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Evaluating modal reservation efficiency before and after failure

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Abstract. The paper considers the reserved structure implemented by using modal filtering. Such reservation is called modal reservation (MR) for short. To ensure certainty, we took a printed circuit boards (PCB) layout with a single MR. Using quasistatic analysis, the maximum voltages at the far end of the transmission line under study were calculated under the excitation of an ultrashort pulse at the near end and the frequency characteristics were analyzed in case of failure of electronic components. The faults of two types were considered: a short circuit and an open circuit. It is shown that the amplitude of the output voltage increases by 38% so the attenuation of the ultrashort pulse decreases from 2.3 to 1.7 times. It is also shown that the bandwidth of the useful signal changes.

1. 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). It is connected to the fact that REE during the whole period of service life must maintain the specified parameters and perform the required functions. Over time, the probability of system failure increases, since reliability is a decreasing function of time. Conducted and radiated emissions arising in power circuits or/and a switching unit can lead to disruption of the onboard REE. Therefore, it is necessary to consider EMC in the early stages of design [1]. One of the methods to increase the reliability of on-board REE is cold standby. Due to the complete duplication of the reserved equipment, the required performance is maintained under the conditions of a complete or partial failure of the functioning part. A classic cold standby [2] does not activate the backup part until an emergency occurs with the main module. Meanwhile, the presence of redundancy can be efficiently used.

Modal reservation (MR), based on modal filtering, can improve the noise immunity of REE [3]. It uses dormant electrical interconnects to increase noise immunity and protect functioning electronic systems from electromagnetic interference. MR is based on the use of electromagnetic coupling between the conductors of the reserved and reserving circuits. The implementation of MR in multilayer printed circuit boards (PCB) has been described in [4, 5]. The effectiveness of MR in various types of interconnects has been considered in [6]. However, the failure of electronic components has not been considered. Meanwhile, it can adversely affect the interference attenuation in MR. Thus, until a failure, the boundary conditions at the ends of the reserved and reserving circuits are almost the same. If we simulate the failure of the reserved circuit as a change in the boundary condition at one of its



ends, then when switching to the redundancy circuit, which becomes active, it turns out that the reserved circuit (which becomes passive) will have a changed boundary condition.

The purpose of the work is to evaluate the effectiveness of MR in the failure of electronic components. For this, the analysis in the time and frequency domains was performed in the case of a failure of the structure with a single MR. Faults of two types were considered: a short circuit (SC) and an open circuit (OC).

2. Preparation to Simulation

As the structure under study, we chose a PCB breadboard model with MR lines of 0.324 m long on the path of 50 Ohm, whose cross section and circuit diagram are shown in Figure 1. The upper and lower planes of the PCB were modeled, for convenience, by a reference conductor of a rectangular cross section. The simulation was conducted in the TALGAT quasistatic analysis system [8] without considering losses in conductors and dielectrics. The values of the parameters of the cross section (Figure 1a) were: the substrate thickness $h = 130 \mu\text{m}$; the dielectric constant of the substrate $\epsilon_{r2} = 10.2$; the distance from the strip to the reference conductor $h_1 = 600 \mu\text{m}$; the dielectric constant of the filling between the conductors and the reference conductor $\epsilon_{r1} = 4$; the width of the conductor $w = 185 \mu\text{m}$; the distance from the end of the conductor to the end of the dielectric $d = 555 \mu\text{m}$; the distance from the end of the strip to the side wall $d_1 = 740 \mu\text{m}$. The schematic diagram for simulating the structure with a single MR is shown in Figure 1b.

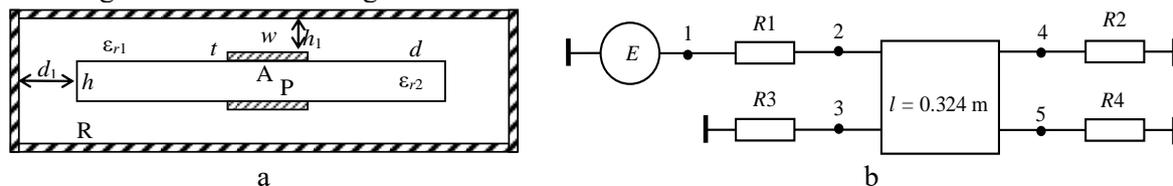


Figure 1. Cross section (a) and schematic diagram (b) of a structure with single MR in the TALGAT system where conductors – active (A), passive (P), and reference (R).

3. Simulating the Time Response

For the decomposition of the exciting pulse to be as complete as possible, its total duration should be less than the difference in the mode delays of the structure under study. For this, the mode delays for Figure 1a (2.37 and 3.08 ns) were calculated as the product of the per-unit-length delays in the TALGAT system by 0.324 m. To excite the structure under study (Figure 1b), we used a pulse in the form of a trapezoid with an EMF amplitude of 2 V and a total duration of 0.6 ns.

Figure 2 shows the voltage waveforms at the near (node 2 in Figure 1b) and far (node 4 in Figure 1b) ends of the reserved conductor under various boundary conditions at one of the ends of the passive conductor, which can occur in the case of a component failure. While in operation, with resistors at the ends of the passive conductor of 50 Ohms, the voltage amplitude at the near end of the reserved conductor is 1 V. After the failure, the voltage waveform at the near end of the reserved conductor changes. For the OC, at the near end of the backup conductor, the voltage amplitude is 0.14 V more than at the far, and for an SC - less. At the far end of the active conductor, there happens decomposition into two main pulses of the even and odd modes, whose amplitudes vary differently depending on the type of failure. The voltage waveforms, in the case of one type failure at the near or far ends of the passive conductor, are the same. The 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 reserved conductor is 0.42 V. With an SC or OC at one end of the passive conductor, the voltage waveforms at the far end of the active conductor change. This is due to the influence that a change in the boundary conditions of passive conductors has on the matching of the active conductor. For an OC 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 ($\pm 38\%$). The maximum pulse amplitude is 0.58 V. On the contrary, for an 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. At the far end of the active conductor under various boundary conditions at one end of the passive conductor, the delay time of the reflected pulses is found to be different. This is explained by the presence of additional pulses, the analysis of which is beyond the scope of the data of the work but can be performed in the future similarly to [9].

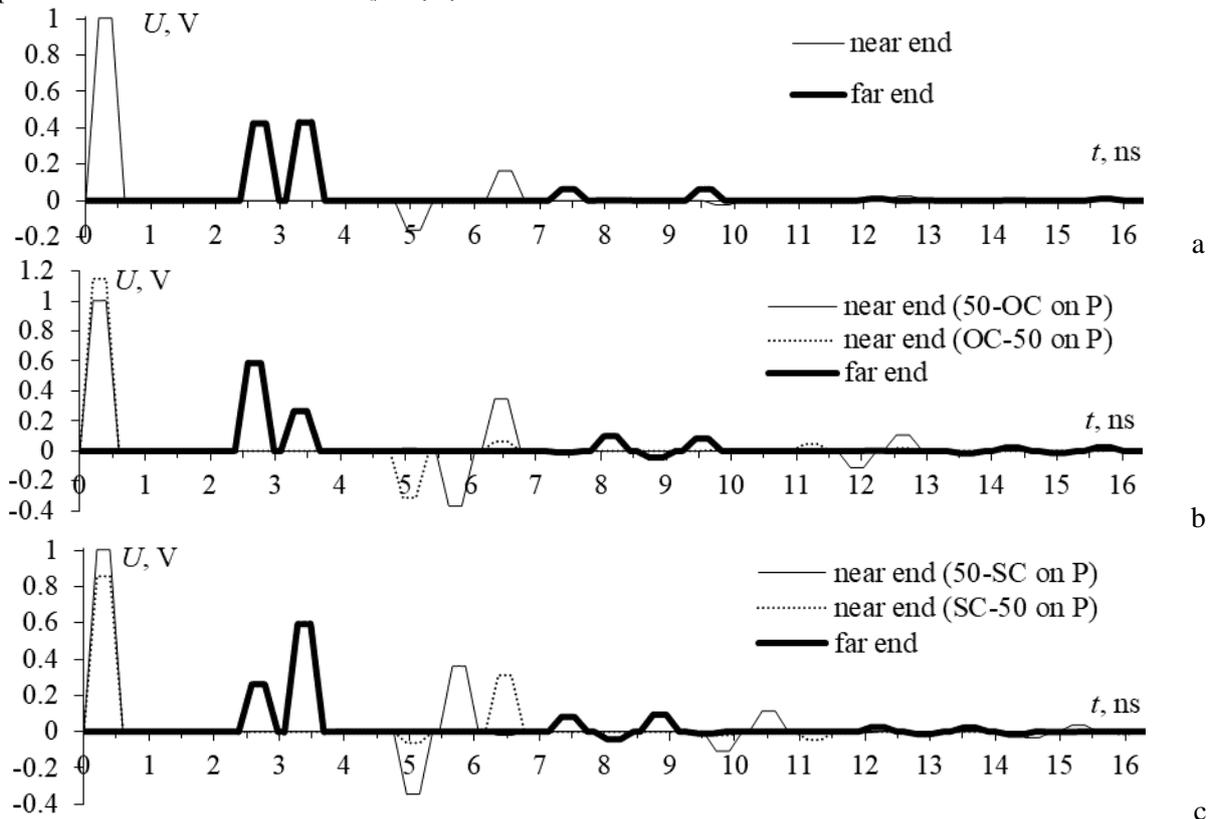


Figure 2. Waveforms at the near and far ends of the active conductor in a structure with MR at 50 (a), OC (b), SC (c) at one end of the passive conductor (P).

4. Simulating the Frequency Response

It is important to evaluate how the bandwidth for the wanted signal changes after a failure. For this, the frequency dependences $|S_{21}|$ the studied structure were calculated under various boundary conditions (Figure 3). It can be seen that the dependencies are different. Table 1 summarizes the resonant frequencies (f_0), which determines the first minimum of the transmission coefficient, as well as the cutoff frequencies (f_{cu}) which determine the bandwidth of the useful signal for all three cases.

It can be seen that the cutoff frequency for the OC and short-circuit at one end of the passive conductor is 11 and 8.8% lower than for the circuit in the working state, and the resonant frequencies are lower by 7 and 11 %, respectively.

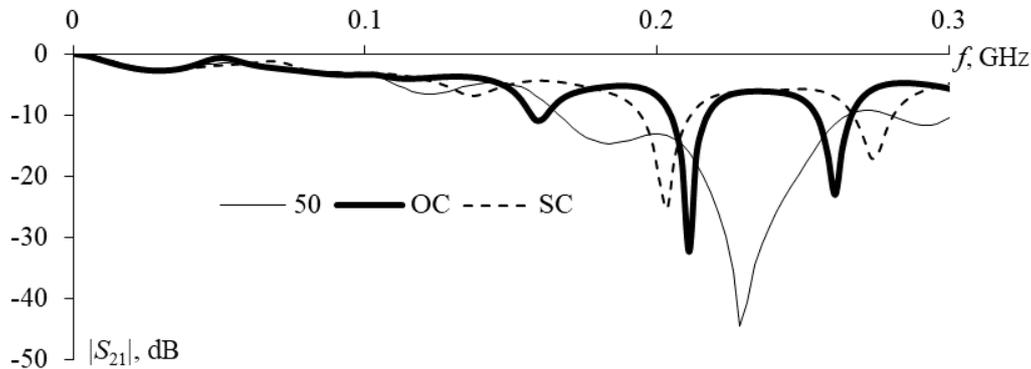


Figure 3. Frequency dependencies $|S_{21}|$ under various boundary conditions at one end of the passive conductor.

Table 1. Cutoff and resonance frequencies under various boundary conditions at one end of the passive conductor.

f_{cu} , MHz			Δf_{cu} , %		f_0 , MHz			Δf_0 , %	
50 Ohm	OC	SC	OC	SC	50 Ohm	OC	SC	OC	SC
91	81	83	-11	-8.8	228	211	203	-7	-11

5. Conclusion

The failure of the system components with MR from the 50-Ohm path was considered. It was assumed that the circuit is in operation, if the boundary conditions at the ends of the conductors are approximately 50 Ohm, and if one component of the system fails, an SC or OC is formed at one end of the circuit.

It was shown that in the case of failure the noise immunity can vary significantly. For a single MR, the amplitude deviates by 38 %, so the attenuation decreases from 2.3 to 1.7. It is also shown that the bandwidth of the useful signal changes.

Acknowledgment

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