Comparing the Estimates of the Radiated Emission from a Structure with Modal Reservation by Two Approaches

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***Abstract*—The results of electrodynamic simulation of a structure with modal reservation are compared with the results obtained using the formerly proposed algorithm based on quasi-static analysis. The radiated emission from structures with and without modal reservation was estimated in the frequency range from 0.5 to 10 GHz. Frequency dependences of the maximum values of the electric field strength and radiation patterns at frequencies of 0.5, 5, and 10 GHz are compared. It was found that the use of modal reservation reduces the radiated emission of the reserved circuit. It was revealed that the use of the proposed algorithm gives sufficiently close, in comparison to electrodynamic analysis, electric field strength magnitudes.**

Keywords—radiated emission, quasi-static, electrodynamic, modal reservation, far field

I. Introduction

Modal reservation (MR) was proposed to simultaneously ensure the electromagnetic compatibility and the reliability of the critical electronic equipment. Devices with MR are widely studied [1], but their radiated emission has not been evaluated, except for the work [2], where a well-known computer-aided design system based on electrodynamic analysis by the finite element method was used to test the proposed algorithm in [3]. This algorithm uses a quasi-static analysis that provides sufficient accuracy without significant computational costs. The algorithm allows calculating the response of a multi-conductor transmission line section at the ends of the segments into which this section is divided. Then it permits to calculate the electric field strength from each segment as an elementary radiator, and in consequence, getting the radiation pattern (RP) via the vector potential in the far zone. The algorithm was tested on two coupled wires above the ground plane, and its results have been compared with those obtained by electrodynamic analysis [4]. Based on that algorithm, a program is created which allows estimating RPs from structures with a single MR and without it. The program was implemented in the TALGAT system [5].

This paper is aimed at testing this program and comparing its results with those obtained earlier in the work [2]. The novelty of these estimates is that they have not been obtained earlier for circuits with MR in our own software product TALGAT.

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II. Problem Statement

The competition of radio electronic device (RED) manufacturers requires that they regularly and rapidly invent more and more advanced types with minimal costs. However, meeting those requirements along with increasing the complexity of REDs becomes impossible without the use of computer-aided design (CAD) systems which are based on computer modeling. Therefore, the availability of an effective CAD system is important to ease and improve specialists' work since it significantly reduces the time spent on developing and improving the quality of the final product, and the financial resources required for this, which will make it more affordable. Consequently, this will be helpful to take the right technical decisions in the RED manufacturing process. An important one of such decisions is ensuring the electromagnetic compatibility and the reliability of REDs. This brings out the challenge of solving the distribution of electric or magnetic potential problems. These problems are described by the approximated (using discretization) partial differential equations resolvable via numerical methods. To decide what type of analysis to use and by which numerical method is a complicated issue because there are a lot of possible options to choose from. The use of electrodynamic analysis makes it possible to analyze complex structures and gives very accurate results. This analysis may be done with many numerical methods, one of which is the finite element method [6] developed by many scientists like in [7] and in [8]. Unfortunately, it is much more difficult to build and understand electrodynamic models than quasi-static ones. Moreover, the quasi-static analysis can give close enough results comparing to the electrodynamic ones and even at a lower computational cost. In this study, we employed a combination of the method of nodal potentials [9], and the method of moments [10] with thin-wire approximation as a quasi-static analysis. The accuracy of this analysis, if used correctly, can be controlled and is quite acceptable. In addition, it was found that this model has unique capabilities for solving optimization problems. Therefore, special attention is paid to the issues of software implementation of this analysis, and this will be covered in the present work by comparing the results of these two different analyses. Furthermore, the obtained results belong to the MR method, which will increase its importance.

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III. Initial Data

We considered the same structures that had been studied in [2]: single and coupled microstrip transmission lines imitating the structures without and with MR. Their cross-sections and equivalent circuits are shown in Fig. 1 and Fig. 2, respectively. The equivalent circuit diagrams show the harmonic sources, the structures with MR and without MR, the termination loads (*R*), and the voltage nodes (*V*1–*V*5). For both structures, the length (*l*) is 1 m, the thickness of the dielectric substrate (*h*) is 510 µm, the thickness of the conductors (*t*) is 65 µm, the width of the conductors (*w*) is 300 µm, and the distance from the conductor to the edge of the dielectric (*d*) is 600 µm. The distance between the conductors (*s*) for the structure with MR is assumed to be 100 µm. A ceramic substrate with a relative permittivity (ε_r) of 10 and loss tangent of tgδ=0 was chosen as the dielectric material. These parameters are taken in view of the technological process standard for manufacturing printed circuit boards corresponding to the 3rd class of accuracy. The resistance of all resistors is equal to 50 Ω. A 1 V harmonic ideal voltage source is connected between the conductor and the reference plane. The distance at which the electric field strength was calculated was chosen to be 1 m, and the far zone geometry sensor was built using theta and phi as coordinate system when θ and φ were changed in general, from 0° to 180° in 1° increments. The simulation was carried out without taking into account losses in conductors and the dielectric. The frequency varied from 0.5 to 10 GHz in increments of 0.5 GHz.

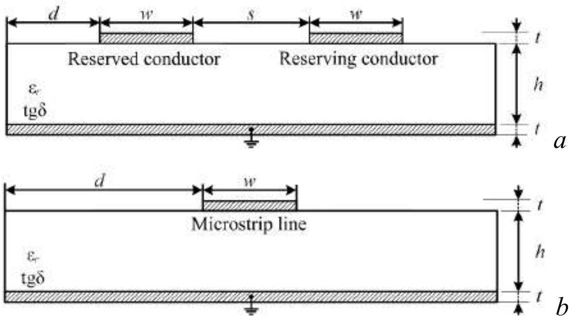


Fig. 1. The cross-sections of the structures with (*a*) and without MR (*b*).

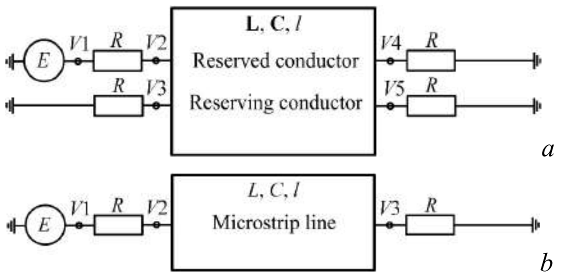


Fig. 2. The equivalent circuit diagrams for the structures with (*a*) and without MR (*b*).

The default minimum size of the cells, which each element of the three-dimensional model was divided into when the structures was modeled using EMPro, was 20 µm. However, using TALGAT, the number of segments on each wire (*n*1) was 640. By means of quasi-static analysis, we calculated the currents in each segment along the conductors. Fig. 3 shows an example of the current distribution for the structures with and without MR at a frequency of 500 MHz in the TALGAT system. The index (n) in Fig. 3 refers to the segment number when all the conductors of the structure are numbered end-to-end. It can be seen that without MR, the current along the wires almost does not change due to good matching, whereas with MR, the strong coupling between the conductors leads to a significant change in the current along the wires.

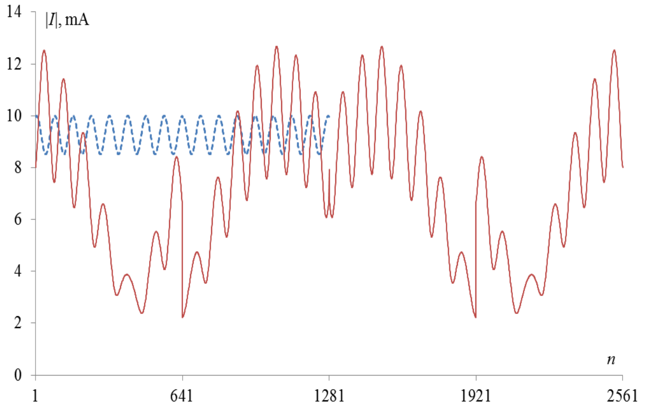
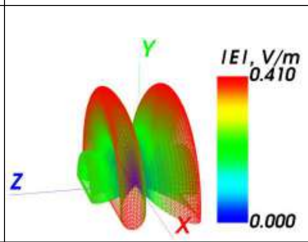
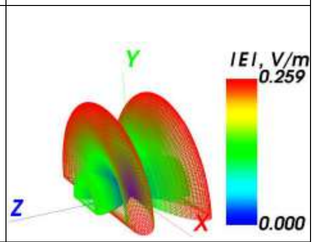
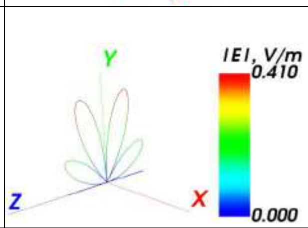
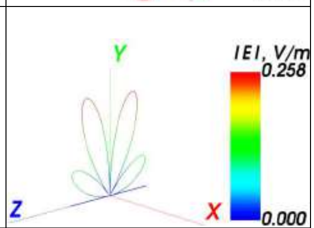
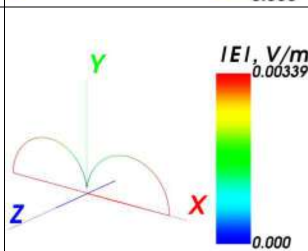
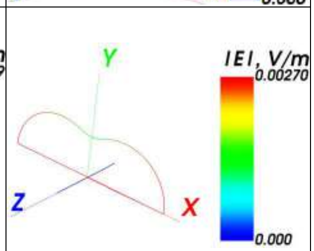
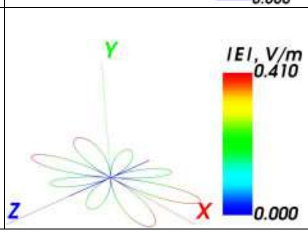
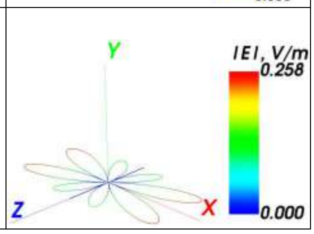


Fig. 3. The current distribution in structures with (–) and without (···) MR.

Then, an equivalent structure was constructed using electrodynamic analysis by replacing the infinite reference plane with two mirror wires and connecting the source between the reserved conductor and its mirror. The field strength (*E*) was calculated using the obtained currents.

TABLE I. Examples of the RP at different values φ и θ for structures with and without MR

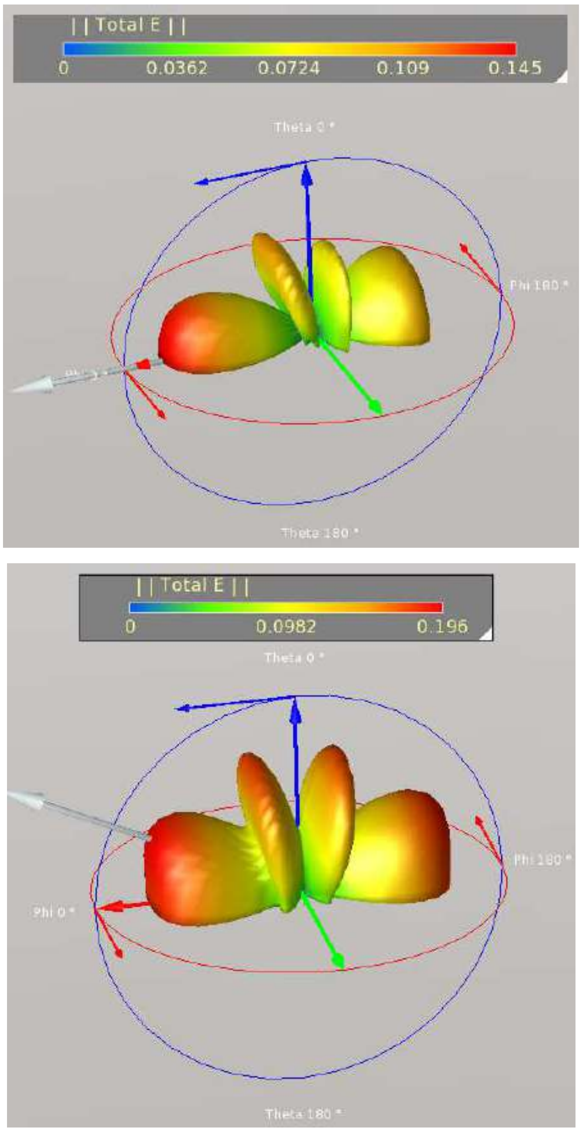
	Without MR	With MR
θ=0–180°, φ=0–180°		
θ=0–180°, φ=90°		
θ=90°, φ=0–180°		
θ=0–360°, φ=180°		

IV. Results

Table I presents a number of examples of the RP for structures with and without MR at different values of φ and θ and a frequency of 500 MHz obtained using TALGAT. As can be seen from the maximum of the RP, at this frequency, the MR reduced the emission of the studied structures by about 1.5 times.

Fig. 4 shows the maximum values of |*E*| when θ and φ changed from 0 to 180° in increments of 10°, depending on the frequency, in the range from 0.5 to 10 GHz in increments of 0.5 GHz. The values were obtained using the TALGAT.

The results show that the values of |*E*| for the structure with MR are lower than for the structure without it in almost the entire frequency range. However, at some frequencies, the opposite result is observed, which may be explained by the fact that the current phase changes along the structure and that the limitations of the applied method add some effect. Fig. 5 presents an example of the RP for the structures with and without MR at a frequency of 500 MHz obtained using EMPro. Moreover, it is apparent that MR reduced the emission of the studied structures at this frequency.



a

b

Fig. 4. RPs of the structures with (*a*) and without (*b*) MR

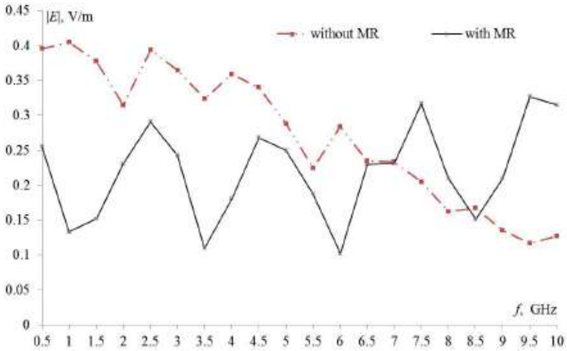


Fig. 5. The maximum frequency-dependent values of |*E*| for the structures with and without MR obtained using TALGAT.

V. Comparing the Results

The maximum values of |*E*| were obtained for structures with and without MR in the two systems (Fig. 6). The results show that the use of MR reduces the radiated emissions, but not at all frequencies. The application of the proposed algorithm gives results which are sufficiently close to those of the electrodynamic analysis of the of |*E*| values.

Since the directions of the maximum radiation for different structures may differ, their RP, for example, is given at θ=0–90°, at frequencies of 0.5, 5 and 10 GHz (Fig. 7). The consistency of the results, taking into account the differences in methods and segmentation, can be considered acceptable. Furthermore, we also note here the MR-related results received earlier: decrement at the low frequencies and increment at the high ones.

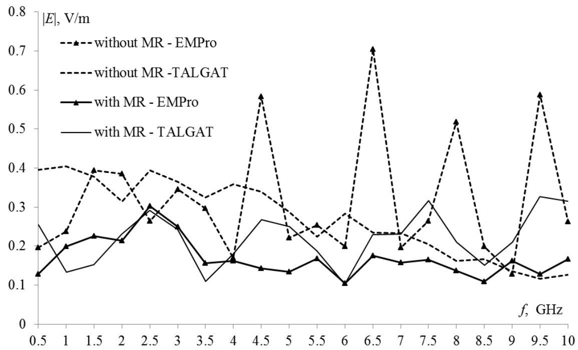
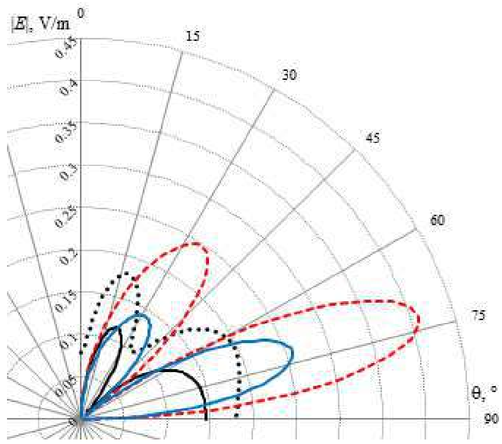


Fig. 6. The maximum frequency-dependent values of |E| for the structures with and without MR obtained in the two systems.



a

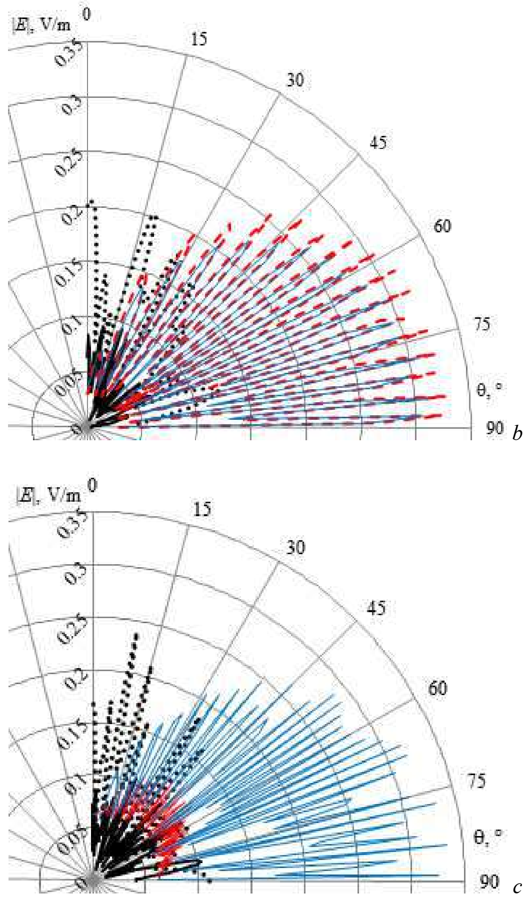


Fig. 7. The RP for the structures with (–) and without (···) MR in EMPro, and with (–) and without (--) MR in TALGAT, at frequencies of 0.5 (a), 5 (b) and 10 (c) GHz.

VI. Conclusion

The proposed algorithm was tested to estimate the radiated emission from microstrip structures with MR. The obtained results were compared and showed that the use of MR reduces the radiated emission due to electromagnetic coupling between the reserved and reserving conductors in an inhomogeneous dielectric medium, in a wide frequency range. At some frequencies, the even and odd modes of the harmonic interference were found to lie in a reversed phase, which leads to a decrease in its amplitude and, as a direct result, a decrease in the current amplitudes and the electric field strength values formed at the far field zone. Consequently, we can expect a decrease in radiated emissions, as well as a decrease in susceptibility to radiated electromagnetic fields. But, there are frequencies or directions where the opposite results were obtained, which in fact is difficult to explain definitely. However, the resonance shifts and field redistribution might be the reason behind this case.

The total elapsed time for simulating the structures with and without MR in EMPro, took more than 58 minutes, while for simulating those structures in TALGAT, it took only about 4 minutes. This confirms that the proposed algorithm not only gives acceptable results comparing to electrodynamic analysis but also decreases the computational costs.

Further work will be oriented towards studying the structures with single and multiple MR and evaluating their radiated emission. Thorough inquiry will be conducted to determine the reasons behind the difference in the reached results and achieve clear explanation.

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