Approach to Estimation of Radiated Emission from Circuits with Modal Reservation

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Abstract – **Proceeding from the increasing importance of radioelectronic devices, and with an intuitive result, an increased interest in studying and ensuring the electromagnetic compatibility of these devices and especially the critical radioelectronic equipment and systems, a new approach had been applied with a name of "modal reservation". In order to investigate the possible options for different arrangements of circuits with reservation, a lot of research work has to be done on those arrangements taking into account so many criteria and factors including the radiation pattern among them. For analysing printed circuit interconnects, the quasi-static approach has an obvious advantage, since the circuit analysis does not always allow obtaining the results of sufficient accuracy, and the electro-dynamic one requires significant computational costs. Combining these approaches is proposed, using the calculated results of the current and voltage in multiconductor transmission lines structure from the quasi-static approach, in the electrodynamic analysis to calculate the far-zone field components for the radiation pattern from this structure. The novelty of the estimations obtained is determined by the concept of combining the studied approaches in order to get accurate result, and the fact that they have never been performed for circuits with modal reservation in such a complex form. This paper aims at developing a mathematical model and algorithm which allow calculating the field strength from a circuit with modal reservation using currents in circuit conductors obtained by quasi-static analysis.The algorithm implementation showed acceptable coincidence of current distribution and radiation pattern obtained from a simple test structure by the proposed algorithm and electrodynamic analysis.**

Index Terms – **modal reservation, far field, radiation, quasi-static analysis, multiconductor transmission lines, electromagnetic compatibility.**

I. INTRODUCTION

CURRENTLY, IN VARIOUS sectors of society and also in the field of managing critical systems, the use of radioelectronic devices (RED) is growing rapidly enough to double the needed efforts for solving their problems. Uninterrupted operation is especially important for critical systems, since they are associated with the risk of large losses, in both material and human. It is noteworthy that the problem of the electromagnetic compatibility(EMC) at the printed circuit level is largely determined by the mutual influence of circuit level conductors [1, 2] or the system internal interference, besides the external interference between the systems.

In addition to the interference caused by useful signals, attention should also be paid to powerful intentional electromagnetic pulses of the nanosecond and sub-nanosecond ranges since they are able to penetrate various REDs [3, 4] and disable them. This is undoubtedly essential both for EMC and information security. The identification and localization of signal extremes is important since their results can be useful for determining the locations of possible spurious interference and radiation in order to take timely measures to eliminate them, to ensure EMC [5] and to increase the noise immunity and reliability of REDs [6].

The evaluation of various radioelectronic equipment and systems reliability under the operation conditions is generally summarized to failure quota of components and the whole equipment and to the analysis of failure mode and mechanism. A failure state entrance can happen under the influence of some factors, which include inefficient choices of protective devices and redundancy methods; inappropriate choices of electric and thermal operating conditions of components and blocks; irrational packaging density. In most cases, such weaknesses may cause overvoltage in the future.

The authors of [7] have first proposed the idea of modal reservation (MR). The essence of MR is to use redundancy to provide RED reliability and EMC (Fig.1). This is achieved by performing such a redundancy in which there are the reserved and reserving circuits form a modal filter: a device that uses modal distortion to attenuate harmful signals due to the difference in the mode delays of the multiconductor transmission lines (MCTL). As a result, the interference pulse, which is less than a certain duration value, will decompose into pulses of smaller amplitude, and the interference at a given frequency can significantly attenuate. This leads to decrease of the susceptibility of the reserved circuit to external conductive emissions. Minimizing the radiated emission is no less important than minimizing the conductive emission of the reserved circuit because it may affect the performance of other REDs. The challenge is to meet the conducted and radiated emissions standards early in the design cycle; otherwise, the following solutions will be costly.

Thus, improving reliability with regard to EMC using different types of reservation on various REDs widely used in science and technology fields is an urgent task. By optimizing this method (reservation), we can improve the interference immunity and reliability of final devices. In order to estimate the radiated emission, we will calculate the electric field intensity from a circuit using currents in circuit conductors obtained by quasi-static analysis.

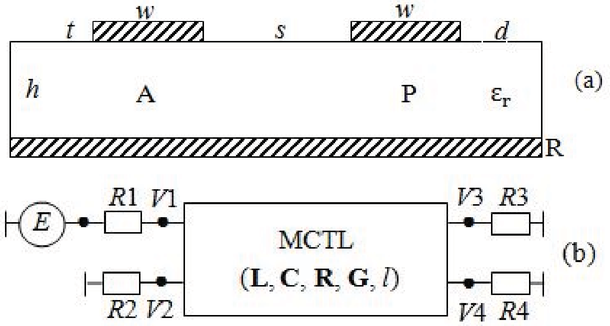

Fig.1. Cross section of the structure of coupled lines for MR where A – active; P – passive; R – reverse conductors (a). Circuit diagram (b).

II. PROBLEM STATEMENT

The static approach assumes that there are no higher type of waves in interconnects, and only the main transverse wave can propagate. This reduces Maxwell's equations to telegraph equations, the solution of which is much simpler, but quite accurate for practical interconnects. Assuming propagation of only the transverse wave, accurate results have been obtained even in the presence of small losses in interconnects. This case is known as the quasi-static approach. Because of its merits, it is widely used by researchers to analyze interconnects. With it, an arbitrary interconnects scheme is represented by a generalized circuit model, in which the voltages and currents at any point are determined from the telegraph equations for each MCTL segment, taking into account the boundary conditions at the ends of the segment. That includes determining the matrices of parameters of MCTL segments, the equivalent parameters of their functions and the response of the MCTL scheme to a given excitation.

Based on the theoretical foundations of the quasi-static response calculation for an arbitrary circuit of MCTL segments which are described in [8, 9], an algorithm has been developed for calculating the time response [10], which allows us to calculate the values of currents and voltages at the nodes of the circuit.

There is a lot of software for EMC simulation such as Empire XPU [11], ANSYS Workbench Platform [12], AWR Microwave Office [13], FEKO [14], CST Microwave Studio [15]. In addition to their EMC modeling capabilities, including multifunctional graphic shells, much attention is paid to visualizing and animating the processes occurring inside the structures under study, which gives the user the most complete information about the nature of the phenomena occurring inside them. In particular, in some software systems (CST MWS, AWR Microwave office, FEKO), dynamic visualization is implemented which displays the changing in the radiation pattern depending on the frequency. However, dynamic visualization of the results of the time domain modeling of signals propagating along the conductors has not been implemented. Meantime, it is necessary for a clearer understanding of the causes, the identification of places and ways to reduce electromagnetic interference. In addition, none of these software packages has the ability to detect and localize signal extremes along the MCTL conductors. All software products discussed above use electrodynamic analysis, while products using quasi-static analysis are not detected. Realizing the importance of that led us to start working on developing domestic tools for modeling circuits with MR.

For this aim, using the quasi-static approach and then the electromagnetic field calculation, we are intending to develop and test mathematical models, computational algorithms and software modules based on them, which allow us to estimate the radiated emission from the circuits with MR.

III. THEORY

Recently, the authors of [16] have modified numerical method which is based on dividing the MCTL into a number of segments. In this case, the calculation of the response is performed not only at the ends of the MCTL, but also at the ends of its segments. This new algorithm has already been implemented in TALGAT software.

As a model of electrodynamic analysis, a model for calculating currents in an arbitrary wire structure by the method of moments had been implemented [17]. It uses thin-wire approximation (current flows along the axis of the wire); step functions as basic functions (the current along the elementary segment of the wire does not change); delta functions as test functions. The advantage of the model is its simplicity and the ability to analyze arbitrary wire structures with an arbitrary location of the generator. From the currents, the antenna characteristics are calculated. This model assumes that the wire antenna is obtained when the wire is excited by a voltage source at one or more points along its length. If we can treat every segment of the wire antenna as an elementary radiator, we can obtain the radiation pattern as the far-zone vector potential given by

$$A = \frac{\mu e^{-jkr_0}}{4\pi r_0}\sum_{n} I(n)\Delta l_n\, e^{-jkr_n}\cos\xi_n$$

where r_0 and r_n, are the radius vectors to the distant field point and to the source points, respectively, and ξ_n are the angles between r_0 and r_n. Then the far-zone field components are

$$E_\theta = -j\omega A_\theta, E_\phi = -j\omega A_\phi.$$

We can combine these two models to get the next algorithm:

1. Quasi-static analysis:
    1.1. Construct MCTL cross section geometric models considering the MR arrangement.
    1.2. Calculate the per-unit-length matrices of MCTLs.
    1.3. Construct MCTL equivalent scheme considering the MR arrangement.
    1.4. Define the excitation.
    1.5. Calculate the frequency response at any points of the circuit (not only in the nodes, but also along any conductor at any segment of the MCTL).
    1.6. Get the current in every segment for all the conductors.
2. Electromagnetic field calculation:
    2.1. Define MCTL location coordinates.
    2.2. Calculate of the electric field intensity in the far zone using the current data.
3. Plot the radiation pattern of the circuit.

IV. PRELIMINARY TEST

In order to achieve the correct implementation of the proposed algorithm we consider the simplest test case of two parallel wires (Fig. 2).We assume short circuit at the input and open circuit at the output, with a length (L) of 0.299 m and a radius (RA)of 0.3 mm and number of segments n=20 for each, considering the surrounding area as air and one of the wires is reference (note that we did not consider the losses to simplify the test). The initial data for designing the circuit diagram are the following: $R1$=0.00001 Ohm $R2$=100000 Ohm and harmonic source E=1 V excitation between the conductors (Fig.2).

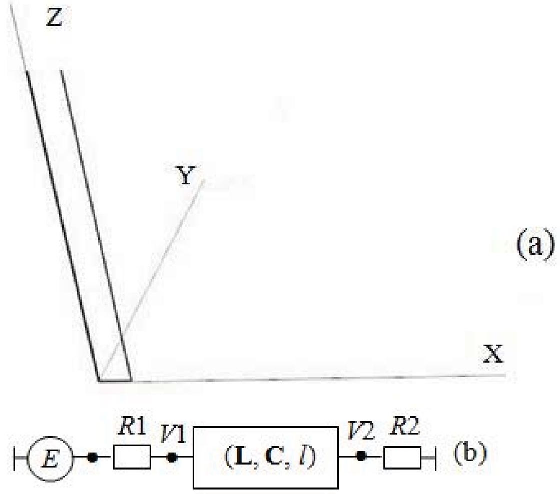

Fig.2. Cross section (a) and circuit diagram of the test structure (b).

By performing the simulation in TALGAT at the frequency of 500 MHz, we can get the frequency response and the current values for each segment. Using the currents for E-field calculation, we obtained the following radiation pattern (Fig. 3).

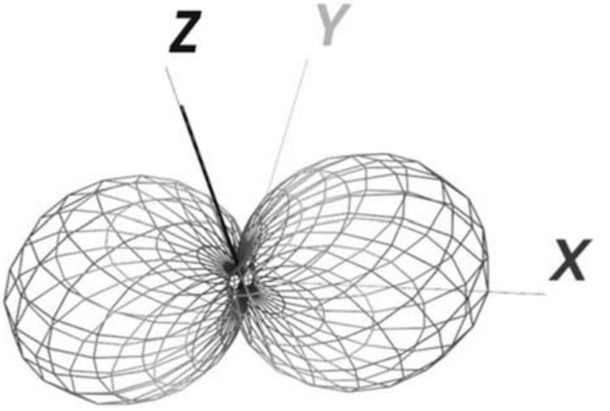

Fig.3. Radiation pattern of the test structure using the proposed algorithm.

In order to achieve realistic fairly results, we have chosen the value of per-unit-length capacitance equal to 14.433 pF after calculating its value for different number of segments at cross section boundaries of conductors, which has changed from 20 segments until convergence at 40 segments. The distance at which we have calculated the electric field intensity in the far zone is about 1.8 m.

V. DISCUSSION OF RESULTS

By performing the simulation in TALGAT system at the same frequency for the same test structure using the electrodynamic analysis, the following radiation pattern was obtained (Fig.4).The models used in this work had been tested, compared and verified in [16, 18].

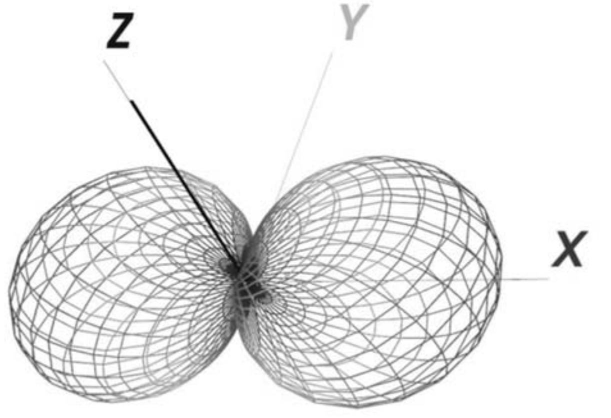

Fig.4. Radiation pattern of the test structure using the electrodynamic analysis.

The simulation shows that using this algorithm gives close enough results in the radiation patterns and maximum absolute value of the total field (3.39 and 3.15 mV/m). For more comparison, the primary results of current distribution are presented in Fig. 5(a). They are very close in maximum values. However, their minimums differ considerably, thus we had changed the number of segments n since their value affect the precision of the simulation results. The results of the current distribution according to the changing in segmentation are shown in Fig. 5.

Fig. 5(c) shows that at n=80 on each conductor, the closest result in maximum and minimum values was obtained.

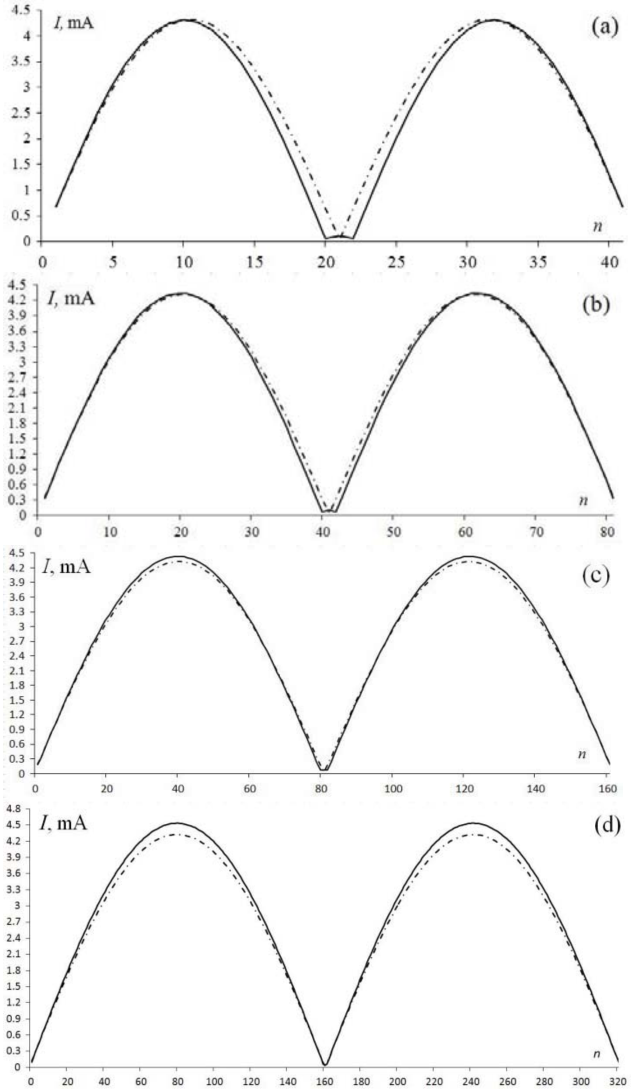

Fig.5. The current magnitudes(I) at every segment (n) using the electrodynamic analysis (—), and using the proposed algorithm (- -).

Accordingly, changing in current distribution leads to changing in the total electric field intensity maximum magnitudes, which are presented in Table 1. The radiation patterns from the test structure with n=80 on each conductor using the electrodynamic analysis and proposed algorithm are similar and omitted here.

TABLE I

The Results of Obtained Maximum Magnitudes of the Current $|I|$ and Total Field Intensity $|E|$

Number of segments	Field calculating		Proposed algorithm	
	$|I|$, mA	$|E|$, mV/m	$|I|$, mA	$|E|$, mV/m
20	4.31	3.15	4.32	3.39
40	4.34	3.18	4.32	3.32
80	4.43	3.25	4.33	3.28
160	4.54	3.33	4.33	3.27

It is important to note that this study evaluated the radiation pattern for half-wavelength wires, considering only one frequency which gives maximum radiation level. Similar study for different frequencies can be easily obtained using the proposed approach.

VI. CONCLUSION

Following up on research and implementation of the proposed algorithm in this work, will give us the possibility of a comprehensive and effective development of MR to increase the reliability and provide EMC of critical REDs. In the future, we will be able to use this work in development of theoretical foundations and methods for constructing and assembling circuits with MR considering the level of radiated emission from them. Developing this algorithm will lead us to create tool for modeling circuits with MR and verify the concepts under study with experiments.

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REFERENCES

[1] Electromagnetic Compatibility Requirements For Space Equipment And Systems, Aerospace Report no. TOR-2005(8583)-1; 8 August 2005.

[2] S. Roy, "Macromodeling of multilayered power distribution networks based on multiconductor transmission line approach," S. Roy, A. Dounavis, IEEE Trans. on Components, Packaging and Manufacturing Technology, vol. 3.,pp. 1047–1056. February, 2013.

[3] K.Yu. Sakharov, et al., "Investigation of the functioning of the local computer network under the influence of ultra-short electromagnetic pulses," K.Yu. Sakharov, EMC Technologies, no. 3 (18)., pp. 36–45, 2006.

[4] Y.S. Cao, et al., "Quantifying EMI: a methodology for determining and quantifying radiation for practical design guidelines," Y.S. Cao, IEEE Trans. on Electromagn. Compat., vol. 59, no. 5., pp. 1424–1431. October 2017.

[5] M.S. Zhang, et al., "Modeling, analysis, and design for noise suppression using embedded planar capacitors in multilayered printed circuit boards," M.S. Zhang, IEEE Trans. on Components, Packaging and Manufacturing Technology., vol. 4., pp. 882–891. January 2014.

[6] P.E. Orlov, et al., "A new concept for creating integrated sensors for monitoring the electromagnetic environment in the onboard equipment of a spacecraft," P.E. Orlov, Aerospace instrumentation. no. 5., pp. 20–23, 2012.

[7] R. Achar, M.S. Nakhla, "Simulation of high-speed interconnects," R. Achar, M.S. Nakhla, Proc. of the IEEE. vol. 89., no. 5., pp. 693–728, 2001.

[8] A.R. Djordjevic, T.K. Sarkar, "Analysis of time response of lossymulticonductor transmission line networks," A.R. Djordjevic, T.K. Sarkar, IEEE Trans. Microwave Theory Tech., vol. MTT- 35., pp. 898-908, 1987.

[9] A.M. Zabolotsky, T.R. Gazizov, "Software implementation of models," in Time response of multi-wire transmission lines, Томск: TUSUR, pp. 21-30, 2007.

[10] Empire XPU (20.01.2020). [Online].Available: http://www.empire.de/.

[11] ANSYS Workbench Platform (20.01.2020). [Online].Available: https://www.ansys.com/products/platform.

[12] AWR Microwave Office (20.01.2020). [Online].Available: http://www.awrcorp.com/products/microwave-office.

[13] FEKO (20.01.2020). [Online]. Available: http://www.feko.info/.

[14] CST MICROVAWE STUDIO (20.01.2020). [Online]. Available: https://www.cst.com/products/CSTMWS.

[15] R.R. Gazizov, et al., "Detection and Localization of Interference and Useful Signal Extreme Points in Closely Coupled Multiconductor Transmission Line Networks," Symmetry 2019, 11(10), 1209,27 Sep 2019.

[16] R.F. Harrington, "Matrix Methods for Field Problems," R.F. Harrington, Proc. of the IEEE. no. 2., pp. 136-149, 1967.

[17] T.R. Gazizov, et al.,"Solving the Complexity Problem in the Electronics Production Process by Reducing the Sensitivity of Transmission Line Characteristics to Their Parameter Variations," Complexity in Manufacturing Processes and Systems, vol. 2019, 03 June 2019.

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