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# Estimation of radiated emissions from a structure with a single modal reservation

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**Abstract**. The paper presents the electrodynamic simulation results for radiated emisions. The authors consider structures with and without a single modal reservation in the frequency range from 0.1 to 10 GHz. Frequency dependences of the electric field strength and radiated power were obtained. Radiation patterns at frequencies of 0.5, 5, and 10 GHz are presented. The authors showed that due to the strong electromagnetic coupling between the reserved and reserving circuits in inhomogeneous dielectric filling, the radiated interference is lower for the structure with a single modal reservation than without it in almost the entire frequency range under study.

## 1. Introduction

To increase the fault tolerance and reliability of critical radio electronic equipment (REE), various design solutions and circuit design approaches are used [1, 2]. One of the most common solutions is reservation [3], a special case of which is modal reservation (MR) [4]. Due to strong electromagnetic coupling between the reserved and the reserving circuits, it is possible to achieve the decomposition of an ultrashort pulse into a sequence of pulses of lower amplitude. For example, in the case of a single MR, where there is only one reserved circuit, it is possible to decompose the ultrashort pulse into two pulses [5]. Previously, the frequency and time characteristics of devices with single and triple MRs have been studied [6], and the efficiency of single MR before and after failures has been analyzed [7]. However, in the published works on MR, the estimation of radiated emissions from a structure with a single MR has not been carried out. In [8], a new approach to estimating the radiated emissions from MR circuits is proposed, which is based on a quasi-static analysis. For further comparison and testing of the proposed approach, it is necessary to perform high accuracy simulation using a well-known method. The purpose of this work is to perform such research.

## 2. Approaches, methods and structures

To estimate the radiated emissions from structures with and without a single MR, we used an electrodynamic approach based on the finite element method. The simulation of the structures under study was carried out in the computer design system Keysight Technologies EMPro 2020.

In this paper, we considered the structure of a single conductor with a length ($l$) of 1 m in an inhomogeneous dielectric filling, which is a microstrip transmission line (MSL), and a coupled MSL that simulates the structure with MR. Cross-sections and equivalent circuits are shown in Figures. 1 and 2, respectively. The equivalent circuit diagrams show the harmonic sources, the structures with a single MR and without it, the ending loads (*R*), and the nodes (*V*1–*V*5). For both structures, the thickness of the dielectric substrate (*h*) is 510 μm, the thickness of the conductors (*t*) is 65 μm, and the width of the conductors (*w*) is 300 μm. The distance between the conductors (*s*) for a structure with a single MR is assumed to be 100 μm. The distance from the conductor to the edge of the dielectric (*d*) is 600 μm for both structures. The dielectric material is a ceramic substrate with a relative permittivity of $\varepsilon_r$=10 and loss tangent of tgδ=0. The selected parameters are chosen taking into account the standard technological process for manufacturing printed circuit boards corresponding to the 3rd accuracy class [9].

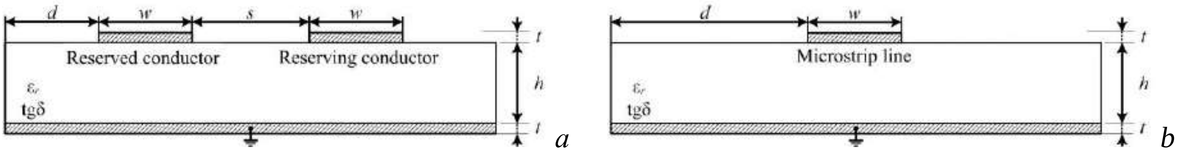



**Figure 1.** Cross-sections of the structures with a single MR (*a*) and without it (*b*).

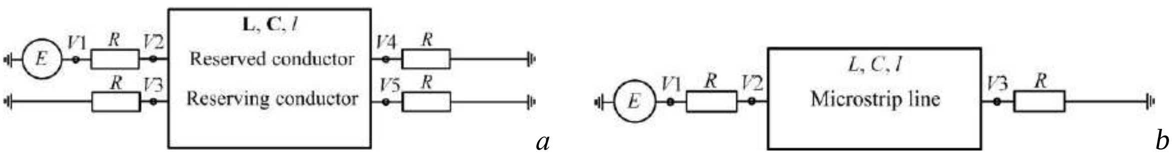



**Figure 2.** Equivalent circuit diagrams for the structures with a single MR (*a*) and without it (*b*).

The resistance values of all resistors in the structures under consideration are equal to 50 Ω. A 1 V harmonic ideal voltage source is connected between the line conductor and the reference plane.

The simulation was performed in the frequency range between 0.1 and 10 GHz. The distance at which the electric field strength was calculated was chosen to be 1 m, and the far zone sensor geometry built using theta and phi as coordinate system when φ and Θ were changed from 0° to 180° in 1° increments. Frequency dependences of the electric field strength and radiated power were obtained. The radiation patterns were obtained for structures with and without a single MR at frequencies of 0.5, 5, and 10 GHz. By constructing a three-dimensional model of the proposed structures, each element was divided (by the default settings) into cells with a minimum size of 20 microns. The simulation was performed without taking into account losses in the conductors and dielectric.

## 3. The results

Figures 3 and 4 show the results of calculating the maximum values of the total electric field magnitudes |*E*| and the radiated power $P_\Sigma$, respectively, for both structures.

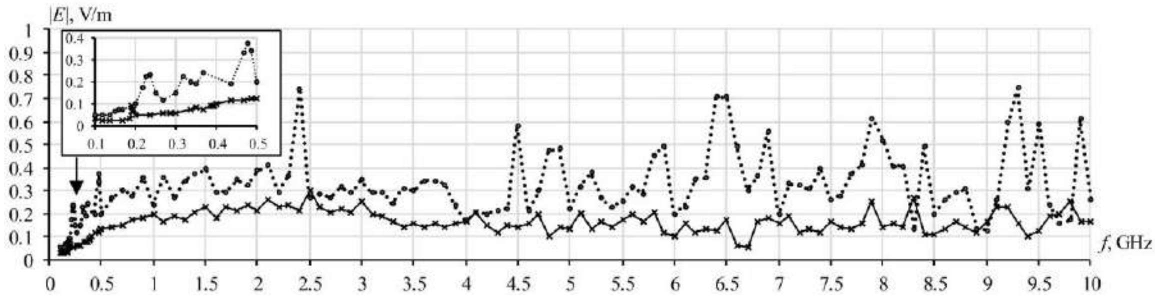



**Figure 3.** Frequency dependences of |*E*| for structures with a single MR (–) and without it (···).

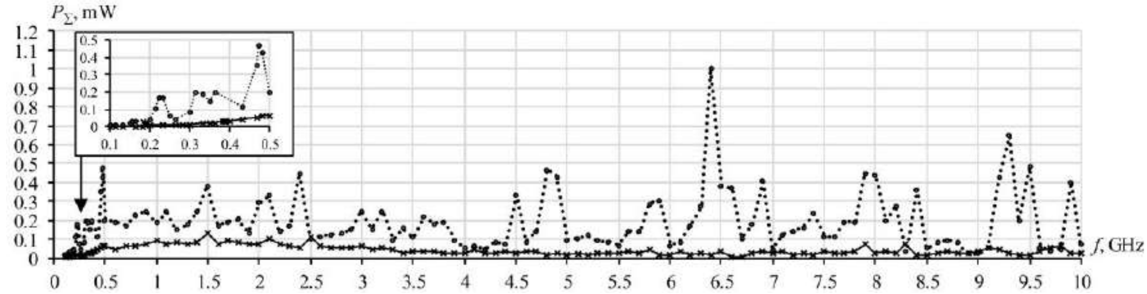



**Figure 4.** Frequency dependences of $P_\Sigma$ for structures with a single MR (–) and without it (···).

Figure 3 shows that with MR, the value of |*E*| decreased in almost the entire frequency range under investigation. Thus, the largest decrease of 4.7 times is observed at a frequency of 9.3 GHz. Figure 4 also shows that the use of MR reduces the radiated power. The largest decrease of 56 times is observed at a frequency of 6.4 GHz. Figure 5 shows the radiation patterns of structures with and without a single MR at the frequencies of 0.5, 5, and 10 GHz.

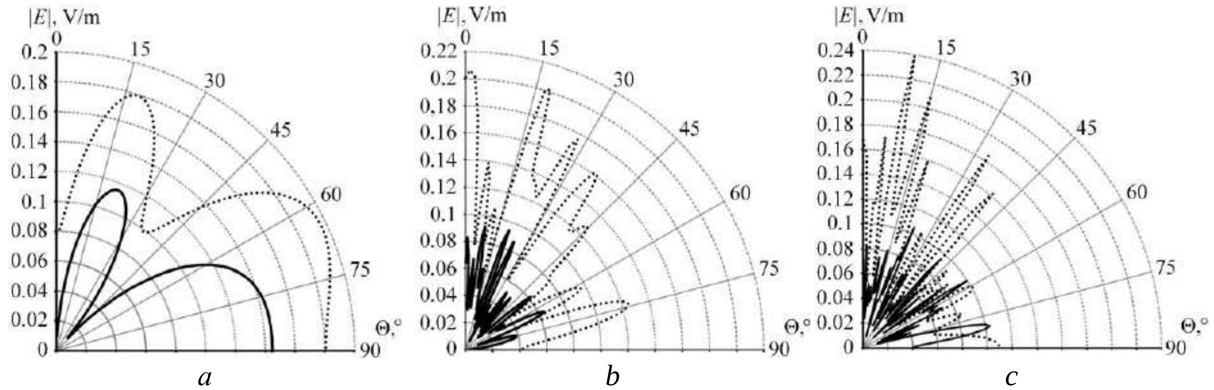
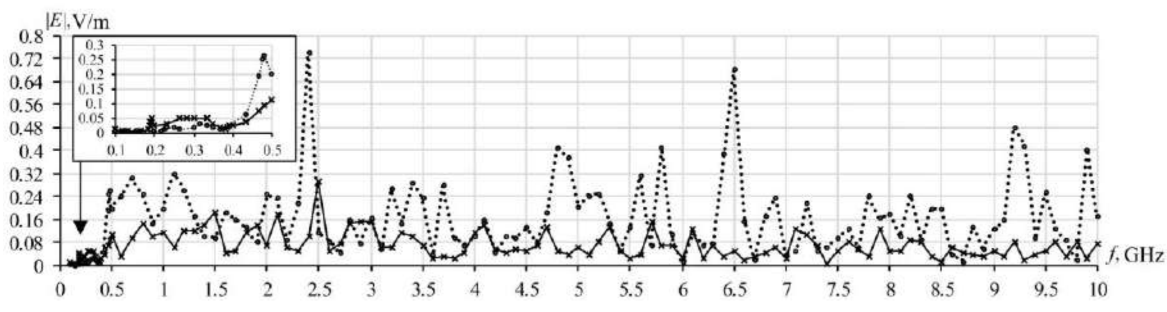
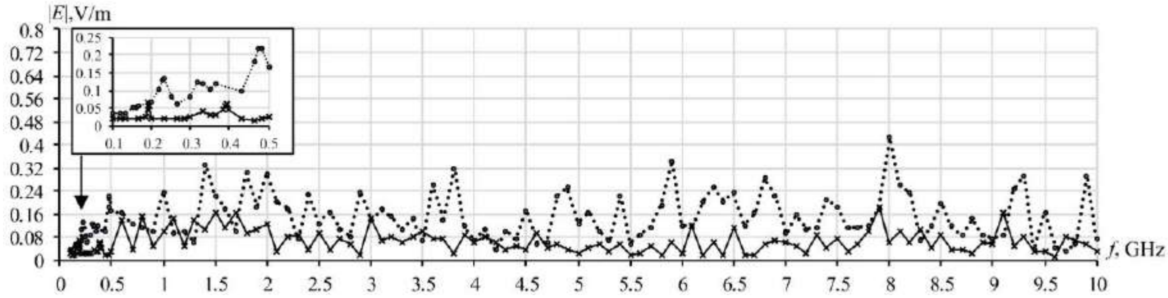



**Figure 5.** Radiation patterns of structures with a single MR (–) and without it (···) at frequencies of 0.5 (*a*), 5 (*b*), and 10 GHz (*c*).

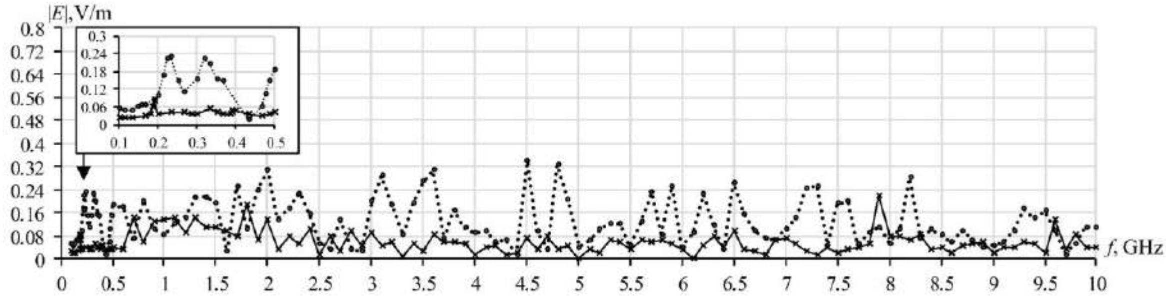
From the results presented in Figure 5, it is clear that the use of MR helps to reduce the electric field strength. Moreover, the decrease is observed at different values of Θ. Therefore, Figure 6 shows the frequency dependences of |*E*| for both structures at Θ = 0°, Θ = 45°, and Θ = 90°. The results show that the values of |*E*| for the structure with MR are less than those for the structure without it in almost the entire frequency range. However, the opposite result is observed at some frequencies. For example, for 7.9 GHz, the value of |*E*| at Θ = 90° for the structure with a single MR is 2 times higher than without it. This is possible due to the phase change of the current along the investigated structure. The limitations of the applied method may have an additional weak effect.




*a*




*b*




*c*

**Figure 6.** Frequency dependences of |*E*| for structures with a single MR (–) and without it (···) at Θ = 0° (*a*), Θ = 45° (*b*), and Θ = 90° (*c*).

## 4. Conclusion

In this paper, the frequency dependences of the electric field strength and the radiated power were obtained for the structures with a single MR and without it. It is shown that the use of a single MR reduces the radiated emissions of the reserved circuit in the frequency range from 0.1 to 10 GHz. This is due to electromagnetic coupling between the reserved and reserving conductors in an inhomogeneous dielectric medium. In the case of harmonic interference, its amplitude at certain frequencies may decrease because it's even and odd modes are in the opposite phase. As a result, the currents flowing in the opposite phase in these conductors decrease. This leads to a decrease in the electric field strength in the far field zone at certain frequencies. At these frequencies, we can expect a decrease in radiated emissions, as well as a decrease in susceptibility to radiated electromagnetic fields.

Meanwhile, there are frequencies or directions where results for the structure with a single MR are higher than for the one without it. This fact is difficult to explain definitely. In general, it might be associated with the resonance shifts and field redistribution.

In order to get a more complete understanding of the effect of MR on radiated emissions, further work will be devoted to studying the structures with a single and multiple MR patterns in various applications. The radiated emissions of such structures will be evaluated before and after the failure.

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