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Using Modal Reservation for Ultrashort Pulse Attenuation After Failure

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***Abstract*— The paper considers the relevance of research on the efficient use of cold standby by means of modal reservation (MR) methods in order to increase resistance to ultrashort pulses. A quasistatic analysis of the ultrashort pulse propagation was performed in structures with single and triple MR on the prototype printed circuit board based on the path of 50 Ohm. The faults of two types were considered: a short circuit and an open circuit. The analysis showed that for a single MR the amplitude of the output voltage increased by 38%, so the attenuation of the ultrashort pulse decreased from 2.3 to 1.7 times. For a triple MR it is shown that the greater the electromagnetic coupling between the standby and one of the three conductors with failure, the greater the deviation, which reaches 36.5%. It was revealed that in case of failure, it is advisable to switch to a circuit whose electromagnetic coupling is less.**

Keywords*— *electromagnetic compatibility, reliability, cold standby, modal reservation, printed circuit board, failure, ultrashort pulse

I. Introduction

When creating maintenance-free or partially serviced radio electronic equipment (REE), for example, for space or aviation applications, much attention is paid to reliability and electromagnetic compatibility (EMC). Conducted and radiated emissions can lead to disruption of the onboard REE. Therefore, it is necessary to consider EMC in the early stages of design [1]. Particularly dangerous is the impact of powerful ultrashort pulses, as existing surge protectors do not protect against them [2]. There are a number of industrial devices that protect against ultrashort pulses but they have large dimensions and high cost, so there is no low-cost or effective protection against ultrashort pulses. However, the increasing role of electronics makes this protection more urgent.

One of the methods to increase the reliability of on-board REE is cold standby [3]. It allows creating highly reliable systems from typified widespread products using the inactive part of electronic equipment in the event of a malfunction in the functioning part. The need for proper protection against ultrashort pulses, as well as the redundancy caused by cold standby, will greatly complicate all parts and, as a result, the final design of the equipment. Meanwhile, the presence of redundancy can be efficiently used.

So, there has been proposed the idea of modal reservation (MR), which allows improving the noise immunity of REE on the basis of modal filtering [4]. The proposed technique employs inactive electrical interconnects to increase noise immunity and protect electronic systems from electromagnetic interference. MR is based on the use of electromagnetic couplings between the reserved and the reserving conductors of the reserved and reserving circuits.

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The implementation of MR in multilayer printed circuit boards (PCB) has been described in [5, 6]. The effectiveness of MR in various types of interconnects has been considered in [7]. However, the failure of electronic components has not been considered. Meanwhile, it can adversely affect the interference attenuation in MR.

The purpose of the work is to investigate MR in the event of failure of electronic components. It was performed through the quasistatic analysis of the ultrashort pulse propagation in structures with single and triple MR on the breadboard model of a PCB based on the path of 50 Ohm. The faults of two types were considered: a short circuit (SC) and an open circuit (OC).

II. Preparation to Simualtion

A. The essence of Modal Reservation

Two implementations of MR in multilayer PCBs are shown in Fig. 1. In both versions, the reference conductor is made as a separate layer, and the two PCBs are glued together with a dielectric layer whose relative permittivity is greater than that of the dielectric substrates of these PCBs. In the structure with single MR (Fig. 1*a*), the reserved circuit is arranged on PCB 1, and the reserving circuit is arranged on PCB 2. The respective paths of the reserved and reserving circuits are arranged in parallel and one below the other in the dielectric layer. In the structure with triple MR (Fig. 1*b*), the reserved circuit and one of the reserving circuits are arranged on PCB 1, the other two reserving circuits are arranged on PCB 2. The paths of the reserved and reserving circuits are arranged at the same level and distance from each other, and the conductors have the same sizes. The reserved and reserving electronic components in both versions are arranged on opposite sides of the reserved and reserving PCBs. The result is a decrease in the susceptibility of the reserved circuit to external conductive emissions and a decrease in the level of conductive emissions from the reserved circuit. This is achieved due to the fact that the interference pulse which is less than a certain duration value is decomposed into pulses of smaller amplitude, and the interference at a given frequency can be significantly attenuated.

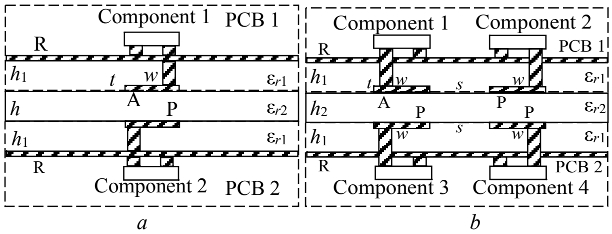

Fig. 1. Cross section of a multilayer PCB for circuits with single (*a*) and triple (*b*) reservation where conductors A - active, P - passive, R - reference

B. Simulation Approach

The simulation was performed in the TALGAT system [8] excluding losses in conductors and dielectrics. It is based on the method of moments and allows performing a quasistatic analysis of structures of arbitrary complexity. The algorithm implemented in the system allows calculating matrices (**L** and **C**) of the line parameters. Using the modified node-potential method in the frequency domain, it is possible to calculate the time response through a fast Fourier transform.

The quasistatic analysis is based on the assumption that only a transverse electromagnetic wave propagates in the structure, in contrast to electrodynamic analysis, where all types of waves are taken into account. However, the comparison of the results of quasistatic and electrodynamic simulation for different cross sections of PCB fragments with MR shows that the results are consistent, and the time spent on quasistatic simulation is 2-3 orders of magnitude less than with electrodynamic one [9].

C. Structures under Research

As the structure under study we chose a PCB breadboard model with MR on the path of 50 Ohm [10] (Fig. 2). It includes sets of electrical connections (differed in the number and length of paths) with single and triple MR. The PCB stack with parameter values is shown in Fig. 3. For the Rogers RO3010 insulator, it was assumed that $\varepsilon_{r2} = 10.2$, for the FR-4 prepreg $\varepsilon_{r1} = 4$. This breadboard model was taken for analysis, since it had been built considering the parameters of the PCB used in the design of real REE.

The cross sections for simulating structures with a length of 0.324 m with single and triple MR are presented in Figs. 4*a* and 5*a*, respectively. For simulation we used the values from Fig. 3. The values of the remaining parameters were the following: the width of the conductor $w = 185$ µm, the distance from the end of the conductor to the end of the dielectric $d = 555$ µm, the distance from the end of the conductor to the side wall $d_1 = 740$ µm, the distance between the conductors for the structure with triple MR $s = 315$ µm.

The schematic diagrams for simulating the structures with single and triple MR are shown in Figs. 4*b* and 5*b*, respectively. In case of failure of the reserved circuit, it is assumed that the reserving circuit takes over the functions of the reserved circuit. In the simulation, the values of the resistors R1 and R2 for the active conductor were chosen equal to 50 Ohms. The resistor values for passive conductors were set to 50 Ohm, 1 MOhm (OC), 1 µOhm (SC) for various failure modes.

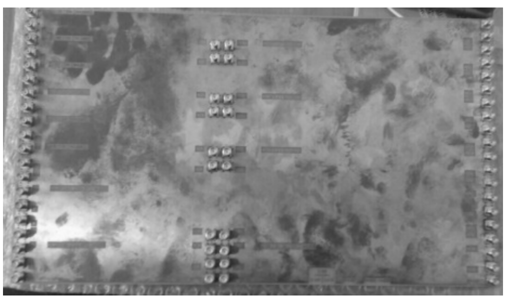

Fig. 2. Photograph of the breadboard model of the PCB with MR

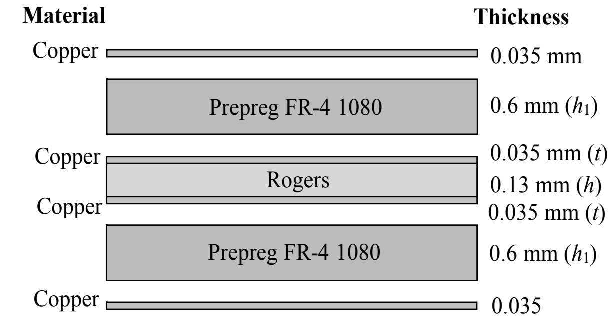

Fig. 3. PCB stack

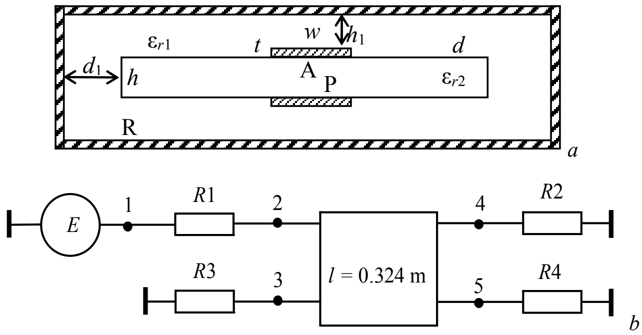

Fig. 4. Cross section (*a*) and schematic diagram (*b*) of a structure with single MR in the TALGAT system

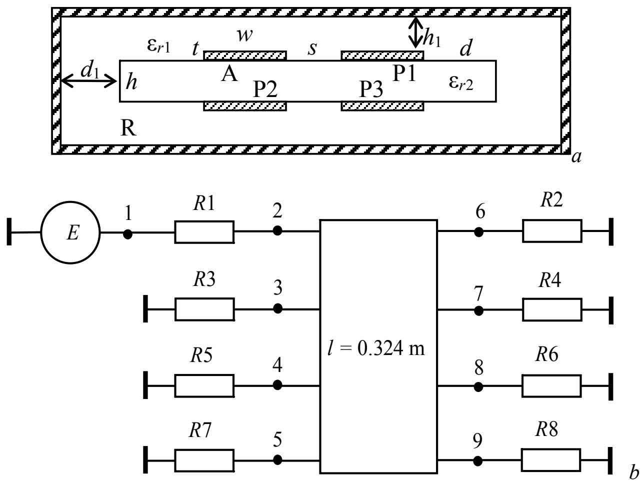

Fig. 5. Cross section (*a*) and schematic diagram (*b*) of triple MR structure in the TALGAT system

III. Simulation Results

In order for the decomposition of the acting pulses to be as complete as possible, their total duration should be comparable with the delay mode differences for the structures under study. For this, we obtained mode delays for Fig. 4*a* (2.37 and 3.08 ns) and for Fig. 5*a* (2.33, 2.5, 3.055, and 3.11 ns) as the product of the calculated per-unit-length mode delays of 0.324 m calculated in the TALGAT system. Fig. 6 shows the forms of EMF with an amplitude of 2 V used to influence the structures under study. The pulse with a total duration of 600 ps was used to analyze the structure with single MR, and 60 ps with triple MR.

Fig. 7 shows the voltage waveforms at the far end of the reserved conductor in the structure with single MR (node 4 in Fig. 4*b*) under various boundary conditions at one of the ends of the passive conductor, which can occur in case of a component failure. There is decomposition into 2 pulses, the amplitudes of which vary differently depending on the type of failure. Response delays of the modes correspond to those calculated from the parameters.

In operation when resistors at the ends of the passive conductor are 50 Ohms, the voltage of each of the pulses at the far end of the redundant conductor is 0.42 V. When a component (SC or OC) fails at one end of the passive conductor, the voltage waveforms at the far end of the active conductor change (Fig. 7). This, hereinafter, is due to the influence that a change in the boundary conditions of passive conductors has on the coordination of the active conductor. In this case, the voltage waveforms are the same, no matter if one type fails at the near or far end of the passive conductor. For idling at one end of the passive conductor, the first pulse is larger in amplitude by 0.16 V, and the second is less by 0.16 V than in operation (± 38%). The maximum pulse amplitude is 0.58 V. On the contrary, for a SC at one end of the passive conductor, the first decomposition pulse is 0.16 V less and the second is 0.16 V larger than in the operating condition. The ratio of half the EMF to the maximum voltage at the far end of the reserved circuit when the component fails is 1.7, and for the circuit in operation – 2.3.

Fig. 8 shows the voltage waveforms at the far end of the reserved conductor in triple MR structure (node 6 in Fig. 5b) for various boundary conditions at one end of one of the passive conductors (P1, P2 and P3). There is decomposition into 4 pulses, the amplitudes of which vary depending on the type of failure. Response delays of the modes approximately correspond to those calculated from the parameters.

In operation, when resistors at the ends of the passive conductor are 50 Ohms, pulse amplitudes are: 0.187, 0.242, 0.219, and 0.216 V. In the event of a component failure (SC or OC) at one end of one of the passive conductors, the pulse amplitudes change (Fig. 8). Moreover, in the event of a failure of one type at the near or far end of the passive conductor, they coincide. The maximum amplitude of the pulses during a SC or OC at one end of the passive conductor is P1 – 2.62 and 2.33 V, P2 –2.92 and 3.27 V, P3 –2.6 and 2.27 V, respectively.

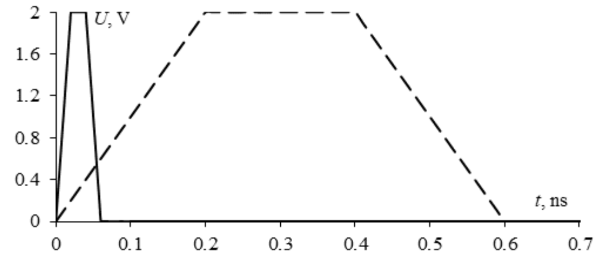

Fig. 6. Waveforms of acting EMF with a duration of 0.6 ns (–) and 0.06 ns (– –)

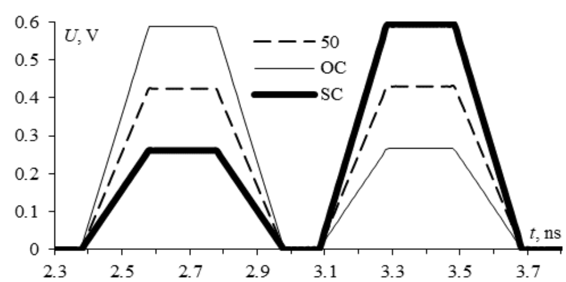

Fig. 7. Waveforms at the far end of the active conductor in a structure with single MR under various boundary conditions at one end of the passive conductor

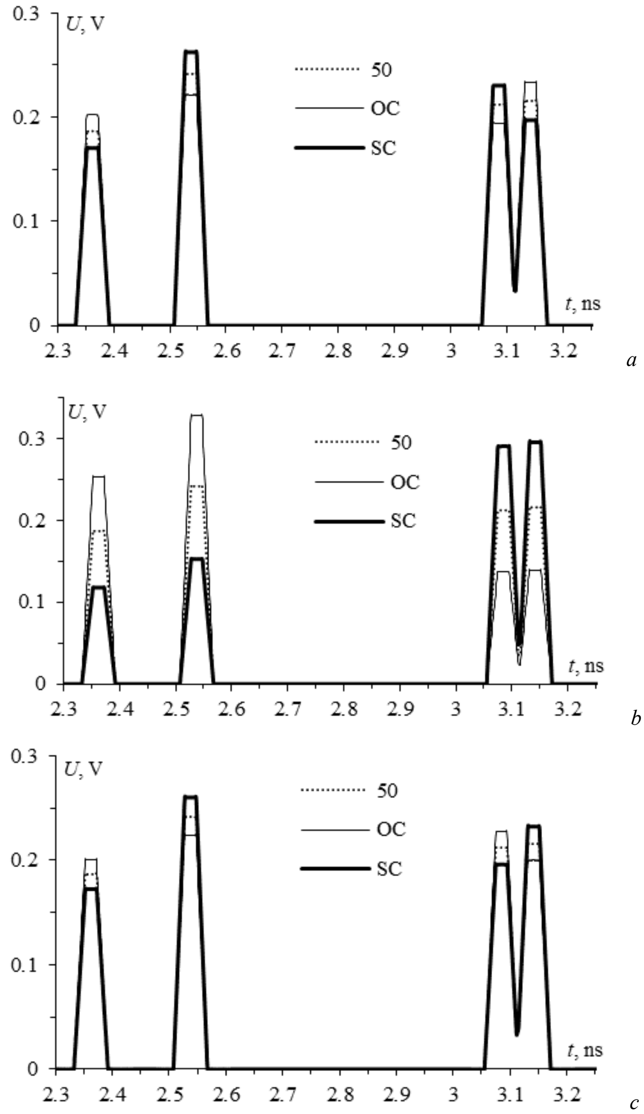

Fig. 8. Waveforms at the far end of the active conductor in triple MR structure under various boundary conditions at the end of the passive conductors P1 (*a*), P2 (*b*), P3 (*c*)

Table I summarizes the deviations of the pulse amplitudes in the event of a component failure at one of the ends relative to the amplitudes of the circuit in operation. A “-” sign indicates a decrease in amplitude. For conductors P1, P2 and P3, the maximum deviations are 8.6, 36.9 and 7.7 %, respectively. The differences are due to the fact that between the reserved and reserving conductor P2, the electromagnetic couplings are stronger than for P1 and P3, and the influence of the boundary conditions on the coordination of the active conductor is more pronounced.

Table II brings together the ratios of half the EMF to the maximum voltage at the far end of the reserved circuit with triple MR in the event of a component failure at one end of the circuit. In this case, in operation, when resistors at the ends of passive conductors are 50 Ohms, this ratio is 4.14.

IV. Conclusion

The failure of the system components with MR from the 50-Ohm path was considered. It was assumed that the circuit was in working condition, if the boundary conditions at the ends of the conductors were approximately 50 Ohm, and if one component of the system failed, a SC or OC was formed at one end of the circuit. It was shown that in case of failure the noise immunity can vary significantly. For single MR, the amplitude deviates by 38 %, so the attenuation decreases from 2.3 to 1.7. For triple MR, it is shown that the greater the electromagnetic coupling between the reserved conductor and one of the three conductors with failure, the greater the amplitude deviation, reaching 36.5 %. Thus, in case of failure, it is advisable to switch to a circuit whose electromagnetic coupling is less. However, it is necessary to study this issue in more detail.

TABLE I. DEVIATIONS (V,%) OF THE DECOMPOSED PULSE AMPLITUDES IN CASE OF FAILURE AT THE END OF ONE OF THE CONDUCTORS FROM THE AMPLITUDES FOR A CIRCUIT WITH TRIPLE MR IN OPERATION

Conductors	**Pulse №**	**Deviations**			
		OC		***SC***	
		V	*%*	*V*	*%*
P1	1	0.015	8.3	–0.017	–8.6
	2	–0.021	–8.3	0.020	8.6
	3	–0.018	–8.3	0.018	8.6
	4	0.018	8.3	–0.019	–8.6
P2	1	0.066	35.6	–0.07	–36.9
	2	0.086	35.6	–0.089	–36.9
	3	–0.075	–35.6	0.078	36.9
	4	–0.077	–35.6	0.076	36.9
P3	1	0.013	7.4	–0.015	–7.7
	2	–0.018	–7.4	0.018	7.7
	3	0.013	7.4	–0.016	–7.7
	4	–0.016	–7.4	0.016	7.7

TABLE II. THE RATIO OF HALF THE EMF TO THE MAXIMUM VOLTAGE AT THE FAR END OF THE CIRCUIT WITH TRIPLE MR (TIMES)

Boundary conditions at one end of the passive conductor	**The ratio of half the EMF to the maximum voltage at the far end of the circuit, times**		
	P1	**P2**	**P3**
OC	4.32	3.05	4.25
SC	3.81	3.38	3.84

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