \mathbf{L}=\begin{bmatrix} 78.86 & 17.63 & 5.65 & 5.62 & 17.57 \\ 17.63 & 78.68 & 17.63 & 5.62 & 5.62 \\ 5.65 & 17.63 & 78.86 & 17.57 & 5.62 \\ 5.62 & 5.62 & 17.57 & 78.62 & 17.54 \\ 17.57 & 5.62 & 5.62 & 17.54 & 78.62 \end{bmatrix}.$$

The differential-mode excitation of a trapezoidal pulse, where U_1 has an amplitude of the electromotive force equal to 100 V and U_2 – minus 100 V was used in this investigation. The rise time equal 1 ns, a flat top equal 10 ns and fall time – 1 ns. The voltage sources are indicated in figure 2 as U_1 and U_2.

The coefficient matrices for the central branches (sections 3, 4, 15 and 16), for the central part of the PS bus (sections 7–10) and for the side part of the PS bus (sections 6 and 11) was demonstrated in [18].

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Table 1. Geometrical characteristic of the cross-sections from figures 3 and 4.

Description	Notation	Value, mm
Outer conductor width	w_1	25
Inner dielectric width	w_2	20
Inner conductor width	w_3	17
Outer conductor height	h_1	13.5
Inner dielectric height	h_2	6.5
Inner conductor height	h_3	3
Lower thickness of the outer conductor in its big part (figure 4 *a*)	t_1	6
Upper outer conductor thickness	t_2	1
Lower thickness of the outer conductor in its small part (figure 4 *b*)	t_3	2
Side thickness of the outer conductor	w	2.5
Diameter of the branch conductor with dielectric layer	d_1	7
Diameter of the branch conductor	d_2	6
Lapped screen thickness	ls	0.06

The GA with parameters: the mutation coefficient – 0.1; the crossover coefficient – 0.5 was chosen to select the best length of the PS bus (MCTL sections 7–12). The number of chromosomes in a population and the number of generations were not changed.

The lengths of the MCTL sections 7 and 12 were assigned variables l_1, the sections 8 and 11 – l_2, the sections 9 and 10 – l_3. The variables (l_1, l_2, l_3) were changed from 0.01 m to 0.5 m. In this way, the general length of the PS bus (l) is defined as

$$l=2(l_1+l_2+l_3). \quad (1)$$

3. Optimization results

Primarily, it was carried out with an increasing number (c) of GA total calculations (20, 100, 150, 200, 300, 400, 600, 700). The relation of the voltage maximum values (U_{max}) and the c after the optimization is demonstrated in figure 4. The variation of GA variables values with increasing the c is shown in figure 5.

Looking at figure 4, it becomes clear that the optimization result does not change after 400 calculations (the voltage of maximum value is equal 20.4 mV). Therefore, the comparison of two approaches was carried out to investigate how the choice of numbers of chromosomes and populations influences the result of optimization. In the first approach, the number of populations (200) was a lot more than the number of chromosomes (2). In the second approach, they were comparable: 10 chromosomes and 40 populations. The choice of these GA parameters was such because the number of GA calculations was equal to 400 in both approaches, and it allowed achieving the convergence of results.

The GA was run 10 times for increasing the accuracy of results in the both cases. The relation of U_{max} and the number of GA runs (n) is represented in figure 6.

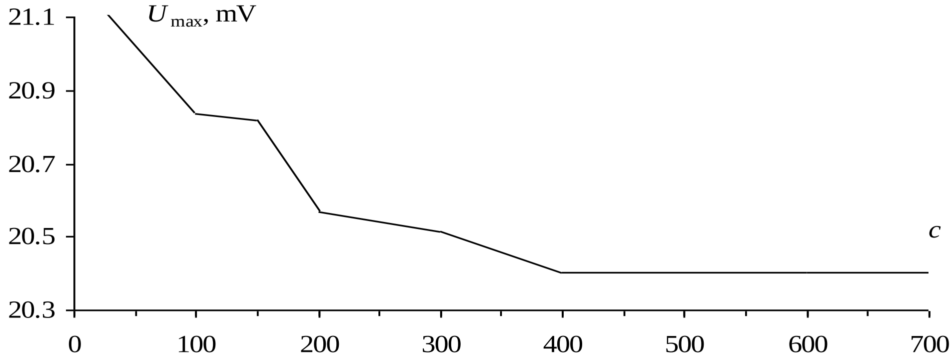

Figure 4. The relation of the U_{max} and the number of GA calculations.

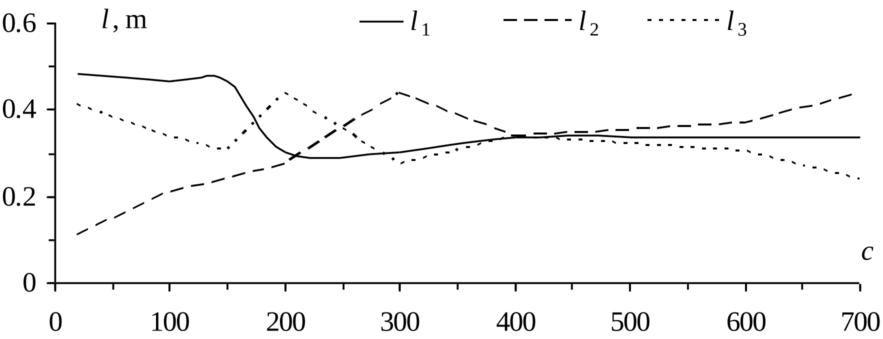

Figure 5. The relation of GA variables and the number of calculations**.**

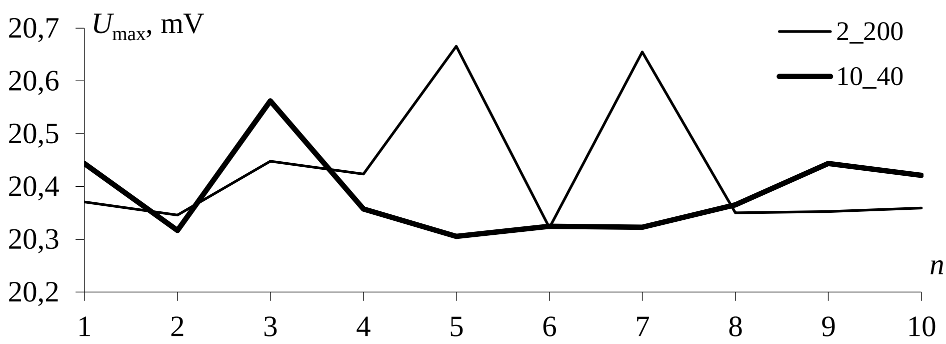

Figure 6. The relation of the U_{max} and GA run with different parameters.

4. Discussion of results

The U_{max} decreases from 21.13 mV to 20.4 mV with grow the *c* up to 400, but after (600 and 700 calculations) it almost does not change (figure 5). So we can conclude that at this number of GA calculations, GA finds the global minimum, and it is not necessary to increase these calculations further. However, the U_{max} without optimization is 5.42 V, but after it, we can decrease it by 270 times (from 5.42 V to 20.4 mV).

We can see how the GA variables are changing in figure 5. As can be seen, if the number was up to 200 calculations, the difference between the variables was rather big, but then it became smaller, and with the number of calculations of 400, the variables had the same values. Besides, with increasing the number of calculations they began to differ again. It is interesting to see that although the values of section lengths differ (after the number of calculations 400), the voltage maximum does not differ (as we can see in figure 4).

After analyzing the results of comparison of two approaches (figure 6) it was concluded, that the first approach with the number of chromosomes 2 and the number of populations 200, has stronger difference between U_{max} with various launches rather than with the number of chromosomes 10 and the number of populations 40. But at the percent ratio, this difference is near 1.5 %, which is very small. Moreover, the values of both cases are have small differences. So, we can conclude that this choice of GA parameters does not impact on optimization results.

5. Conclusion

The optimization of a PS bus with the variation of its length using GA with 10 GA runs has been investigated. The comparison of two approaches of optimization has been done which are different by a set of chromosomes and populations with the same number of GA calculations. We managed to decrease the voltage maximum amplitude by 270 times. But the choice of its different numbers of chromosomes and populations not significantly impacted optimization results.

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