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Analysis of frequency characteristics of a structure with single modal reservation before and after failure

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Abstract. The paper considers reservation structure implemented by using modal filtering. Such reservation is called modal reservation (MR) for short. To ensure certainty, we took a PCB layout with a single MR. It is shown that in quasi-static simulation, for the structure with losses in conductors and dielectrics, the cut-off frequency for an OC and an SC at one end of the passive conductor is 5.5 and 1.6 %, respectively, lower than for the circuit in operating condition, and the resonance frequencies are 8 and 11.6 %, respectively, lower. In electrodynamic simulation, for the conductor-loss structure and dielectrics, the cut-off frequency for an OC and an SC at one end of the passive conductor is 1.3 and 2.7 %, respectively, lower than for the circuit in operating condition, and the resonance frequencies are 7.3 and 10.65 % lower. The differences of resonance frequencies (f_0), cut-off frequencies (f_{cu}) in quasi-static and electrodynamic simulations are no more than 5.66 and 1.6 %, respectively.

1. Introduction

Reservation is one of the ways to increase reliability, allowing the use of an inactive part of electronic equipment in the event of a malfunction in a functioning part [1]. Modal reservation is a method of reserving electrical connections, characterized by using electromagnetic couplings between the reserved and reserving conductors of the reserved and reserving circuits to ensure electromagnetic compatibility [2]. The result is a decrease in the susceptibility of the reserved circuit to external conducted emissions and a decrease in the level of conducted emissions from the reserved circuit. The implementation of MR in multilayer printed circuit boards (PCB) has been described in [3, 4]. The effectiveness of MR in various types of interconnects has been considered in [5, 6]. The attenuation of an ultrashort pulse before and after the failure of electronic components, simulated by either a short circuit (SC) or an open circuit (OC) at one end for the structure with single MR, has been considered in [7]. However, the frequency response for the MR structure after failure has not been considered before. The aim of the work is to investigate a structure with a single MR in the frequency domain in the event of a failure of electronic components.

2. Preparation to simulation

As a structure under study, we chose a PCB breadboard model with MR on the path of 50 Ohm [10] (figure 2). It includes sets of electrical connections with lengths of 0.324, 0.185, 0.141 with single

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MR. The PCB stack with parameter values is shown in figure 1. For the Rogers RO3010 insulator, it was assumed that $\varepsilon_{r2} = 10.2$ and tgδ = $22*10^{-4}$, for the FR-4 prepreg - $\varepsilon_{r1} = 4$ and tgδ = $25*10^{-3}$. 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 simulation was carried out in the TALGAT system [8] with and without losses in conductors and dielectrics.

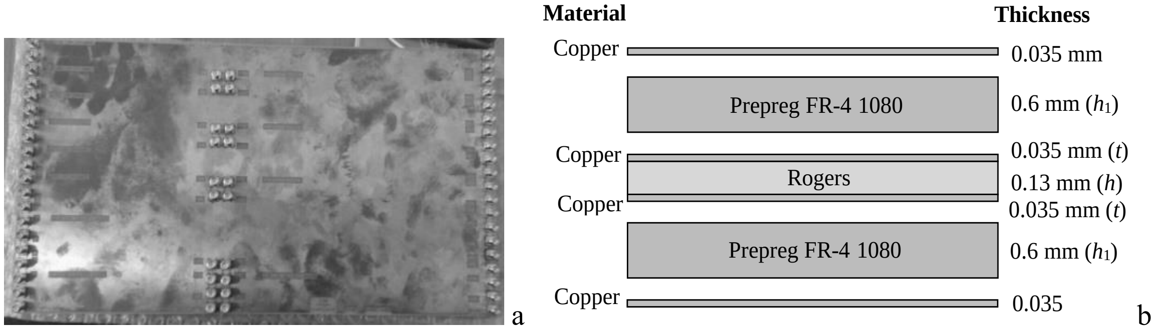

Figure 1. Photograph (a) and stack (b) of the breadboard model of the PCB with MR.

The cross section for simulating the structure with a length of 0.324 m with single MR is presented in figure 2a, respectively. For simulation, we used the values from figure 1b. 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, and the distance from the end of the conductor to the side wall d_1 = 740 μm. The schematic diagram for simulating the structure with single MR is shown in figure 2b, respectively. In case of failure of the reserved circuit, the reserving(standby) circuit is assumed to take 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.

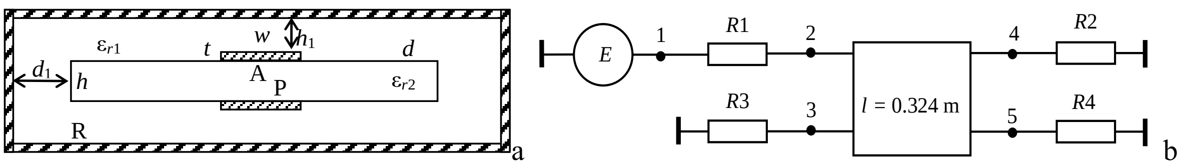

Figure 2. Cross section (a) and schematic diagram (b) of a structure with single MR in the TALGAT system where conductors – active (A), passive (P), and reference (R).

3. Quasi-static and electrodynamic simulation of frequency response

S-parameters were used to analyze the structure with single MR in the frequency domain with and without losses. In particular, $|S_{21}|$ and $|S_{11}|$ represent the transmission and reflection coefficients, respectively. The structure in this research was analysed by quasistatic and electrodynamic approaches. The estimation of the bandwidth change of the useful signal after a failure is extremely important. For a 0.324 m long structure, the frequency dependencies were calculated for $|S_{21}|$ under different boundary conditions (figure 3) in the frequency range from 10 MHz to 1 GHz. The results show that the dependencies are different. The resonance frequencies (f_0) that define the first minimum transmission ratio and the cut-off frequencies (f_{cu}) that define the useful signal bandwidth for all three cases are shown in Table 1. It can be seen that in quasi-static simulation for the structure with losses in conductors and dielectrics, the cut-off frequency for OC and SC at one end of the passive conductor is 5.5 and 1.6 % lower than for the circuit in operating condition, and the resonance frequencies are 8 and 11.6 % respectively, lower than. In electrodynamic simulation for conductor- and dielectric-loss

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structure, the cut-off frequency for an OC and an SC at one end of the passive conductor is 1.3 and 2.7 % respectively, lower than than for the circuit in operating condition, and the resonance frequencies are 7.3 and 10.65 % lower. The deviation of resonance (f_0) and cut-off (f_{cu}) frequencies in quasi-static and electrodynamic simulations is less than 5.66 and 1.6 %, respectively. It should be noted that $|S_{21}|$ for the 50-OC and OC-50, 50-SC and SC-50 variants is completely the same. Therefore, the values of $|S_{21}|$ only for the 50-OC and 50-SC variants on the passive conductor are shown in figure 3.

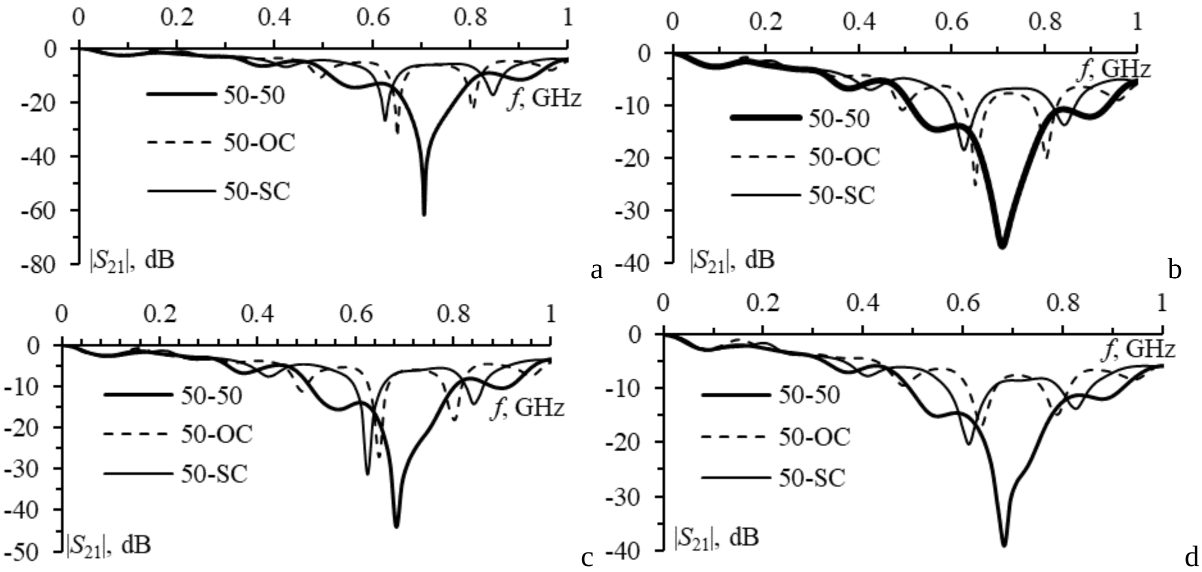

Figure 3. Frequency dependencies of $|S_{21}|$ for a structure with single MR before and after failure for quasi-static (without (a) and with (b) losses) and electrodynamic (without (c) and with (d) losses) analyses

Table 1. Cut-off and resonance frequencies under different boundary conditions at one end of the passive conductor.

approach		f_{cu}, GHz			Δf_{cu}, %		f_0, GHz			Δf_0, %	
		50	OC	SC	OC	SC	50	OC	SC	OC	SC
Quasistatic (Q)	Lossless	0.29	0.253	0.254	–12.7	–12.4	0.706	0.651	0.626	–7.8	–11.3
	Lossy	0.252	0.238	0.248	–5.5	–1.6	0.708	0.651	0.626	–8	–11.6
Electro-dynamic (E)	Lossless	0.27	0.252	0.25	–6.7	–7.4	0.685	0.648	0.625	–5.4	–8.8
	Lossy	0.225	0.222	0.231	–1.3	2.7	0.685	0.635	0.612	–7.3	–10.65
$\frac{Q-E}{Q+E}$, %	Lossless	±3.5	±0.2	±0.8	–	–	±1.5	±0.23	±0.08	–	–
	Lossy	±5.66	±3.48	±3.55	–	–	±1.6	±1.24	±1.13	–	–

Frequency dependencies were calculated for a 0.324 m long structure at $|S_{11}|$ under different boundary conditions (figure 4) in the frequency range from 10 MHz to 1 GHz. It can be seen that for variants 50-50, 50-OC, 50-SC at the ends of the passive conductor, the reflection coefficient in the bandwidth does at least about -10 dB. However, for cases OC-50, SC-50 at the ends of the passive conductor, the reflection coefficient in the bandwidth is about -6 dB. Note that $|S_{21}|$ for the 50-OC and OC-50, 50-SC and SC-50 variants is the same, but $|S_{11}|$ is different.

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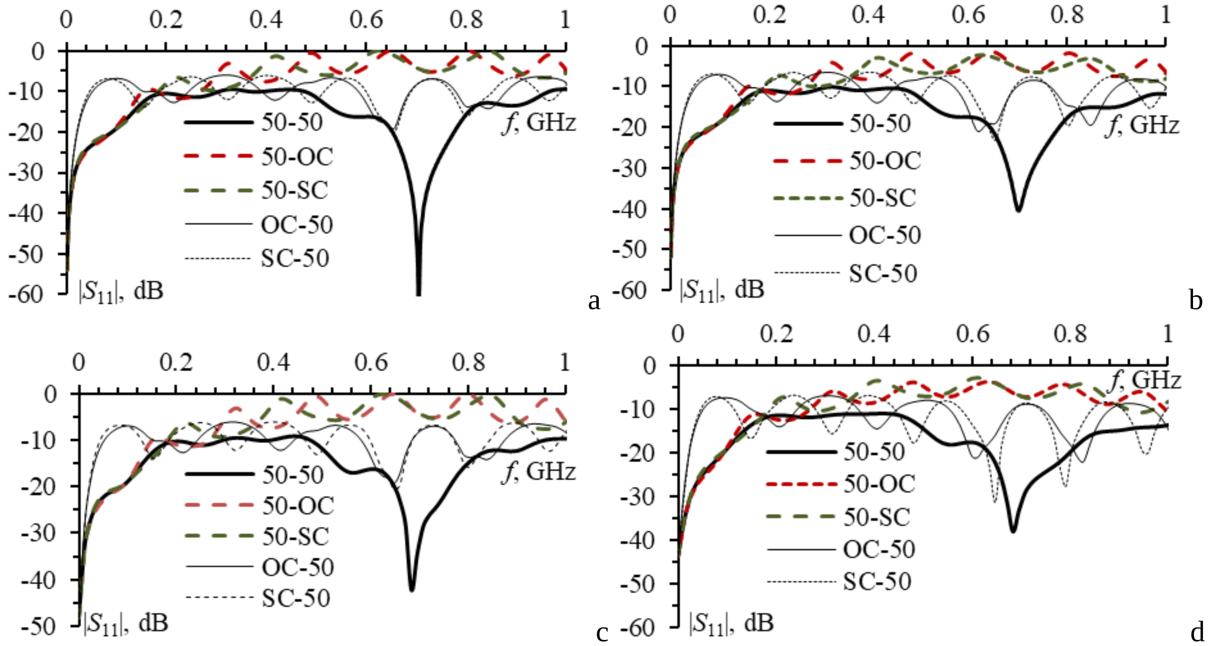

Figure 4. Frequency dependencies $|S_{11}|$ for a structure with single MR before and after failure for quasi-static (without (a) and with (b) losses) and electrodynamic (without (c) and with (d) losses) analyses

4. Frequency response for structures with different lengths

To understand how frequency characteristics change depending on the length of the structure, the dependencies of $|S_{21}|$ and $|S_{11}|$ for the structure under research with lengths of 0.185 and 0.141 m are shown in figures 5–6 respectively. The quasi-static simulation was performed considering the losses in conductors and dielectrics. The resonance and cut-off frequencies for all three cases are presented in table 2.

It can be seen that when the length of the structure decreases with MR, the cut-off frequencies and resonances increase.

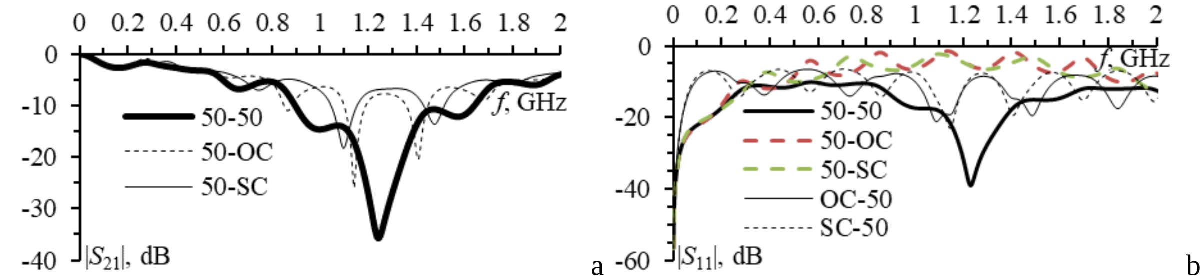

Figure 5. Frequency dependencies of $|S_{21}|$ (a) and $|S_{11}|$ (b) with losses for a 0.185 m long structure with single MR before and after failure

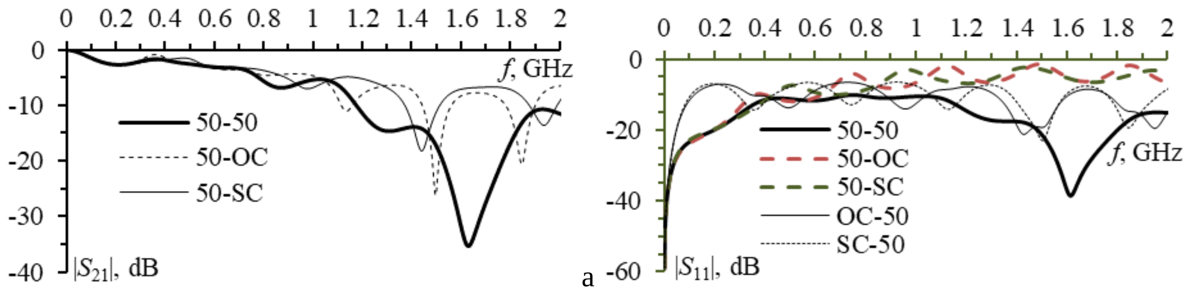

Figure 6. Frequency dependencies of $|S_{21}|$ (a) and $|S_{11}|$ (b) with losses for a 0.141 m long structure with single MR before and after failure.

Table 2. Cut-off and resonance frequencies under different boundary conditions at one end of the passive conductor

length (l), m	f_{cu}, GHz			Δf_{cu}, %		f_0, GHz			Δf_0, %	
	50	OC	SC	OC	SC	50	OC	SC	OC	SC
0.324	0.252	0.238	0.248	–5.5	–1.6	0.708	0.651	0.626	–8	–11.6
0.185	0.438	0.415	0.436	–5.25	–0.45	1.24	1.14	1.1	–8.1	–11.3
0.141	0.572	0.542	0.57	–5.24	–0.35	1.63	1.495	1.44	–8.3	–11.66

5. Conclusion

To sum up, for the first time, the paper presents the results of the study into frequency characteristics of the structure with single MR. The results of quasi-static, electrodynamic simulations with and without losses in conductors and dielectrics were compared in the range of frequencies from 10 MHz to 1 GHz. In addition, the values f_{cu}, f_0 were obtained for sections with lengths of 0.141, 0.185, 0.324 m. It is shown that in quasi-static simulation for the structure with losses in conductors and dielectrics, the cut-off frequency for an OC and an SC at one end of the passive conductor is 5.5 and 1.6 % lower than for the circuit in operating condition, and the resonance frequencies are 8 and 11.6 %, respectively, lower. In electrodynamic simulation for conductor- and dielectric-loss structure, the cut-off frequency for an OC and an SC at one end of the passive conductor is 1.3 and 2.7 %, respectively, lower than for the circuit in operating condition, and the resonance frequencies are 7.3 and 10.65 % lower. The differences of resonance frequencies (f_0), cut-off frequencies (f_{cu}) in quasi-static and electrodynamic simulations are no more than 5.66 and 1.6 %, respectively. It is shown that for variants 50-50, 50-OC, 50-SC at the ends of the passive conductor, the reflection coefficient in the bandwidth does not exceed –10 dB. However, for variants OC-50, SC-50 at the ends of the passive conductor the reflection coefficient in the bandwidth reaches approximately -6 dB. It is shown that the smaller the length of the structure with MR, the higher the cut-off and first resonance frequencies.

Acknowledgment

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