Optimization of Protective Varnish Thickness for Crosstalk Minimization in Multiconductor Bus of Spacecraft PCB

Roman S. Surovtsev, Talgat R. Gazizov

***Abstract*— The results of the optimal choice of the protective varnish thickness for crosstalk minimization in multiconductor bus of spacecraft printed circuit board are presented. The investigation for various resistances at the bus ends is performed: a case close to matching (all resistances of 50 Ω), mismatch at the end (resistances of 50 Ω at the beginning of the bus, 1 MΩ – at the end), full mismatch (resistances of 5 Ω at the beginning of the bus, 1 MΩ – at the end). As a result, it was found that in the case of a full mismatch, due to the simple increasing of the varnish layer thickness, it is possible to reduce the amplitude of the near-end crosstalk of the bus; and by choosing the optimum thickness value of the varnish layer, the amplitude of the far-end crosstalk can be reduced almost by half.**

***Index Terms*—electromagnetic compatibility, crosstalk, protective varnish**

I. Introduction

NOWADAYS radio electronic equipment (EE) is widely used in almost all spheres of human activity. Therefore, the correct and uninterrupted work of EE depends on the safety of each person and of modern society at large. In this regard, one of the urgent tasks of EE designing is to provide electromagnetic compatibility (EMC) of critical systems, for example on-board equipment of a spacecraft. This is because of the complex electromagnetic environment, use of the unpressurised body together with the high circuit density and the increasing of the spectrum upper frequency limit of signals used. The solution of new tasks requires the increasing the number of the spacecrafts simultaneously operating in Earth's orbit and the increasing their active shelf life. For example, the Global Navigation Satellite System requires 24 simultaneously operating spacecrafts.

To ensure EMC of spacecraft equipment the system tests under the conditions of stringent electromagnetic environment are performed [1]. It is recommended to carry out this tests in frequency range up to 1, 18, 20 and 100 GHz [2–5]. The traditional means of EMC assurance are electromagnetic shields, but their effectiveness is worsened by the apertures and resonances of an enclosure at high frequencies. Then, high-frequency electromagnetic interference, bypassing the enclosures, can penetrate into EE and, due to high field density, disable low-frequency circuits of the on-board EE. Besides the reducing of protective effectiveness the additional shielding leads to the increasing of the spacecraft weight and so the cost of the placement into orbit. Finally, if, as a result of the tests, incompliance is revealed, then it is not always evident what changes for the design of the printed circuit board (PCB) and electrical circuits are necessary in order to successfully pass the repeated tests [6]. This leads to the relevancy for repeated testing, which leads to the additional costs. The solution of this problem is the preliminary simulation and assurance of EMC at the spacecraft equipment designing stage.

At the spacecraft PCB designing stage, developers must solve problems of signal integrity. As for spacecraft equipment, thematic issues of the leading EMC journal – IEEE Transactions on EMC are useful. Issues dealing with aerospace EMC [7], signal integrity, power integrity and EMC at the PCB level [8] are especially urgent. Special attention in the context of signal integrity assurance is given to crosstalk in the PCB interconnections. The exceeding of the permissible interference level degrades the internal system electromagnetic environment, and can lead to the spacecraft malfunction or loss.

Many approaches for decrease or cancellation of the crosstalk in the PCB interconnections are known. So, there are known approaches to the crosstalk reduction in the pair of coupled microstrip lines by means of defected conductor [9] and a conductor with a step shaped form [10]. There are also known the reduction of interference in multiconductor lines due to changes in dielectric filling parameters [11], including anisotropic [12]. One of the approaches to crosstalk cancellation is interesting because it is based on mounting of guard trace between the signal conductors [13–15]. The results of the simulation of a coupled line with a guarded trace grounded at one end and with open circuit at the other where the crosstalk reduction is shown to be more than 50% are interesting [15]. In a pair of connected lengthful lines, far-end crosstalk has a greater amplitude compared to the near-end, so more attention is attended to the far-end crosstalk cancellation [16–21]. The investigation of the dependence of far-end crosstalk level in the coupled four-conductor transmission line (with zero loads at the beginning of the line and matched at

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the end) on the thickness of the additional dielectric layer and the line length is noteworthy [22]. But this study was carried out on the simple idealized structure examples and not on real spacecaft PCB. In addition, in these investigations, the emphasis is placed only on the far-end crosstalk.

The aim of this paper is to assess the possibility to choice the protective varnish optimal thickness for minimization of the crosstalk level in multiconductor interconnection of a spacecraft PCB.

II. Initial Data for Simulation

For the investigations, an eight-conductor bus on the Bottom layer of the real spacecraft PCB with length l of 74 mm was chosen (Fig. 1).

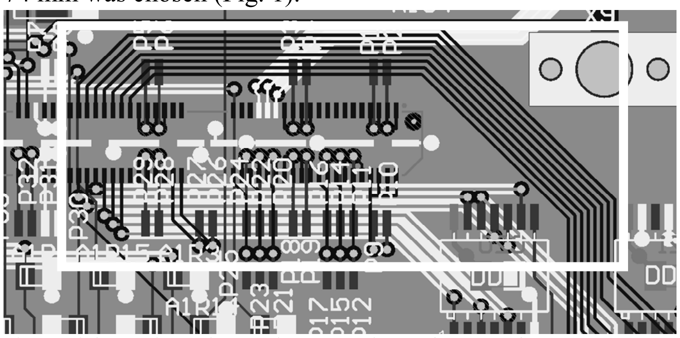

Fig. 1. Eight-conductor bus on the Bottom layer of spacecraft PCB

The PCB cross-section is shown in Fig. 2. It consists of the following layers (relative dielectric permittivity for the frequency of 1 GHz): IS420ML fiberglass (h_4=0.2 mm, ε_{r4}=4.9), IS420ML1080 prepreg (h_3=0.1446 mm, ε_{r3}=4.49), solder resist (h_2=20 μm, ε_{r5}=3.5), EP 730 protective varnish (h_1≈3×20 μm, ε_{r1}=3.5–5). The thickness of the foil on Top and Bottom layers of t_1=65 μm, the thickness of the foil on Mid 1, Mid 2, Power and Ground layers of t_2=35 μm.

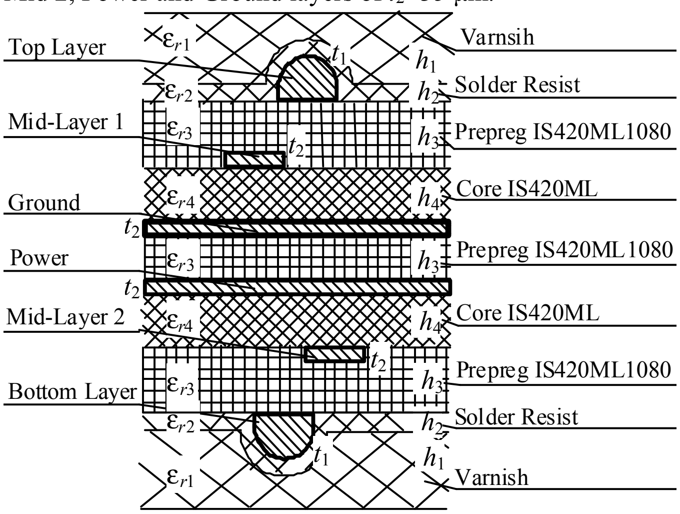

Fig. 2. The cross-section of spacecraft PCB fragment

The simplest case, when the protective varnish is coating the full bus surface is chosen for the simulation. Fig. 3 shows the fragment of the geometric model of the bus cross-section in TALGAT software [23]. The width of the conductor base (w) is 300 μm, and the space between the conductors (s) is 320 μm.

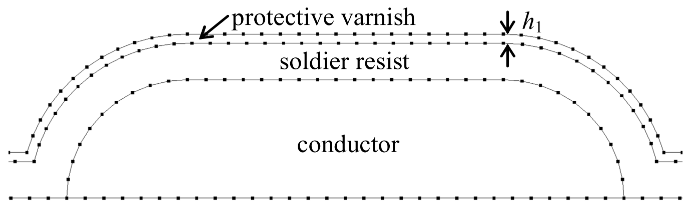

Fig. 3. Cross-section fragment of the bus in TALGAT software

To evaluate the impact of the protective varnish layer thickness in the crosstalk levels, the calculation of waveforms at the ends of passive conductors is performed. Exciting pulse has a trapezoid shape with parameters: e.m.f. amplitude 6 V, duration of the flat top of 8 ns, and the rise and fall durations of 1 ns each. For clarity, the circuit diagram of the bus is shown in Fig. 4.

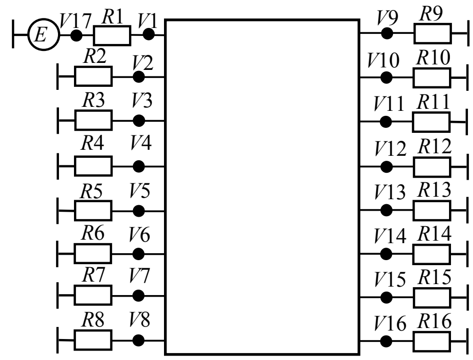

Fig. 4. Circuit diagram of the bus

III. Quasistatic Simulation of the Bus

Crosstalk level estimation is desirable for the various matching cases. Indeed, for the mismatched bus resulting signal at the bus ends is defined by superposition of incident and reflected waves of each mode of a multiconductor line. Essentially, induced signals in case of the mismatching will be close to the sum of the near- and far-end crosstalk in the matching case. The following matching cases are considered: a case close to the matching (all resistances of 50 Ω), mismatch at the end (resistances of 50 Ω at the beginning of the bus, 1 MΩ – at the end), full mismatch (resistances of 5 Ω at the beginning of the bus, 1 MΩ – at the end).

A. Simulation with 50 Ω loads

The bus simulation with 50 Ω loads was performed ($R1$=$R2$=…=$R16$=50 Ω). First case is the case when only one conductor is active (outer) and the other conductors are passive. The maximum (over all ends of the bus) crosstalk amplitude dependence on h_1 changing in the range 5, 10, …, 200 μm is given in Fig. 5.

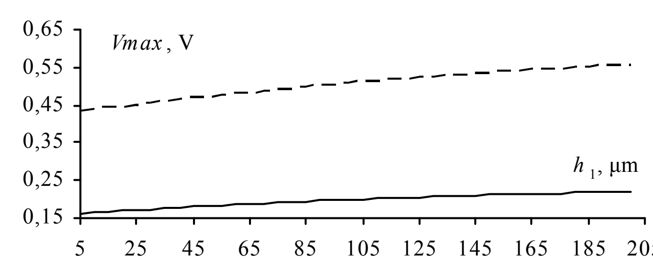

Fig. 5.The maximum crosstalk amplitude dependence from h_1 for N_{ACT}=1 (—) and N_{ACT}=7 (– –)

It is seen that the maximum crosstalk amplitude increases from 0.16 V to 0.22 V (by 40%) in the range of h_1, and its maximum level is about 3.5% of the e.m.f. level. For example, Fig. 6 shows the crosstalk waveforms at the near-end of passive conductors (the first three from the active conductor) for the extremity of the range of h_1 variation.

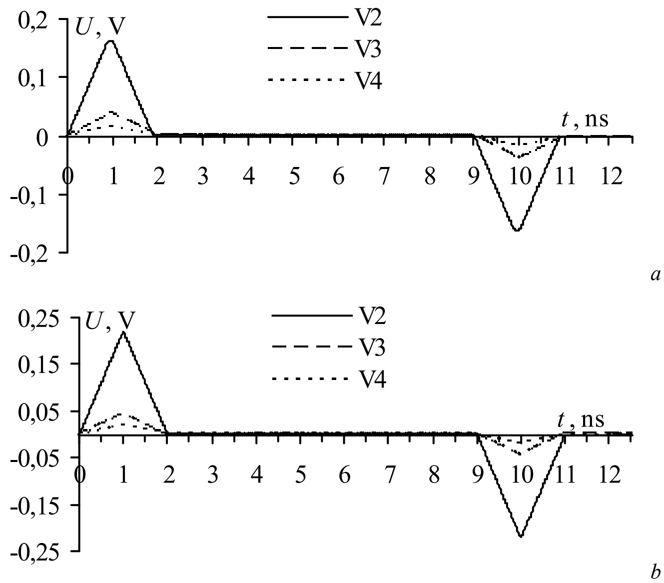

Fig. 6. Near-end crosstalk waveforms for l=74 mm, h_1=5 (*a*) and 200 μm (*b*)

The far-end crosstalk waveforms for a number of values of h_1 are shown in Fig. 7. It is seen, they behave differently: the crosstalk level on the nearest conductor decreases by 10 times, and then (when h_1 passing from 100 μm to 120 μm) it changes the polarity, and increases to 0.02 V at h_1=200 μm.

A similar simulation is performed for all possible cases of influences on the bus. At first, the source is successively moved along conductors 2–4 (the remaining cases were not considered because they are mirror), and then the number of active conductors is successively increased to 2, 3, 4, 5, 6 and 7, and they are moved over all the bus conductors. Summary results for the case when all conductors are active except central one (N_{ACT}=7) are shown in Fig. 5. From the obtained results, it is seen that the crosstalk amplitude increased of 2.5–2.65 times in the range of h_1 and can be of 5–17% of the signal amplitude in active conductor and the increasing by h_1 drive up the crosstalk amplitude by 30%.

Then, the impact of the line length increasing (l=150, 225, 300 mm) on the crosstalk waveform and amplitude was evaluated. As the result, the weak increasing of the near-end crosstalk amplitude and duration which is proportional to bus length is observed (Fig. 8).

For far-end crosstalk, with the l increasing, the amplitude increasing up to 0.13 V (8.7% of the signal in the active conductor) and the signal step duration increasing caused by the reflection from the far-end of the bus is observed (Fig. 9*a*). An increase of the protective varnish layer thickness reduces the crosstalk level to 0.05 V (3.3% of the level in the active conductor) and changes its polarity (Fig. 9b).

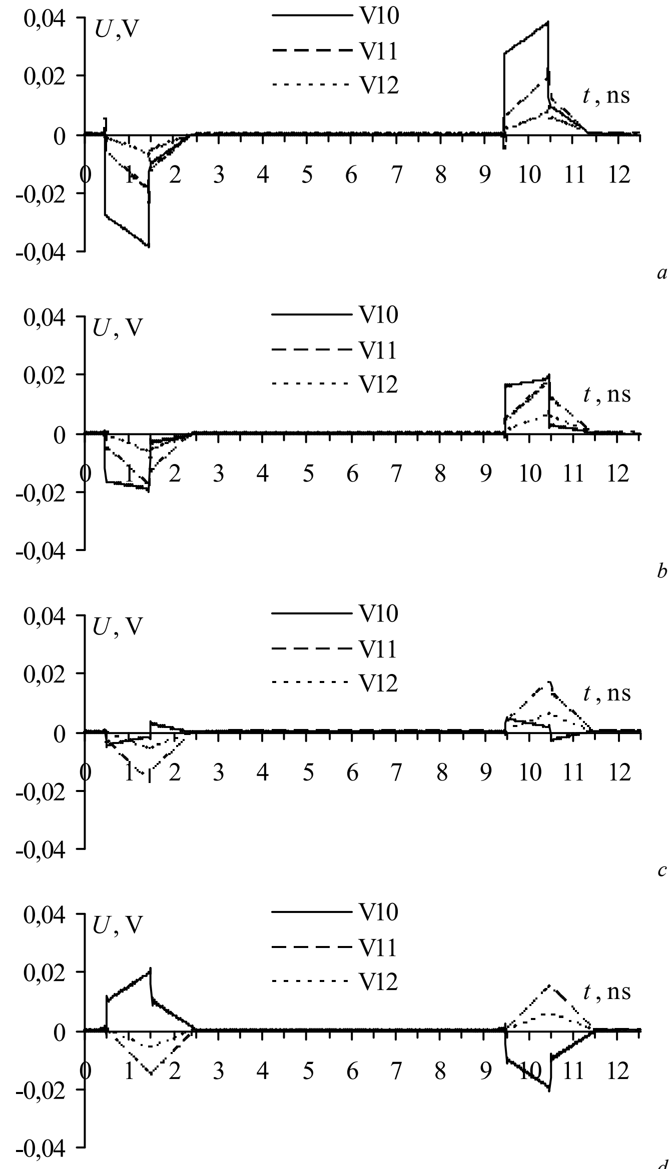

Fig. 7. Far-end crosstalk waveforms for l=74 mm, h_1=5, 50, 100, 200 μm (*a-d*)

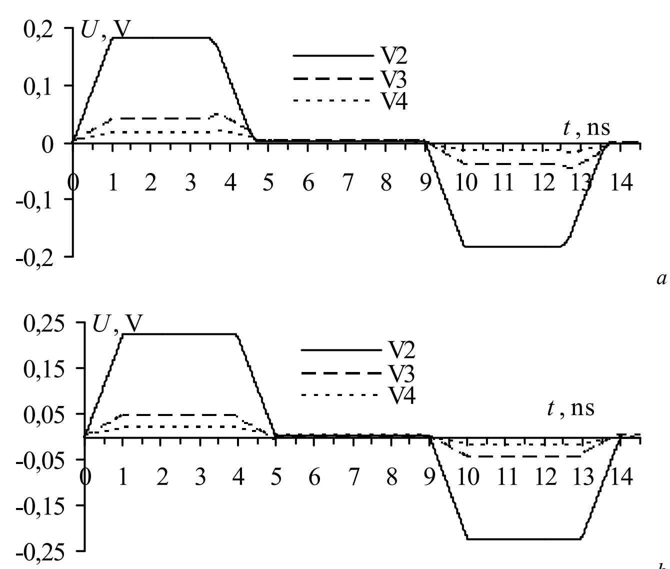

Fig. 8. Near-end crosstalk waveforms for l=300 mm, h_1= 5 (*a*), 200 μm (*b*)

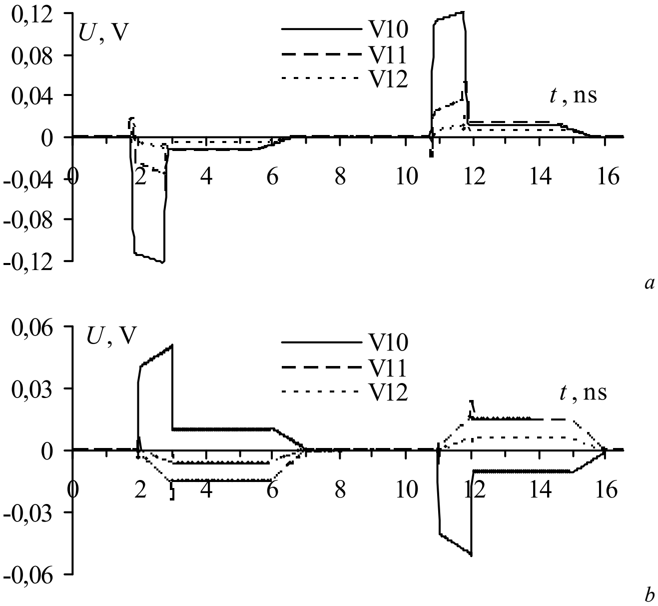

Fig. 9. Far-end crosstalk waveforms for l=300 mm, h_1= 5 (a), 200 µm (b)

B. Simulation with 50 Ω at near-end and 1 MΩ at far-end

The bus simulation with mismatching at the far-end was performed ($R$1=$R$2=…=$R$8=50 Ω, $R$9=$R$10=…=$R$16=1 MΩ) (Fig. 10, 11).

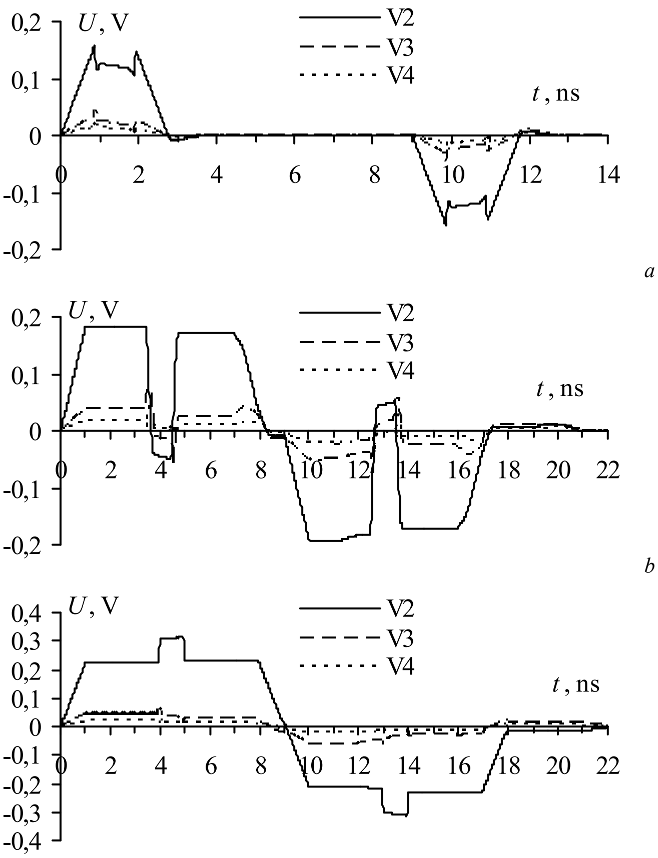

Fig. 10. Near-end crosstalk waveforms for h_1=5 µm and l=75 mm (a), l=300 mm (b) and h_1=200 µm, l=300 mm (c)

For the near-end crosstalk with minimal protective varnish thickness, a signal dip of 0.03 V is observed (2% of the signal in the active conductor) for l=75 mm and of 0.23 V (15% of the signal in the active conductor) for l=300 mm. The dip can be explained by the addition of two signal components: near-end crosstalk and crosstalk from the signal reflected from the far-end of the bus (Fig. 10a, b). The increasing of the protective varnish thickness leads to a crosstalk component from the far-end reflected signal polarity changing, increasing the peak value of the total signal to 0.32 V (21% of the signal in the active conductor) for length of 300 mm and a layer thickness of 200 µm (Fig. 10c).

For the far-end crosstalk, the addition of two signal components is observed: far-end crosstalk with the crosstalk from the signal reflected from the far-end of the bus (Fig. 12a). With the increasing of the bus length (from 75 to 300 mm) the amplitude and the duration of the sum of these components are increased (Fig. 11a, b). The protective varnish thickness increasing leads to the increasing of the components sum peak value up to 0.53 V (35% of the signal in the active conductor) (Fig. 12c).

Thus, the mismatch at the far-end leads to an increasing in the peak value of the crosstalk amplitudes at the near- and far-ends to 0.32 V and 0.53 V, respectively.

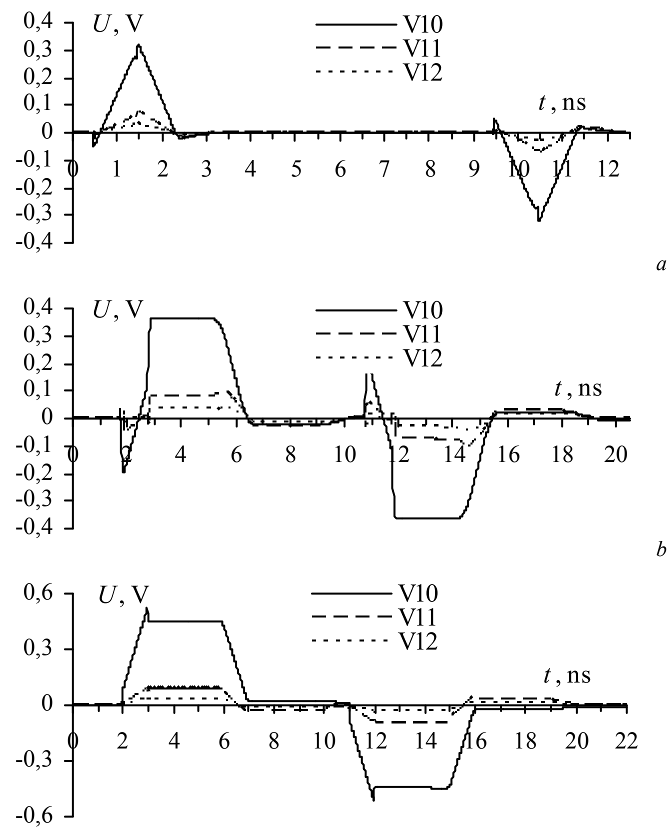

Fig. 11. Far-end crosstalk waveforms for h_1=5 µm, l=75 mm (a), l=300 mm (b) and h_1=200 µm, l=300 mm (c)

C. Simulation with 5 Ω at near-end and 1 MΩ at far-end

The bus simulation with a full mismatching was performed ($R$1=$R$2= ... =$R$8=5 Ω, $R$9=$R$10= ... =$R$16 =1 MΩ). This case simulates a small output resistance of the driver and a high input resistance of the receiver. At the near end, the oscillations are observed with amplitude up to 0.05 V (less than 2% of the level in active conductor) for l=75 mm and

0.2 V (6.6% from the signal in active conductor) for *l*=300 mm (Fig. 12*a*, *b*). The increasing of the protective varnish thickness leads to the near-end signal amplitude reducing to 0.1 V (3.3% from the signal in active conductor) for *l*=300 mm and the varnish layer thickness of 200 μm (Fig. 12*c*).

The oscillations are also observed for far-end crosstalk. With the increasing of bus length (from 75 to 300 mm), a serious increase in amplitude (from 0.55 to 1.9 V, which is 18 and 63% of the level in active conductor) and the signal duration are observed (Fig. 13). The increasing of the protective varnish thickness to 100 μm leads to decreasing of the crosstalk amplitude to 0.75 V (25% of the level in active conductor) (Fig. 14*a*), and its farther increasing to 200 μm leads to signal amplitude increasing to 1.2 V (40% of the level in active conductor) (Fig. 14*b*).

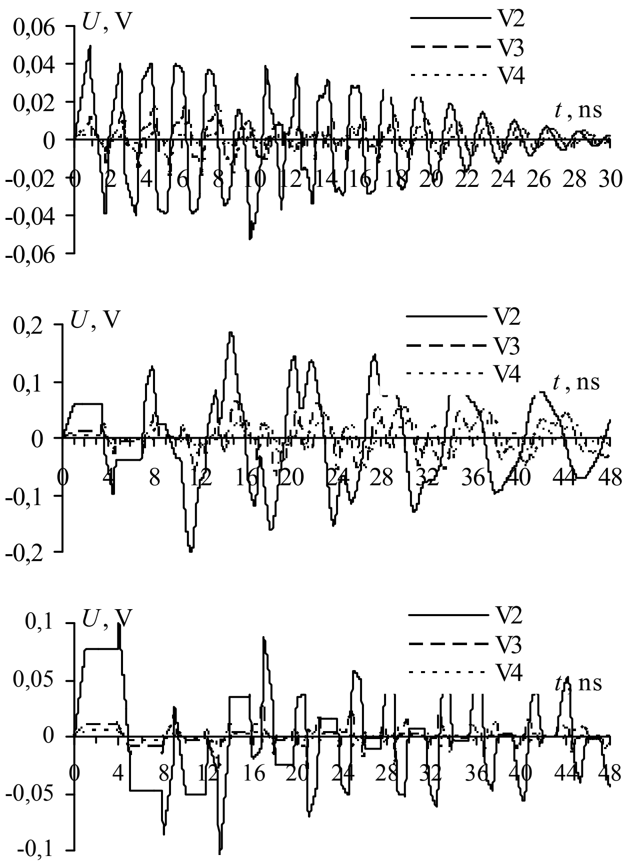

Fig. 12 Near-end crosstalk waveforms for h_1=5 μm, *l*=75 mm (*a*), *l*=300 mm (*b*) and h_1=200 μm, *l*=300 mm (*c*)

Thus, in case of a full mismatch, the crosstalk amplitude at the near-end of the line is small (up to 0.1 V), and at the far-end it is large (up to 2 V). By the protective varnish thickness increasing, it is possible to reduce the amplitude of the near-end crosstalk. By choosing the optimum thickness value of the varnish layer, the amplitude of the far-end crosstalk can be reduced almost by half. This suggests that there is a simple way to reduce the crosstalk level without changing the PCB layout and introducing additional components, namely, by choosing the optimal thickness of the protective varnish coating at the latest stage of the PCB assembly.

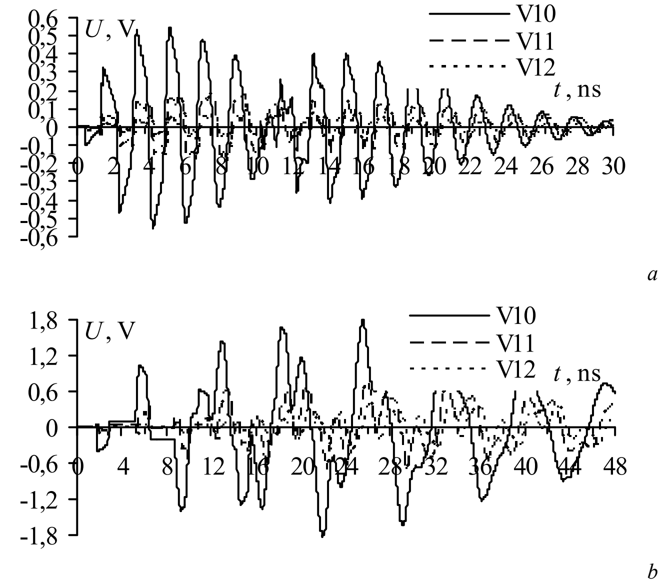

Fig. 13. Far-end crosstalk waveforms for h_1=5 μm, *l*=75 (*a*) and 300 (*b*) mm

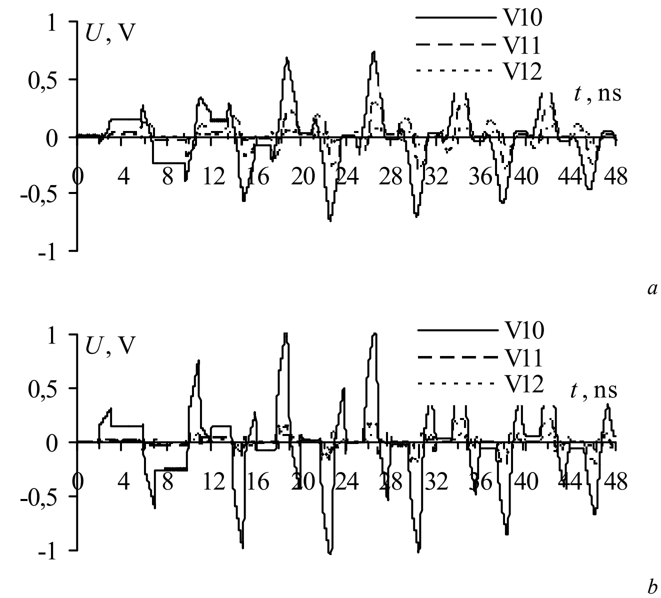

Fig. 14. Far-end crosstalk waveforms for *l*=300 mm, h_1=100 (*a*) and 200 μm (*b*)

IV. Conclusion

The task of crosstalk minimizing in multiconductor interconnects by means of the protective varnish PCB coating is quite difficult, and its solution requires the complex studies. The main part of them is a large number of computational experiments on the various and sundry examples of multiconductor interconnection with various dielectric filling and various PCB coating process. In this paper, only full protective varnish coating (when the coating layer is applied to the full PCB surface) is considered. The main result of the paper is that in the case of a full mismatch, due to the simple increasing of the protective varnish layer thickness, it is possible to reduce the amplitude of the near-end crosstalk of the bus; and by choosing the optimum thickness value of the coating layer, the amplitude of the far-end crosstalk can be reduced almost by half. The simulation results show the possibility of the developing the technique of protective coating with optimal thickness for the crosstalk amplitude reduction and signal integrity important.

At the same time, the other techniques of protective varnish coating remain unexplored: application of the coating layer only to critical interconnects along its entire length; coating only on critical sections along the interconnection, along its entire width; coating only on critical sections along the length and width of the interconnection. The above techniques of applying the protective varnish are more difficult in implementation in comparison with the considered, but can be more effective due to the selective rather full interconnection coating. Thus, to solve the EMC improvement task by PCB coating with an optimal thickness, it is necessary to carry out a large number of computational experiments, detailed analysis and systematization of the results. The next step is a series full-scale experiments, which will confirm the feasibility of the technique in practice, and will also allow to develop the technology of the crosstalk reduction by PCB coating.

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