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Abstract. The paper investigates the results of N-norm calculations for a device with a single modal reservation. Using a quasistatic approach, we obtained a time response at the far end of the reserved and reserving conductors for the structure with and without losses. The authors analyse N-norms of decomposed pulses at the far end of the reserved and reserving conductors. The results show that the probability of failure of the reserving equipment is lower than that of the reserved equipment.

1. Introduction

To improve the reliability of unattended or semi-attended radio-electronic equipment (REE), especially for space or aircraft systems, the developers use reservations [1]. The probability of system failure increases over time because reliability is a decreasing function of time. The total duplication of the operating part of the REE provides the required operability under conditions of complete or partial failure. In terms of the load level, there are hot, warm, and cold reservations, with the last type being the most common due to the simplicity of implementation.

Conducted and radiated emissions from the power and switching circuits can cause malfunction of the on-board REE. Therefore, it is especially important to consider electromagnetic compatibility at an early stage of the design of an onboard electrical power system [2]. Modal reservation (MR) is a long-term solution of a cold reservation [3, 4]. Its main idea is to trace reserved and reserving conductors on a printed circuit board (PCB) with strong electromagnetic coupling between them. This makes it possible to use modal distortions to suppress conducted interferences of short duration.

Figure 1 shows a schematic diagram of a generic transmission line with a single MR. Due to different phase velocities, the even and odd mode components of an ultra-short pulse (USP) propagate with various delays. This causes the input excitation to decompose into a sequence of pulses of smaller amplitude. In the case of the single MR, two unipolar pulses are generated at the far end of the reserved conductor and two bipolar pulses at the far end of the reserving conductor. Thus, USPs with critically high amplitude and short duration could threaten components terminating not only the reserved (*R3*) but also the reserving (*R4*) transmission line may be damaged.

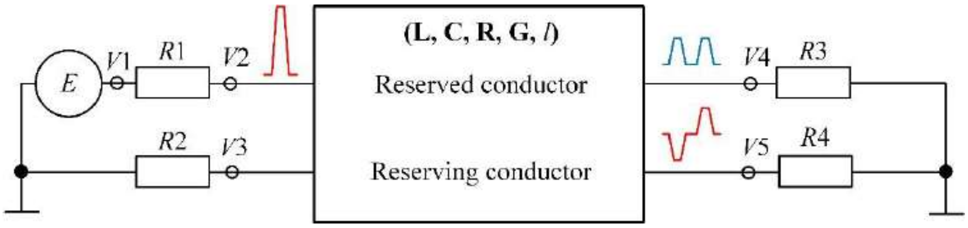

Figure 1. Schematic diagram of a generic transmission line with the single MR.

The papers [5, 6] describe the MR implementation in multilayer PCBs. In [7] the authors considered the reduction of the USP before and after the failure of the electronic components; the failure was simulated by short or open circuits at one end of the structure with the single MR. In [8] the estimation of efficiency of the single modal reservation before and after failure is presented. However, the authors in well-known publications on MR have not assessed the damage risk to the reserving equipment. The study aims to determine and compare the critical values of unipolar and bipolar pulses using *N*-norms for the single MR of the microstrip transmission line (MSL).

2. Approaches, methods, and designs

N-norms have been used to analyse the critical values of unipolar and multipolar pulses in [9–11]. They allow estimating the impact of a powerful pulse on electronic equipment and components. Table 1 shows the analysed norms and their characteristics [12]. The *R(t)* function is continuous, differentiable, and represents the waveform of the actual signal.

As a simulation method, we used the quasistatic approach based on the method of moments in the TALGAT system [13,14]. The system includes the calculation of *N*-norms used to determine the limit of the susceptibility of the transmission line elements. The calculation is based on the application of mathematical operators to the full signal waveform. It is assumed that only a transverse T-wave propagates in the transmission line. The simulation was performed with and without conductor and dielectric losses.

Table 1. N-norm parameters: description and application.

	N1	*N2*	*N3*	*N4*	*N5*
Formula	$\lvert R(t)\rvert_{max}$	$\left\lvert \frac{dR(t)}{dt} \right\rvert_{max}$	$\left\lvert \int_0^t R(t)dt \right\rvert_{max}$	$\int_0^\infty \lvert R(t)\rvert dt$	$\left[\int_0^\infty \lvert R(t)\rvert^2 dt\right]^{\frac{1}{2}}$
Name	The peak value (absolute)	The peak derivative (absolute)	The peak pulse (absolute)	Rectified general pulse	The square root of the action integral
Application	Circuit failure /electric breakdown / electric arc effects	Component sparkling / circuit failure	Dielectric breakdown (if *R* means the *E* field)	Equipment damage	Component burnout

A trapezoidal pulse with the following parameters was injected into node *V*1: the rise time t_r, fall time t_f and flat top time t_d were 100 ps each, the amplitude of e.m.f. was 2 V. In the matched case, a pulse of the similar waveform but with an amplitude of 1 V was observed at the *V*2 node. The voltage waveforms at the far end of the reserved (*V*4) and reserving (*V*5) conductors were analyzed. Figure 2 shows the cross-section of the MSL with the single MR. The reserved conductor is located near the reserving conductor to ensure strong electromagnetic coupling. To meet the conditions of decomposition and matching of the source with the transmission line, the following geometrical parameters were used: the conductor width w = 0.85 mm, the conductor spacing s = 0.2 mm, the conductor height t = 0.035 mm, the substrate height h = 0.5 mm, the length l = 1 m. The relative dielectric constant ε_r = 4.5 and the dissipation factor of the substrate tan δ = 0.025 are given for 1 MHz frequency. Resistances $R1$, $R2$, $R3$, $R4$ are equal to 50 Ω.

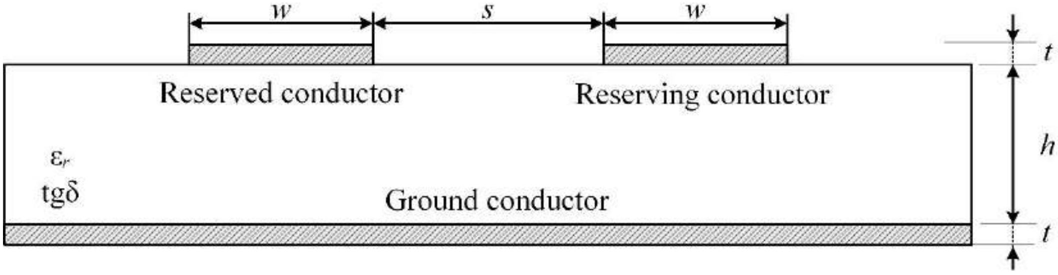

Figure 2. Cross-section of the MSL with the single MR.

3. Results of time response simulation

Figures 3 and 4 show the voltage waveforms in nodes $V2$, $V4$, $V5$ for the structure with and without losses, respectively. Table 2 summarizes the calculated norms for $V4$ and $V5$.

Table 2. N-norms for V 4, V 5 nodes.

Parameters		*N1*	*N2*	*N3*	*N4*	*N5*
Without losses	*V4*	0.49508	$5.7081\cdot10^{9}$	$20.01\cdot10^{-11}$	$2.003\cdot10^{-10}$	$8.994\cdot10^{-6}$
	V5	0.4932	$5.7081\cdot10^{9}$	$9.865\cdot10^{-11}$	$2.003\cdot10^{-10}$	$8.994\cdot10^{-6}$
	Deviation, times	1.004	1	2.028	1	1
With losses	*V4*	0.2562	$1.4851\cdot10^{9}$	$19.32\cdot10^{-11}$	$2.053\cdot10^{-10}$	$5.339\cdot10^{-6}$
	V5	0.2353	$1.4684\cdot10^{9}$	$7.605\cdot10^{-11}$	$1.538\cdot10^{-10}$	$4.83\cdot10^{-6}$
	Deviation, times	1.088	1.011	2.54	1.334	1.105

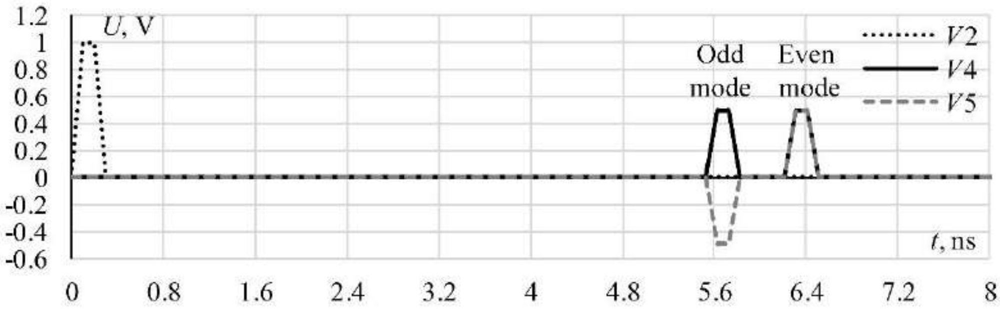

Figure 3. Time response of the device with the single MR without losses.

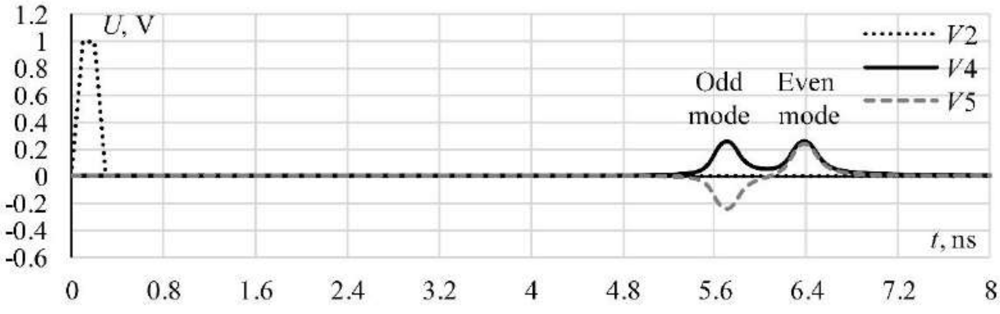

Figure 4. Time response of the device with the single MR with losses.

In the simulation with and without losses, it was observed that the USP decomposed into two pulses of the same amplitude and polarity at the far end of the reserved conductor. Two pulses of different polarity came to the far end of the reserving conductor. The quasistatic analysis showed that in the case of simulation with the losses taken into account, the values of all calculated norms in node $V5$ are less than in node $V4$. The largest deviation was observed in the third and fourth norms. In the case of the simulation without losses, the calculated norms $N1$, $N2$, $N4$, and $N5$ for nodes $V4$ and $V5$ were practically the same, and norm $N3$ differed by 2.02 times. The results showed that the effect of dispersion and losses reduces the critical values of the USP. And for bipolar pulses, it decreased more strongly than for unipolar pulses. This may be due to the specific features of the structure under study. We can conclude, preliminary, that if the component is exposed to pulses of different polarity, the probability of dielectric breakdown and equipment damage is lower.

4. Conclusion

Thus, for the first time, the analysis of voltage N-norms at the end of the reserved and reserving MSL with the single MR was performed. The results were obtained for the structure with and without losses. It was found that considering the excitation, the probability of failure of the reserving equipment is lower, however, without taking into account the real electrical and physical parameters of the protected equipment it is impossible to provide a numerical characteristic of the probability. It should be noted that the absence of supply voltage in the reserving circuit was not taken into account. Therefore, it is advisable to conduct additional numerical and natural experiments.

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