Studying the circuit switching order after failures for a shielded structure with triple modal reservation

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***Abstract*—The paper considers modal reservation (MR) which allows both increasing the circuit reliability and implementing the effect of modal filtering. A quasistatic analysis of the ultrashort pulse propagation was performed in structures with triple MR. It was assumed that the circuit is without failures if the boundary conditions at the ends of the conductors approximately correspond to 50 Ohms, and if one component of the system fails, a 0 or ∞ is formed at one of the ends of the circuit. In particular, a triple MR significantly increases the resistance to ultrashort pulses. The optimal switching order was determined for the shielded structure with triple modal reservation. For this structure, a preferable circuit switching option was the one which produced the smallest voltage amplitudes (U_{max}) of the pulses resulted from the acting ultrashort pulse decomposition. Thus, the choice of this option provides the best protection against ultrashort pulses during the entire operation of the system. As a result switching option 3 is optimal.**

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

I. INTRODUCTION

With the growth of technical progress, the complexity of electronic equipment increases, exacerbating the problem of ensuring the necessary reliability of systems and components, as well as electromagnetic compatibility (EMC). When creating partially serviced radio electronic equipment, the replacement with a cold standby equipment is widely used, when a backup element or system is in a cold standby mode before its use instead of the main element [1]. At the same time, both reliability and EMC depend on the location of the backup conductors relative to each other [2]. Modal reservation (MR) uses such reservation to ensure EMC [3]. This is achieved by performing reservation in which the backup, or reserved, and the redundant, or reserving, circuits form a modal filter (MF) [4], i.e. a device that uses modal distortion caused by the difference in transmission line per-unit-length mode delays to attenuate unwanted signals [5]. MR allows protection against ultrashort pulses [6, 7] and reduces the size of the reserved systems. With a triple MR, 3 additional redundant circuits are used, while 4 modes arrive at the output. In cold standby, before failures, the reserving conductors are in an idle mode until they are used instead of the main element.

Preliminary studies of structures with a triple MR have shown that in the event of a backup circuit failure, simulated either by a short circuit (0) or by an open circuit (∞) at one end, the maximum voltage at the circuit output changes after switching to a redundant circuit. The implementation of MR in multilayer printed circuit boards (PCB) is described in [8]. The attenuation before and after failures for a structure with a double MR is considered in [9]. However, the most preferable order of switching the circuits in structures with a triple MR after consecutive failures has not been studied.

The purpose of this work is to investigate the circuit switching order using the example of a shielded PCB layout with a triple MR in the case of failure of electronic components. In this work, a quasistatic simulation of the propagation of an ultrashort pulse in a four-conductor structure with MR in a 50 Ohm path was performed. Failures of two types were considered: 0 and ∞.

II. STRUCTURES UNDER RESEARCH

The cross section for simulating the structure with a length of 0.324 m with a triple MR based on the path of 50 Ohm is presented in Fig. 1*a*. The simulation was performed in the TALGAT system [10]. Cross-sectional parameters are: the substrate thickness $h = 130$ μm; the distance between the conductors for a structure with a threefold MR is $s = 315$ μm; the dielectric constant of the filling between conductors $\varepsilon_{r1} = 4.3$; the dielectric constant of the substrate $\varepsilon_{r2} = 10.2$; the distance from conductors to ground planes $h_1 = 600$ μm; the conductor width $w = 185$ μm; the distance from the end of the conductor to the end of the dielectric $d = 555$ μm. A schematic diagram for modeling a structure with a triple MR is shown in Fig. 1b. In the case of consecutive failures of each redundant circuit (0 or ∞), it is assumed that the switching device (SD) transfers the functions of the backup to the redundant circuit. For simulation, the resistor values for active conductors were 50 Ohm, and for passive conductors were set to 50 Ohm, 1 MOhm (∞), 1 μOhm (0) for various failure modes [11].

Thus, the structure with triple MR is symmetrical, since the conductors C1 and C2, C3 and C4 have the same distances between the conductors is *s*, also C1 and C3, and C2 and C4 are located on a substrate thickness is *h*. That is, before failures, when the values of *R*1-*R*8 are 50 Ohm for any of the active conductors C1-C4, the output characteristics will be the same.

Fig. 2 shows the options for choosing an active conductor after failures. For example, before failures, conductor 1 is an active wire, while conductors 2–4 are redundant. After the failure at one of the ends of the active conductor, you can switch to one of the passive ones.

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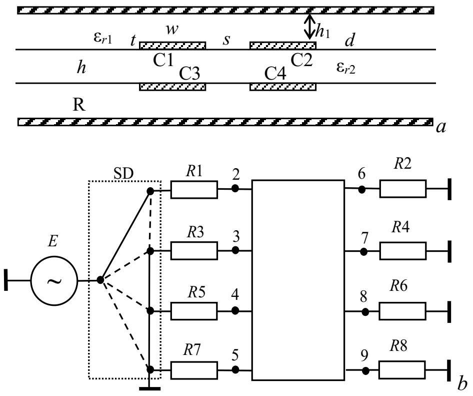

Fig. 1. Cross section (a) and schematic diagram (b) of a structure with a triple MR where C (1-4) are conductors, SD is a switching device

Consider option 1. After the failure of conductor 1, the SD switches to conductor 2, and conductors 3 and 4 remain redundant, which you can switch to after the failure of conductor 2. However, since the structure is symmetrical, after the failure of conductors 1 and 2, it does not matter which conductor to switch to: 3 or 4. After the failure of conductor 3, there is only one switching option, which is the same for all branches after the first failure. Thus, the diagram in Fig. 2 is simplified to Fig. 3.

III. Simulation Results

An EMF pulse with an amplitude of 2 V and a duration of 60 ps was applied to the input of the structure under study (Fig. 1). the U_{max} at the far end of the backup conductor is 0.243 V (will be shown below), Before failures, with resistors at the ends of passive conductors of 50 Ohm. In the event of a component failure (0 or ∞) at one of the ends of the backup conductor, it switches according to options 1, 2 or 3 to one of the redundant conductors. Now it becomes backup, and at one of the ends of the failed conductor the boundary conditions change (from 50 Ohm to 0 or ∞). Therefore, the voltage waveform at the far end of the backup conductor changes, which is reflected in a change in the pulse amplitudes.

Simulation was performed for all switching options and failures. The U_{max} at the end of the backup conductor are summarized in Table. 1. Note that these are only those amplitudes the voltage waveforms of which are not identical for different failure modes. So, for example, the waveforms with an active conductors C1, C2, C3 or C4 are identical. The waveforms are also identical if the boundary conditions on the passive conductors are symmetrical for different failure modes. Thus, the waveforms of the option 50-50 at C2, 50-50 at C3, 50 0 at C4 are identical to 50-50 at C2, 50-50 at C3, 0-50 at C4, etc.

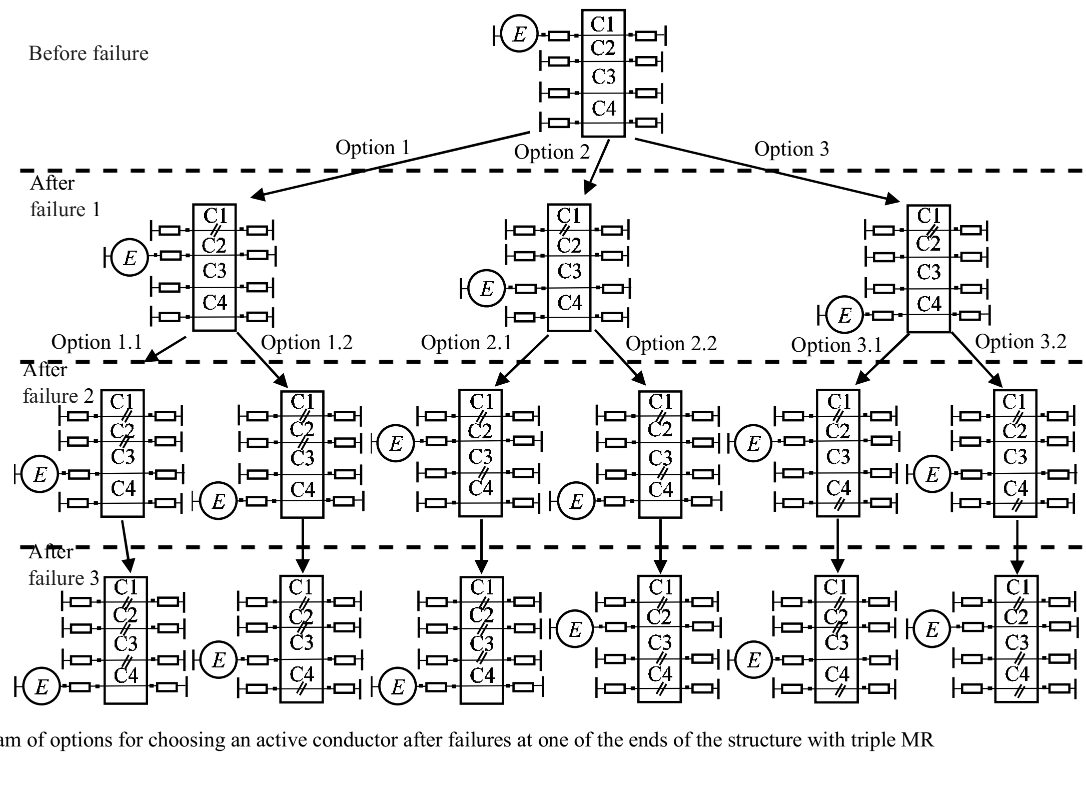

Fig. 2. Diagram of options for choosing an active conductor after failures at one of the ends of the structure with triple MR

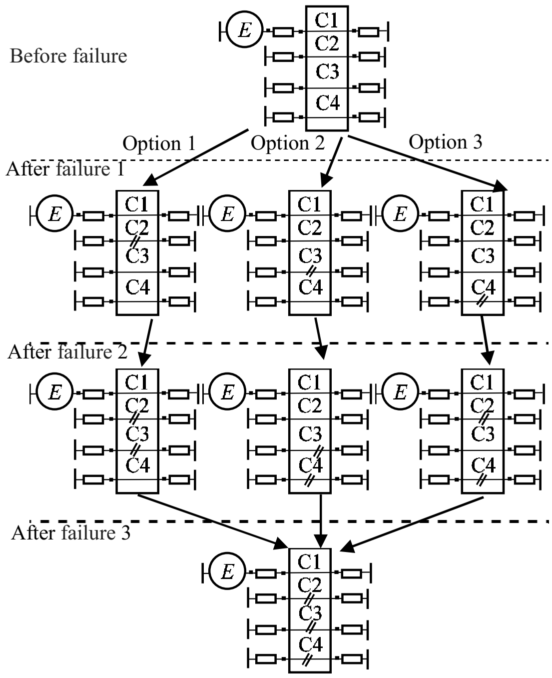

Fig. 3. Simplified diagram for choosing the active conductor

On the active conductor before failures, for options 1, 2, 3 after failure 1, there is a change in amplitude from 0.243 to 0.2639, 0.3293, 0.2615 V, respectively. On the active conductor, for options 1, 2, 3 after failure 2, there is a change in amplitude to 0.3577, 0.3545, 0.284 V, respectively. Thus, for this structure, switching option 3 is preferable since the amplitude of 0.2615 and 0.284 V after failures 1 and 2 are the smallest of the three options. In Table 1, all listed values are in bold.

Fig. 4 demonstrates, as examples, the reduced waveforms the U_{max} of which are less than those for the structure before failures. The amplitudes of each of the pulses are summarized in Table 2, which also shows the average value approximately equal to 0.21 V. It can be seen that the lower the U_{max}, the closer each of the pulses is to the average value.

TABLE I. U_{MAX} VALUES AT THE END OF THE ACTIVE CONDUCTOR AFTER FAILURES AT ONE OF THE ENDS OF THE STRUCTURE WITH MR

Option	**After failure 1**	**U_{max}, V**	**Option**	**After failure 2**	**U_{max}, V**	**After failure 3 (for all options)**	**U_{max}, V**
1	50–∞, 50–50, 50–50	0.2347	1	50–∞, 50–∞, 50–50	0.3045	50–∞, 50–∞, 50–∞	0.3231
						50–∞, ∞–50, 50–∞	0.3169
				50–∞, ∞–50, 50–50	0.302	50–∞, 50–0, 50–∞	0.3014
				50–∞, 50–0, 50–50	0.3096	50–∞, 0–50, 50–∞	0.2987
				50–∞, 0–50, 50–50	0.3213	50–0, 50–0, 50–∞	0.3102
						50–0, 0–50, 50–∞	0.333
	50–0, 50–50, 50–50	**0.2639**		50–0, 50–0, 50–50	0.3042	50–0, 50–∞, 50–∞	0.347
				50–0, 0–50, 50–50	0.3179	50–0, ∞–50, 50–∞	0.3499
				50–0, 50–∞, 50–50	0.3547	50–∞, 50–∞, 50–0	0.344
				50–0, ∞–50, 50–50	**0.3577**	50–∞, ∞–50, 50–0	0.344
						50–∞, 50–0, 50–0	0.3164
2	50–50, 50–∞, 50–50	**0.3293**	2	50–50, 50–∞, 50–∞	0.3061	50–∞, 0–50, 50–0	0.3394
				50–50, 50–∞, ∞–50	0.3049	50–0, 50–0, 50–0	0.2958
				50–50, 50–∞, 50–0	0.353	50–0, 0–50, 50–0	0.2973
				50–50, 50–∞, 0–50	**0.3545**	50–0, 50–∞, 50–0	0.3651
						50–0, ∞–50, 50–0	0.3686
	50–50, 50–0, 50–50	0.2966		50–50, 50–0, 50–0з	0.3056	50–∞, 50–∞, 0–50	0.3278
				50–50, 50–0, 0–50	0.3193	50–∞, ∞–50, 0–50	0.3236
				50–50, 50–0, 50–∞	0.3025	50–∞, 50–0, 0–50	0.3333
				50–50, 50–0, ∞–50	0.3142	50–∞, 0–50, 0–50	0.331
						50–0, 50–0, 0–50	0.304
3	50–50, 50–50, 50–∞	0.2295	3	50–∞, 50–50, 50–∞	0.2337	50–0, 0–50, 0–50	0.306
				∞–50, 50–50, 50–∞	0.2186	50–0, 50–∞, 0–50	0.3818
				50–0, 50–50, 50–∞	0.258	50–0, ∞–50, 0–50	0.3834
				0–50, 50–50, 50–∞	0.2493	50–∞, 50–∞, ∞–50	0.2973
						50–∞, ∞–50, ∞–50	0.299
	50–50, 50–50, 50–0	**0.2615**		50–0, 50–50, 50–0	0.2718	50–∞, 50–0, ∞–50	0.3025
						50–∞, 0–50, ∞–50	0.3122
				0–50, 50–50, 50–0	**0.284**	50–0, 50–0, ∞–50	0.3265
				50–∞, 50–50, 50–0	0.2539	50–0, 0–50, ∞–50	0.3285
				∞–50, 50–50, 50–0	0.2527	50–0, 50–∞, ∞–50	0.3284
						50–0, ∞–50, ∞–50	0.3325

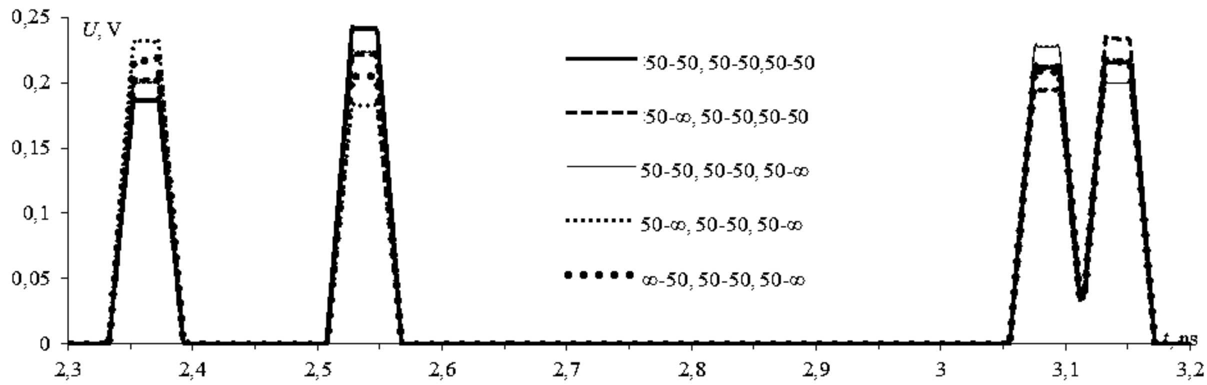

Fig. 4. Voltage waveforms at the end of an active conductor for failure cases with a lower maximum value in comparison with those for the original structure without failures

TABLE II. AMPLITUDES (V) OF PULSES AT THE END OF AN ACTIVE CONDUCTOR FOR FAILURE CASES WITH A LOWER MAXIMUM VALUE, IN COMPARISON WITH THE ORIGINAL STRUCTURE (FIRST LINE)

Failure options	V_1	V_2	V_3	V_4	V_{av}
50–50, 50–50, 50–50	0.188	**0.243**	0.214	0.217	0.215
50–∞, 50–50, 50–50	0.204	0.223	0.196	**0.235**	0.214
50–50, 50–50, 50–∞	0.202	0.225	**0.229**	0.201	0.214
50–∞, 50–50, 50–∞	**0.234**	0.184	0.212	0.218	0.212
∞–50, 50–50, 50–∞	**0.219**	0.206	0.21	0.217	0.213

IV. CONCLUSION

The paper considers MR which allows both increasing the circuit reliability and implementing the effect of modal filtering. It was assumed that the circuit is without failures if the boundary conditions at the ends of the conductors approximately correspond to 50 Ohms, and if one component of the system fails, a 0 or ∞ is formed at one of the ends of the circuit. The optimal switching order was determined for the shielded structure with triple modal reservation. For this structure, a optimal circuit switching option was the one which produced the smallest U_{max} of the pulses resulted from the acting ultrashort pulse decomposition. Thus, the choice of this option provides the best protection against ultrashort pulses during the entire operation of the system. As a result switching option 3 is optimal.

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