Simulation of ESD Effects on PCB Bus of Spacecraft Autonomous Navigation System

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***Abstract*—Importance of an investigation of the ESD effects on a printed cictuit board (PCB) bus of spacecraft autonous navigation system is highlighted. Simulation results of the ESD signals propagation along the conductors of the PCB bus are presented. The ESD current source according to the IEC 61000-4-2 was used. The peak voltage of 471 V in the active conductor of the bus with 50 Ohm terminations was obtained. The crosstalk peak voltages in the passive conductors were in the range of 1–32 V.**

Keywords—electrostatic discharge; printed circuit board; autonomous navigation system; quasistatic analysis; spacecraft.

I. Introduction

Nowadays the researchers of electromagnetic compatibility (EMC) field have properly studied a problem of the electric signals propagation in multiconductor transmission lines (MCTL) [1]. However, the study of particular aspects of the ultrashort pulses propagation along conductors of high density printed circuit boards (PCB) remains important, because of uncontrolled propagation possibilities [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 EMC. 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 voltage amplitude measurements. The quasistatic 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 quasistatic 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], wherein 3 fixed durations of the ultrashort pulse were considered. Meanwhile, the bus investigation with the variation of the ultrashort pulse durations and forms is important for radioelectronic equipment performance and interference immunity increasing. Indeed, for performance increasing duration of useful signals is decreased, while shorter interfering signals are more dangerous. Therefore, the importance of genetic algorithms usage in the investigations with variation of ultrashort pulse duration is emphasized in [13]. The optimization results for the ultrashort pulse duration by maximization criteria of peak voltage in the autonomous navigation system (ANS) PCB bus are also presented in this paper. Meanwhile, the one ultrashort pulse in trapezoidal form only (with different durations also) was used as the excitation in these investigations. But it is important to investigate this ANS PCB bus under other excitations, for example, electrostatic discharge (ESD).

The purpose of this work is to investigate the ANS PCB bus under the ESD excitation.

II. Structure under Simulation and Excitation Parameters

The theoretical bases of quasistatic response calculation along the each conductor of the each MCTL section are presented in details in [8]. ANS PCB bus investigated in [13] was taken as a structure for the investigation. PCB fragment is presented in Fig. 1. The circuit diagram of the investigated bus is described in details in [13]. The bus conductors have its own numbers which are presented in Fig. 1.

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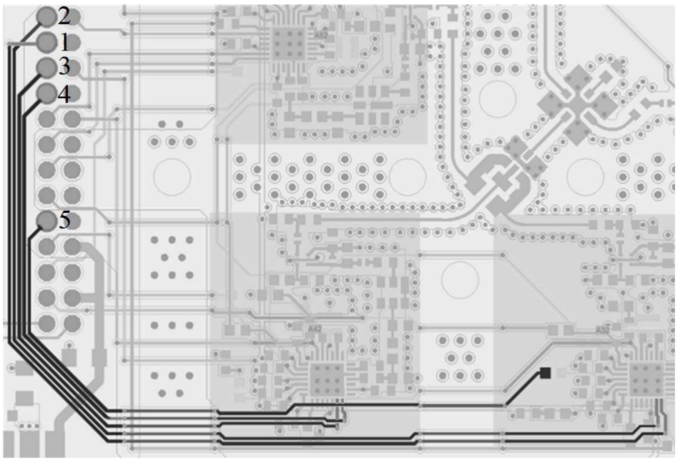

Fig. 1. Investigated bus on the ANS PCB fragment

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.

The ESD, which parameters and the selection justification are described in [14] was chosen as excitation. The current form according to the IEC 61000-4-2 [15] standard was used. It was excited on each conductor by turns and the voltage waveforms were calculated along the each conductor. Also the case was considered when the all conductors except the central were under the ESD excitation.

III. Simulation Results

Simulation results when the four conductors were active and the central one was passive are presented in Fig. 2. We should remark that the crosstalk waveforms only are shown in the last case, because it is more interesting. Also, signal waveforms in the active conductors are almost the same and would be shown in the later cases. Simulation results for the first active conductor are presented in Fig. 3, for the second – in Fig. 4, for the third – in Fig. 5, for the forth – in Fig. 6, and for the fifth – in Fig. 7, where U_b and U_e are the voltage waveforms at the input and output respectively.

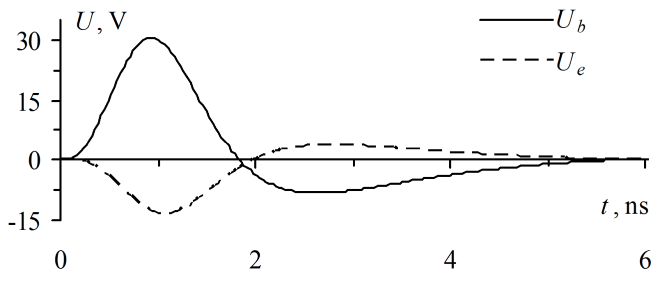

Fig. 2. Signal waveforms along the conductor 3 with active conductors 1, 2, 4, 5

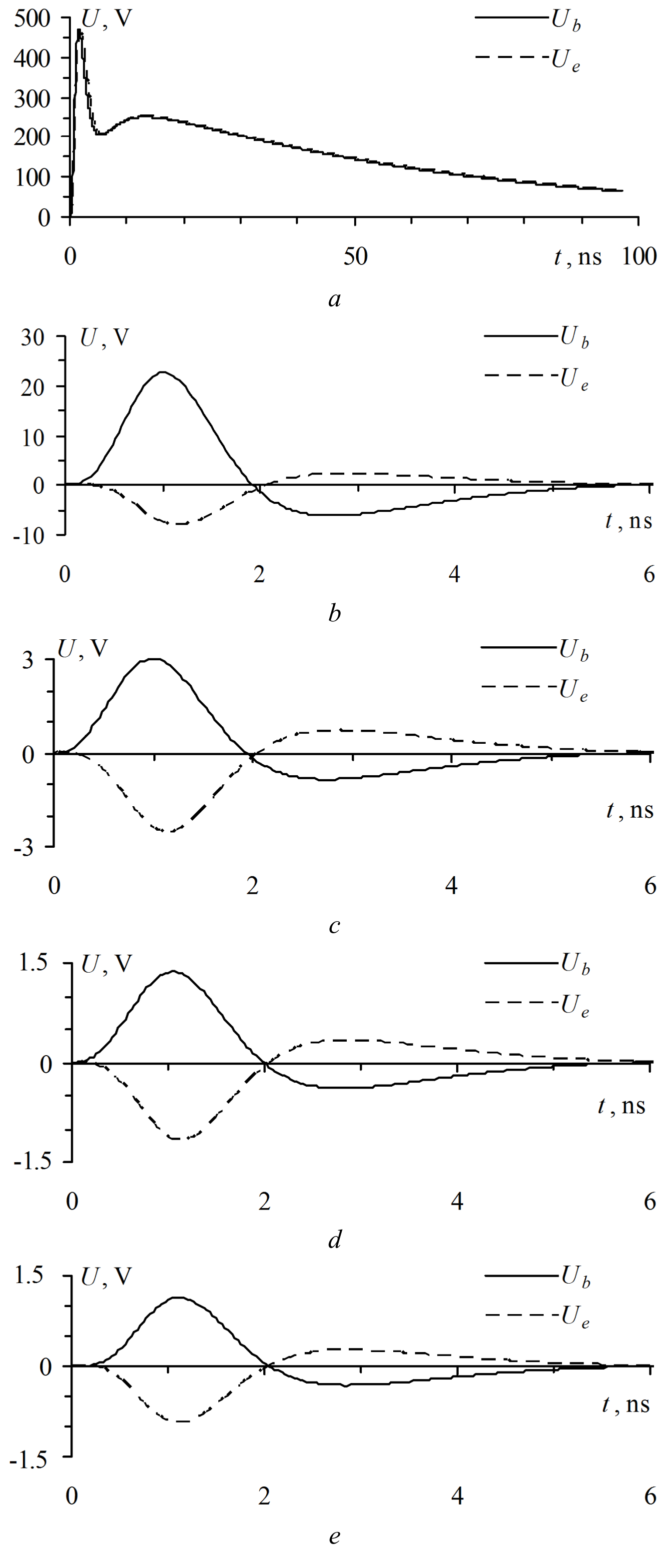

Fig. 3. Signal waveforms along the conductors 1 (*a*), 2 (*b*), 3 (*c*), 4 (*d*) и 5 (*e*) when when the active was the conductor 1

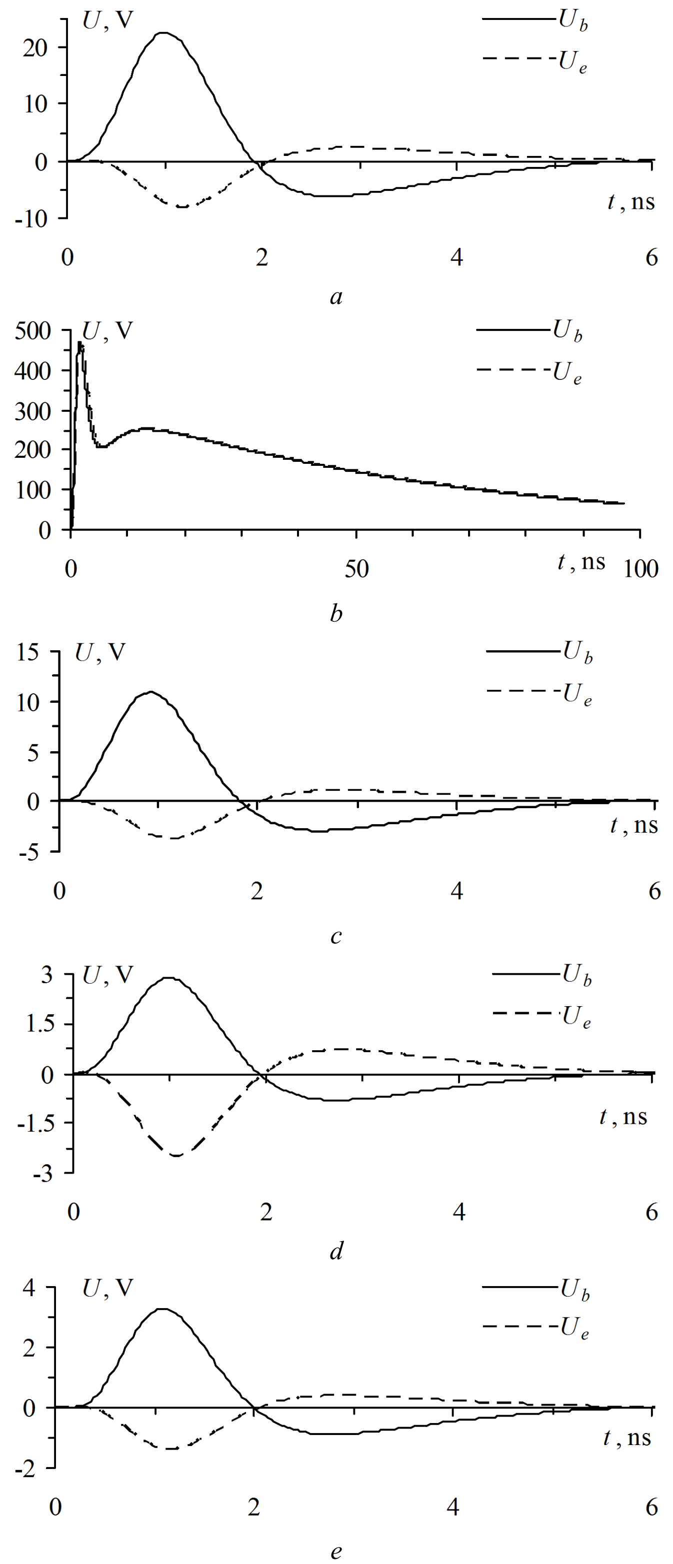

Fig. 4. Signal waveforms along the conductors 1 (*a*), 2 (*b*), 3 (*c*), 4 (*d*) и 5 (*e*) when the active was the conductor 2

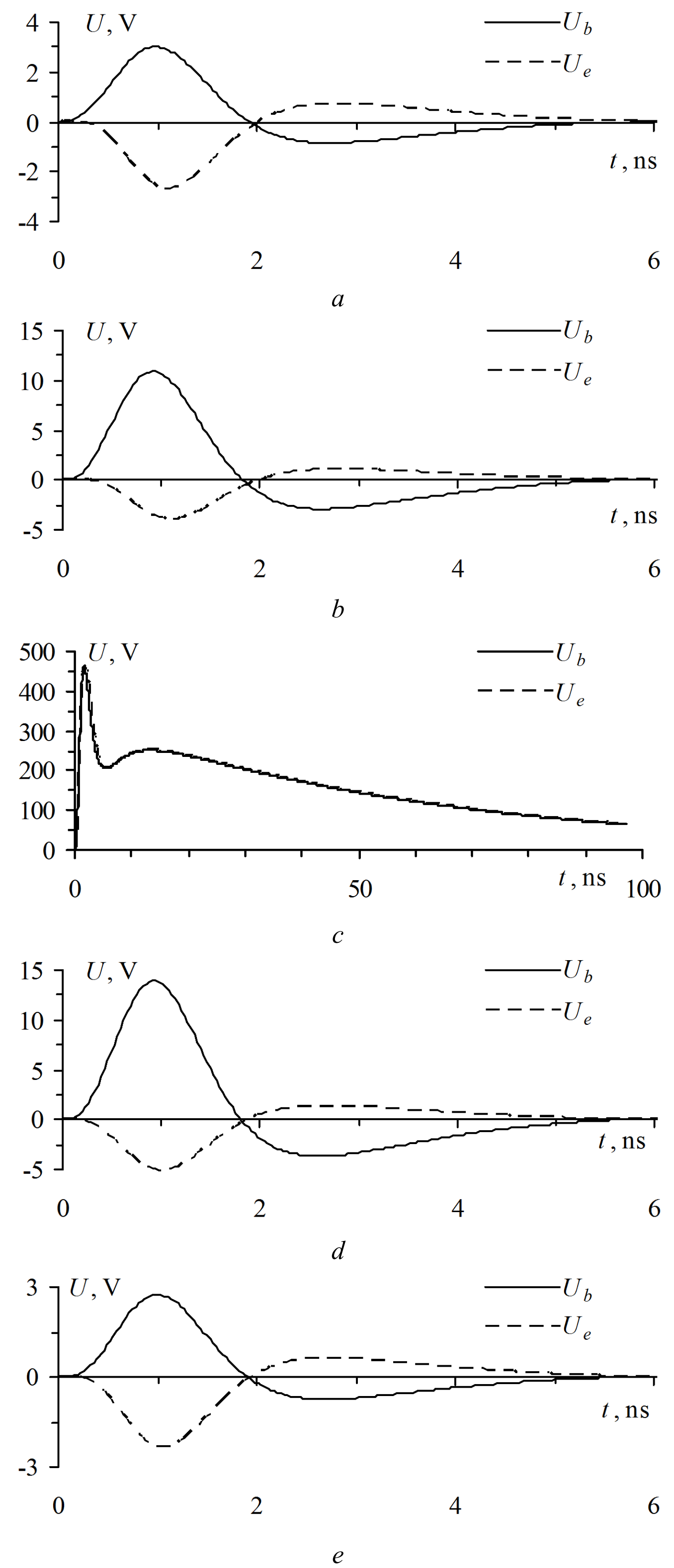

Fig. 5. Signal waveforms along the conductors 1 (*a*), 2 (*b*), 3 (*c*), 4 (*d*) и 5 (*e*) when the active was the conductor 3

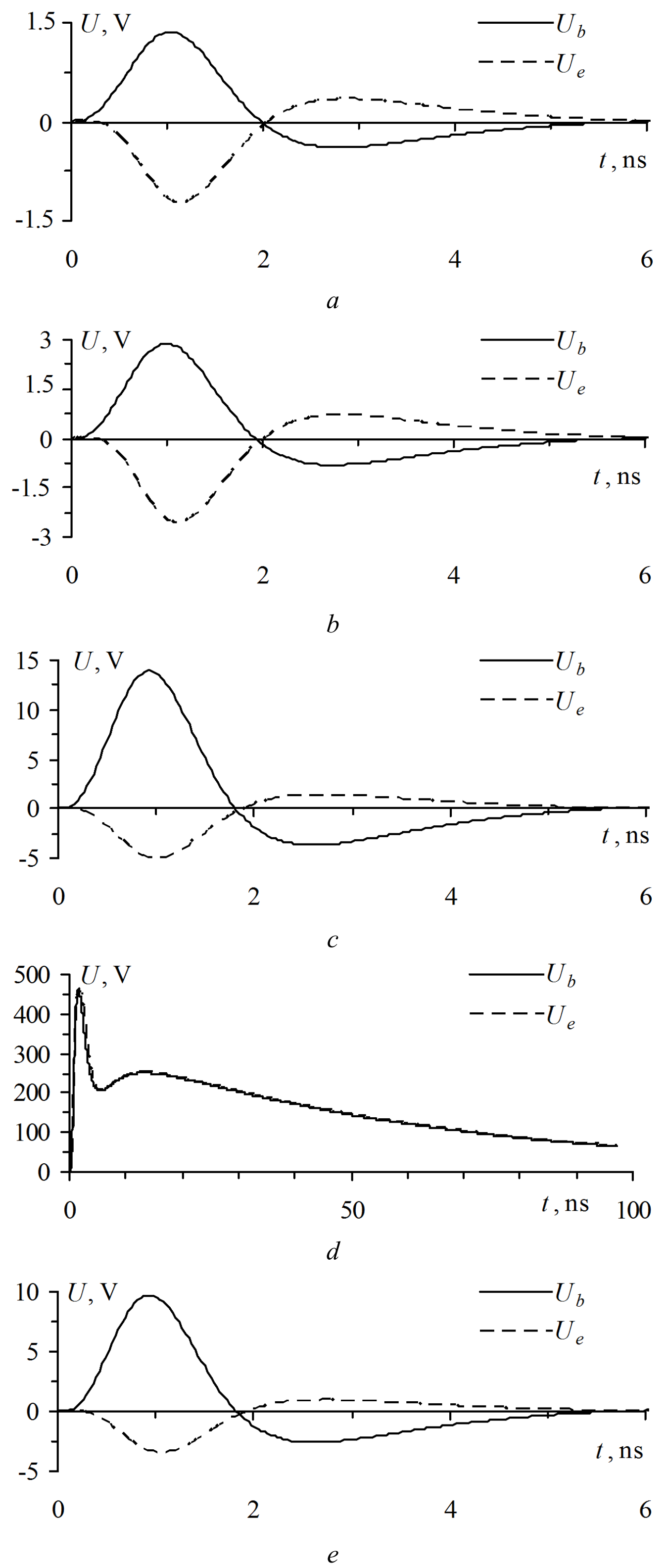

Fig. 6. Signal waveforms along the conductors 1 (*a*), 2 (*b*), 3 (*c*), 4 (*d*) и 5 (*e*) when the active was the conductor 4

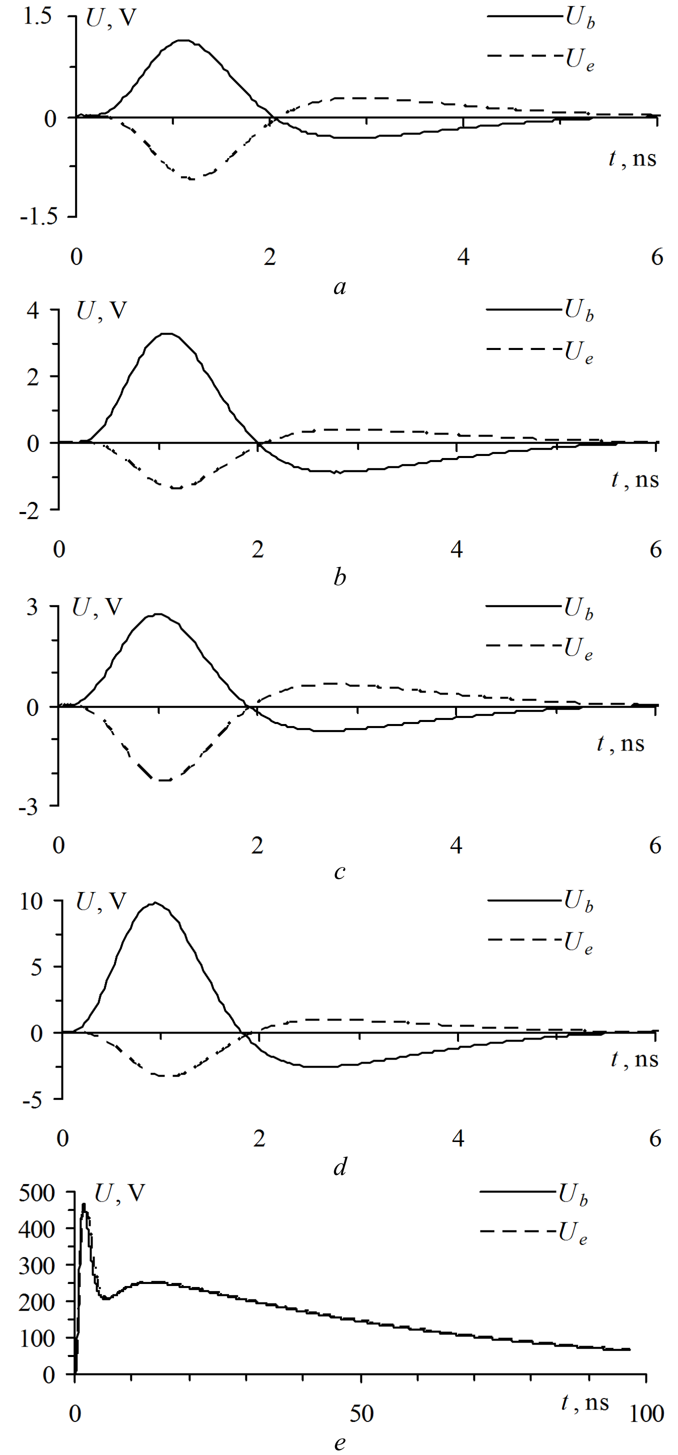

Fig. 7. Signal waveforms along the conductors 1 (*a*), 2 (*b*), 3 (*c*), 4 (*d*) и 5 (*e*) when the active was the conductor 5

IV. Discussion of Results

Let us consider the signal waveforms when an active was the conductor 1. The voltage amplitude of 470 V which is rather dangerous for integrated circuits (IC) is observed in this conductor (Fig. 3 *a*). Peak voltage values coincide with the voltages at the input or the end of the conductor, so they are not shown in the figures. The highest crosstalk amplitude is in the conductor 2 (Fig. 3 *b*). It is 5% only of the signal level in the active conductor but equals to 24 V that is rather dangerous. The significant negative voltage (minus 7 V) is revealed in this conductor also. The crosstalk amplitude decreases from 3 V to 1 V in conductors 3–5.

Let us consider the signal waveforms when an active was the conductor 2. The voltage amplitude in the active conductor is the same with the amplitude from the case 1 (about 470 V). The highest crosstalk amplitude is revealed in the conductor 1 (Fig. 4 *a*). It is 23 V that is 4.8% of signal level in the active conductor. Also the high crosstalk amplitude (13 V) is in the conductor 3 (Fig. 4 *c*) that is 2.7% of signal level in the active conductor. The crosstalk amplitudes in the conductors 4 and 5 are almost the same and are 3 and 3.2 V respectively. But it is remarkable that the crosstalk is a bit higher in the far conductor than the crosstalk in the near one.

Let us consider the signal waveforms when an active was the conductor 3. The signal amplitude in the active conductor is like in previous cases. The highest crosstalk amplitude is revealed in the conductor 4 (Fig. 5 *d*). It is 14 V that is 2.9% of signal level in the active conductor. Also we should remark that the crosstalk amplitude revealed in the conductor 2 is 11 V. The crosstalk amplitudes in the far conductors are 3 V.

The situation with active conductor 4 is similar: the crosstalk amplitudes in the neighbor conductors are 14 V and 10 V (Fig. 6 *c*, *e*). The crosstalk amplitudes in the far conductors are 3 V and 1.5 V (with distance from the active conductor). The highest crosstalk amplitude with the active conductor 5 is also in the near conductor and is 10 V (Fig. 7 *d*). The amplitudes in the other conductors decrease from 4 V to 1.5 V.

Let us consider the case with 4 active conductors when the central one was passive (Fig. 2). The crosstalk amplitude in this case is 32 V that is 6.8% of the signal level in the active conductors. The significant negative voltage (minus 14 V) is also observed. Comparing this case with the first one we can see that the positive voltage is greater by one third, and the negative voltage – by two times.

Therefore, the highest crosstalk amplitude is in the last case (with 4 active conductors) and the smallest crosstalk amplitude in the conductor being neighboring to the active one is in the case with active conductor 5.

V. Conclusion

This work shows the importance of the ANS PCB bus investigation under the ESD excitation. Simulation of ESD excitation on the different bus conductors (including at once several) has been carried out. First of all, it shows that the considerable peak voltages along the investigated bus conductors (higher than the voltages at the ends of the conductors) do not appear under the ESD excitation (in contrast to the ultrashort pulse [11, 12, and 13]). It is also important that the voltage amplitude in the active conductor can be near 0.5 kV and disable the IC. The crosstalk can be also dangerous because it can be deemed in many circuits as the useful signal (1–2 ns, 1.5–24 V) and be the reason of IC upset. Indeed, the highest crosstalk amplitudes are 32 V (Fig. 2), 24 V (Fig. 3), 23 V (Fig. 4), 14 V (Fig. 5, 6), 10 V (Fig. 7). Also we should remark that these results are obtained for the resistances of 50 Ohm while the high input impedance of real IC cans double these values. Such amplitudes can strongly influence on operation of radioelectronic equipment of critical assignment. Therefore, it is necessary to give more attention to EMC providing in such equipment, the spacecraft in particular. And the methodology used in this paper is completely applicable for this.

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