Simulating the Influence of Electrostatic Discharge on a Spacecraft Power Supply Bus

Rustam R. Gazizov
Department of Information System of Security
Tomsk State University of Control Systems and Radioelectronics
Tomsk, Russian Federation
gazizovtsk@yandex.ru

Ruslan R. Gazizov
Department of Television and Control Tomsk State University of Control Systems and Radioelectronics
Tomsk, Russian Federation
ruslangazizow@gmail.com

Timur T. Gazizov
Department of Television and Control Tomsk State University of Control Systems and Radioelectronics
Tomsk, Russian Federation
timurtsk@gmail.com

Abstract—**The paper investigates the influence of electrostatic discharge (ESD) on a spacecraft power supply bus. The simulation of the ESD propagation along the conductors of the power supply bus was carried out for the cases when the start and the end signal propagation nodes are located both in the branch conductors and in the central part of the power supply bus. The signal waveforms were calculated for each simulation case: at the input, and the output of the conductor, with the voltage maximum and minimum. It was revealed, that the voltage maximum was 671 V and the voltage minimum was minus 227 V. The crosstalk maximum was 179 V.**

Index Terms—**simulation, electrostatic discharge, power supply bus, voltage maximum, voltage minimum.**

I. Introduction

Nowadays, space exploration is developing at a rapid pace, which affects the quality of the created satellites and the requirements for their components. The main trends in this are the increase of interference immunity and reliability of the spacecraft being created, along with the decrease in its overall dimensions. To ensure interference immunity and reliability, it is necessary to take into account all possible signals and influences appearing during spacecraft operation. The interesting statistics of failures that occurred on the spacecraft and led to dramatic losses or even the loss of the spacecraft itself has been presented in [1]. It shows that the most common cause of these is electrostatic discharge (ESD). Indeed, a similar problem has been known for a long time and is being actively studied by physical scientists. For example, the interference induced on conductors from radiation caused by ESD in a spacecraft has been studied in [2]. Possible crosstalk interference and, in particular, ESD during spacecraft operation have been investigated in [3]. A new method for predicting how ESD will be distributed in the components of a spacecraft is proposed in [4]. A new method for protecting spacecraft equipment from ESD based on nanoconductive insulators has been developed in [5]. However, the authors of this work were attracted by how ESD will affect the power supply bus of a spacecraft, as well as in what places its voltage maximum and minimum will be detected.

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The aim of this work is to investigate the influence of ESD on a spacecraft power supply bus.

II. Simulation Parameters

The power supply bus, which the research laboratory “Security and Electromagnetic Compatibility of Radioelectronic Equipment” in TUSUR is developing for JSC “Information Satellite Systems Reshetnev” was chosen as a research structure. A new design for the power supply bus is being developed to reduce the spacecraft mass and increase interference immunity of the spacecraft onboard cable network. As an excitation, we chose ESD since it is the main cause of both partial disruption of the spacecraft’s nodes and its complete failure [3]. ESD parameters are given in [6]. The ESD current shape is set according to IEC 61000-4-2 [7]. A feature of this article is that investigation of the propagation of ESD on a spacecraft Power Supply Bus are carried out for the first time. The modeling tasks are to investigate the interference from an active conductor to a passive conductor, to investigate the influence of the geometric parameters of the device on the distribution of ESD, to investigate the features of ESD propagation along the entire conductor. The signal was applied at 4 different points on a spacecraft power supply bus and examined at each point on the conductor. This method allows understanding how ESD changes along the entire length of the spacecraft power supply bus conductor The computer simulation software of the electromagnetic compatibility TALGAT and the quasistatic analysis were used in the investigation.

Two cases of the circuit diagrams of the power supply bus are presented in Fig. 1. The difference in the circuit diagrams is in the place of ESD excitation. It is important to note that the bus in the circuit diagram is in the center of the diagram and consists of 4 Multi-Conductor Transmission Line (MCTL) sections (7–10). Other MCTL sections are branch conductors of the power supply bus. The length of MCTL sections 1–4, and 13–16 is 0.5 m, 9–12 is 1 m, 5–8 is 0.03 m, 6 and 7 is 0.25 m. All resistors are 50 Ohm.

In the first case, ESD excitation was applied to the side branch conductor (MCTL section 1), and in the second case—to the central branch conductor (MCTL section 5), as shown in Fig. 1.

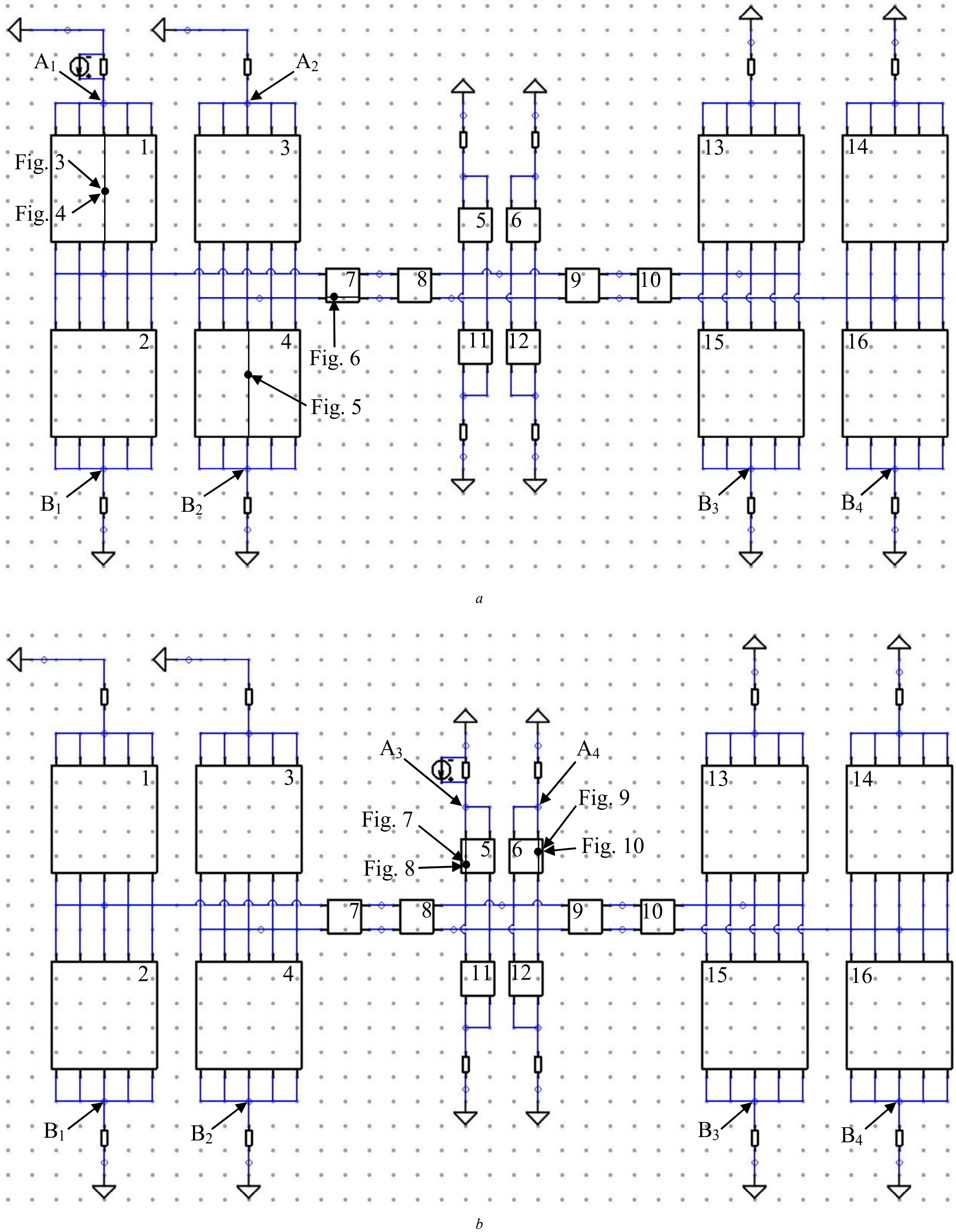

Fig. 1. Circuit diagrams of the power supply bus with an ESD source in the side (*a*) and central branch conductors (*b*)

The simulation was performed as follows: first, we selected the start node (A), in which the signal waveform was calculated; and then the end node—where this signal will arrive (node B). In both cases, 4 simulations were performed: in the conductor under the influence of ESD (nodes A_1–B_1, A_1–B_3 in Fig. 1 *a*; nodes A_3–B_1, A_3–B_3 in Fig. 1 *b*) and the crosstalk interference was calculated in the neighbor conductor (nodes A_2–B_2, A_2–B_4 in Fig. 1 *a*; nodes A_4–B_2, A_4–B_4 in Fig. 1 *b*). In Fig. 1 *a*, the arrows show the localization points of the voltage maximum which waveforms are presented in Figs. 2–5. Fig. 1 *b* presents similar results for the second case. Each MCTL section is divided into 10 segments; in each the signal waveform was calculated. However, the graphs show only most important results: the signal waveform at the beginning and at the end of the conductor, as well as with the voltage maximum and minimum.

III. Simulation Results

The voltage waveforms calculated between nodes A_1 and B_1 are shown in Fig. 2, where U_b is the waveform at the input of the conductor, U_e—at the output, $U_{\max}$ is the waveform with the voltage maximum, $U_{\min}$—with the voltage minimum. Similar results are shown in Fig. 3 (for nodes A_1 and B_3), Fig. 6 (for nodes A_3 and B_1) and Fig. 7 (for nodes A_3 и B_3). The crosstalk waveforms calculated in the neighboring conductor between nodes A_2 and B_2 are presented in Fig. 4. Similar results are shown in Fig. 5 (nodes A_2 and B_4), Fig. 8 (nodes A_4 and B_2) and Fig. 9 (nodes A_4 and B_4).

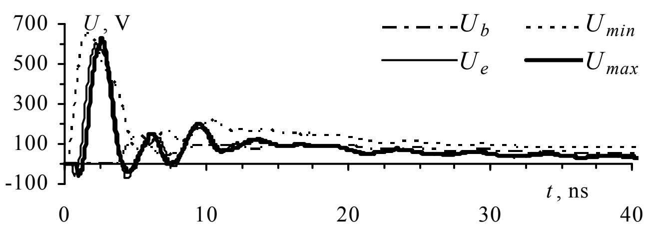

Fig. 2. Voltage waveforms from node A_1 to B_1

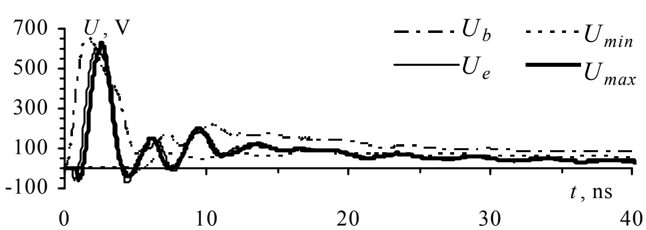

Fig. 3. Voltage waveforms from node A_1 to B_3

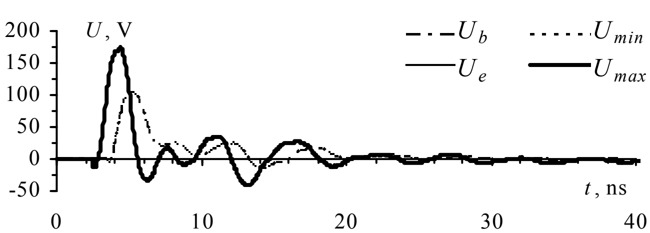

Fig. 4. Voltage waveforms from node A_2 to B_2

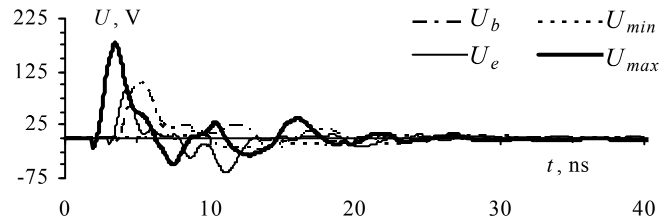

Fig. 5. Voltage waveforms from node A_2 to B_4

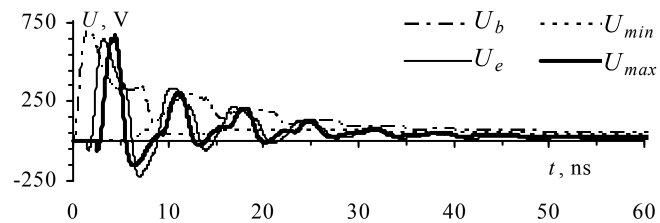

Fig. 6. Voltage waveforms from node A_3 to B_1

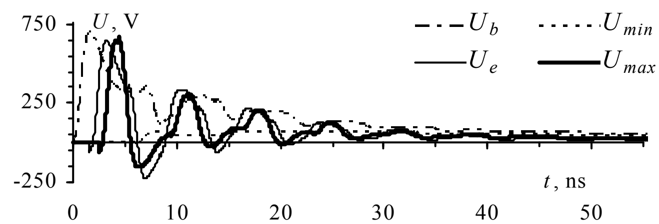

Fig. 7. Voltage waveforms from node A_3 to B_3

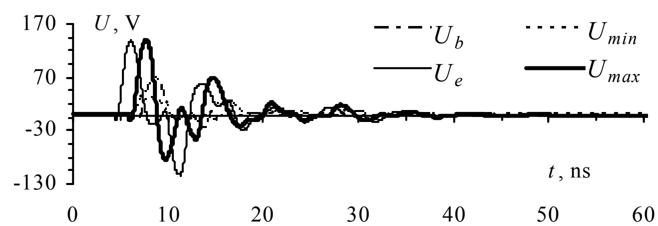

Fig. 8. Voltage waveforms from node A_4 to B_2

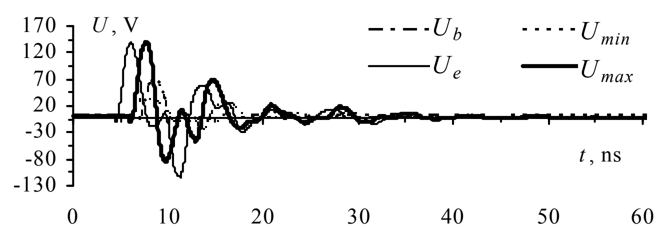

Fig. 9. Voltage waveforms from node A_4 to B_4

TABLE I. LOCALIZATION AND VALUES OF VOLTAGE MAXIMUM

Fig.	MCTL Section	Segment	U_{max}, V
2	1	5	634
3	1	5	634
4	3	5	176
5	8	1	179
6	5	3	671
7	5	3	671
8	6	8	141
9	6	8	141

TABLE II. LOCALIZATION AND VALUES OF VOLTAGE MINIMUM

Fig.	MCTL Section	Segment	$U_{\min}$, V
2	1	7	-30
3	1	7	-73
4	4	6	-42
5	9	5	-65
6	5	6	-227
7	5	6	-227
8	6	3	-115
9	6	3	-115

IV. DISCUSSION OF RESULTS

Consider the voltage waveforms shown in Fig. 2. The maximum is located in segment 5 of the MCTL section 1. The main pulse of 634 V was observed, as well as two more, with smaller amplitudes: 130 V and 150 V. In addition, the voltage minimum of minus 30 V was detected, which is not so significant comparing to the maximum amplitudes.

Consider the voltage waveforms shown in Fig. 3. The situation is similar to the previous one since the maximum and minimum values are located in the same place.

Consider the voltage waveforms shown in Fig. 6. The maximum is located in segment 3 of the MCTL section 5. The main pulse of 674 V was observed, as well as three more with smaller amplitudes: 299 V, 208 V and 65 V, respectively. In addition, the voltage minimum of minus 227 V was detected, which is also significant comparing to the maximum amplitudes.

Consider the voltage waveforms shown in Fig. 7. The situation is similar to the previous one since the voltage maximum and minimum values are located in the same place.

Consider the crosstalk waveforms from the ESD excitation in the neighboring conductor. As shown in Fig. 4, the crosstalk maximum of 176 V was observed. In addition, several more pulses of different polarity are observed, with an absolute value of up to 35 V. The crosstalk maximum is located in segment 4 of the MCTL section 4. Also, the voltage minimum of minus 45 V was detected.

As shown in Fig. 5, the crosstalk maximum of 179 V was observed. In addition, several more pulses of different polarity were observed, with an absolute value of up to 37 V. The crosstalk maximum is located in the segment 1 of the MCTL section 8. Also, the voltage minimum of minus 65 V was detected.

Consider Fig. 8, in which we see the crosstalk maximum of 141 V. Also, there are two more negative pulses with amplitudes of 90 and 50 V. In addition, there is a second positive pulse with amplitude of 70 V. The voltage maximum is located in segment 8 of the MCTL section 6. The voltage minimum of minus 115 V was revealed also.

In Fig. 9, the situation is similar to the previous one since the voltage maximum and minimum are located in the same place.

Consider the tables of localization and values. The maximum amplitude of the voltage maximum obtained by the ESD excitation on the central branch conductors of the power supply bus is 671 V (Fig. 6, 7). There is also the highest amplitude of the minimum of minus 227 V obtained in this case.

V. CONCLUSION

The presented results demonstrate that the highest values of the voltage maximum were obtained in the case when the ESD excitation was performed on the central branch conductor of the power supply bus. Moreover, the situation is similar to the voltage minimum. In addition, it is shown that such excitation generates significant amplitudes of crosstalk on the neighboring conductor.

Thus, the study shows the examples of evaluating the influence of the ESD excitation on the power supply bus. Similarly, it is possible to evaluate the common-mode and differential-mode excitations of ESD. There is also a possibility to study this power supply bus with other parameters of ESD and the bus itself.

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