Quasistatic and Electromagnetic Simulation of Interconnects of Printed Circuit Boards with Modal Reservation

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***Abstract* – Quasistatic and electromagnetic simulation of three cross-sections of interconnects of new PCBs for circuits with redundancy is performed. It is shown that the results are consistent. The relative difference was 4% for the difference of per-unit-length delays of modes and 40% for the pulse amplitudes. Meanwhile, the simulation time of quasistatic analysis is 263-1261 times less than that of electromagnetic analysis.**

***Index Terms* – Quasistatic and electromagnetic simulation, modal reservation, interference immunity.**

I. Introduction

INTERFERENCE immunity and fault tolerance of electronic systems are vital for society because malfunction can cause substantial losses. Moreover, nowadays, there is an increasing threat of intentional electromagnetic interference into electronics [1]. Such attacks can result in malfunction or failure of electronic equipment [2]. Particularly, the impact of ultra-wideband (UWB) pulses is especially dangerous, as existing surge protectors do not protect against them [3]. There are only some industrial devices that protect against UWB pulses but they have large dimensions and high cost. Thus, currently there is no both low-cost and effective protection against UWB pulses. However, the increasing role of electronics makes this protection more urgent. Importance of this problem is representatively reflected in AMEREM/EUROEM/ASIAEM conferences. For example, a recent ASIAEM 2015 hold a separate technical topic “IEMI Threats, Effects and Protection” and important special sessions (Design of Protective Devices and Test Methods. Evaluation of HEMP/IEMI Impacts on Critical Infrastructure).

Reservation is an efficient way to overcome fault of electronics. It allows using of the similar idle part of electronic equipment in case of fault in the functioning part. However, it doubles hardware. Necessity of proper protection against UWB pulses considerably complicates all the parts and, as a result, the final design. Meanwhile, as there is redundancy, we can search for ways of its rational use.

Based on accounting of electromagnetic coupling between reserved and reserving conductors of the reserved and reserving circuits, a method of modal reservation [4] can improve the protection of electronic systems against electromagnetic interference. Efficiency of modal reservation in different types of interconnects is considered in the paper [5].

Practical realization of this requires a thorough theoretical research using a computer simulation, inasmuch as realization of natural experiment is costly and time-consuming. Simulation permits to obtain the first evaluation without material and time costs. The base for this is the development of simulation methods and computer technology. Electromagnetic and quasistatic simulation can be applied. Each of the approaches has its strengths and weaknesses, as well as the optimal area of its use. Electromagnetic analysis based on Maxwell’s equations takes into account all ongoing wave processes, requiring more computing resources than the quasistatic analysis. Quasistatic analysis is based on telegraph equations, taking into account the assumptions and limitations of use. Unfortunately, it is not always taken into account and often simulation is performed using only a single type of analysis without alignment of a modeling methodology with the specific task [6]. A number of simulation results [7] demonstrates that this approach can be inefficient.

The aim of this paper is to compare results of electromagnetic and quasistatic simulation of new PCB structures with modal reservation.

II. Method of Modal Reservation

Modal reservation is a type of reservation of electrical connections that accounts for electromagnetic couplings between reserved (active) and reserving (passive) conductors of reserved and reserving circuits. As a result, a reserved circuit becomes less vulnerable to external conducted emissions, and we get less conducted emissions from the reserved circuit [8–10]. If a reserved circuit fails, similar result can be obtained in the reserving circuit. As the duration of an interfering pulse is less than the difference between delays of even and odd modes in the structure of coupled line formed by a couple of conductors of reserved and reserving circuits, this interfering pulse is distorted, i.e. it is decomposed into pulses of lower amplitudes (if signal is considered in the time domain). The result is demonstrated by the example of propagation of interfering pulse of 2 V and durations of fronts and flat top of 100 ps in a coupled line. Pulse is excited between a reserved route (active conductor) and a reference conductor, reserving route is used as passive conductor. The results of quasistatic simulation (Fig. 1) of the time response at the near and far ends of the reserved route (points $V2$ and $V4$) show two decomposition pulses with amplitudes of 0.5 V that is two times less than the interfering pulse (1 V) at the near end of the active conductor. Decomposition of an interfering pulse into two pulses with lower amplitudes (and, consequently, smaller vulnerability of the reserved circuit to external conducted emissions) can be explained by difference of delays of even and odd modes. If an interfering pulse is excited between the passive and reference conductors, there is similar time response at the end of an active conductor. Amplitude frequency response (Fig. 2) shows weakening of spectrum parts of an initial pulse and existence of resonant frequencies (spectrum parts with zero amplitude), thus, interfering signal can be attenuated till zero in a particular range of frequencies.

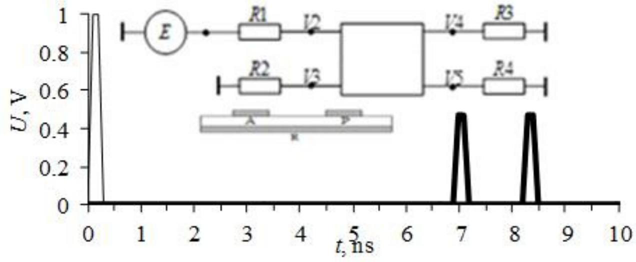

Fig. 1. Signal at the near (–) and far ends (=) of active conductor

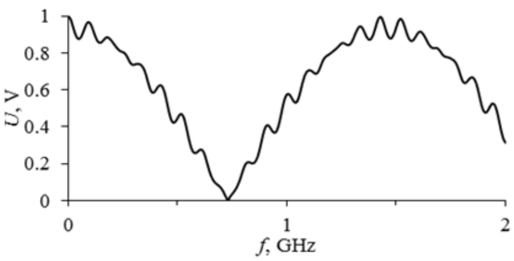

Fig. 2. Frequency response to harmonic excitation

III. Simulation Approaches

Simulation was executed in the TALGAT (quasistatic analysis) and CST MWS (electromagnetic analysis) software without accounting the losses. In CST MWS a combination of the perfect boundary approximation with the Finite Integration Technique is used [11]. The transient solver allows making full-wave 3D analysis of structures of various complexities. In general, the CST MWS is too widespread to give it a more detailed description. The TALGAT software is based on the method of moments and allows to make 2D quasistatic analysis. The algorithm implemented in the system allows to calculate all elements of a moment matrix by fully analytical formulae only, avoiding the time-consuming and approximate numerical integration. It can be useful for effective calculation of a capacitive matrix of two-dimensional systems of various complexities [12].

In this paper three cross sections of electrical connections are considered. These cross sections allow to implement the method of modal reservation: coupled microstrip line, coupled line with broadside coupling, symmetrical lines with broadside coupling. In the considered structures there are only two conductors (except reference), therefore only two modes are propagating along the line: even and odd modes. Simulation was performed in the time domain. A trapezoidal signal with EMF of 2 V and durations of rise, flat top and fall times of 100 ps was chosen as excitation source. The signal was excited between the reference and active conductors of structures. A length of structures is equal to 1 m. Schematic diagram of simulations is shown in Fig. 1.

IV. Simulation Results

Cross section of coupled microstrip line is shown in Fig. 3. The reserved and reserving circuits have one reference conductor as a separate layer; corresponding traces of the reserving and reserved circuits are traced in pairs that are parallel to each other, located in the same layer and with the minimum allowable gap between the reserved and reserving traces [8, 9]. Parameters of the cross sections: h = 0.25 mm, t = 0.105 mm, w = 1 mm, s = 0.5 mm, d = 1.75 mm, ε_{r1} = 5. Loads at the ends of the line were defined by the condition

$$R = \left(Z_e Z_o\right)^{0.5}, \tag{1}$$

where Z_o – odd mode impedance, and Z_e – even odd impedance.

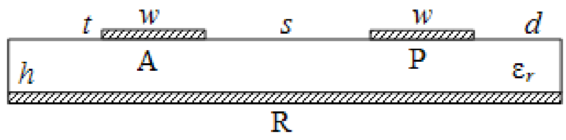

Fig. 3. Cross section of coupled microstrip line where conductors: A – active, P – passive, R – reference

The simulation results are shown in Figs. 4, 5, the parameters are given in Table I. The waveforms were taken from points $V2$ and $V4$ (near and far ends of the active conductor), $V3$ and $V5$ (near and far ends of the passive conductor). The relative difference between results of TALGAT and CST MWS were calculated by the formula

$$\frac{P_{CST} - P_{TALGAT}}{P_{CST}} \cdot 100\% \cdot \tag{2}$$

Hereinafter, in the Fig. 5, the line (–) indicates the results obtained in TALGAT system, and a dotted line (- -) – in CST MWS. There are two pulses at far end of the line instead of one. This is because the pulse duration is less than the difference of even and odd modes in the structure (Table II), formed by a pair of conductors of the reserving and reserved circuits.

A structure of coupled lines with broadside coupling is shown in Fig. 6. Reserved and reserving circuits have one reference C-shaped conductor.

Parameters of the cross sections: h = 0.25 mm, t = 0.105 mm, w = 1 mm, s = 4 mm, ε_r = 5. Loads at the ends of the line were defined by the condition (1). The simulation results are shown in Figs. 7, 8, the parameters are given in Table I.

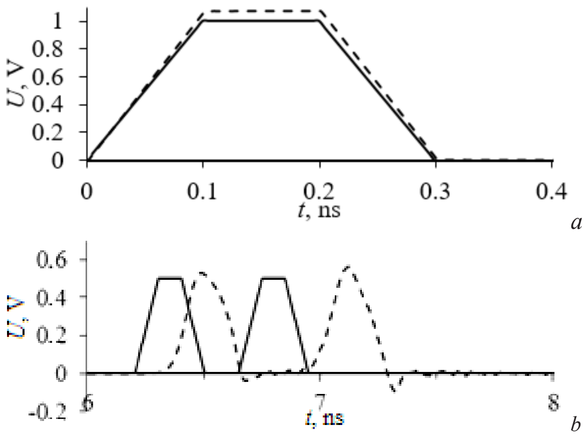

Fig. 4. Waveforms at near (*a*) and far (*b*) ends of active conductor for structure of Fig. 3

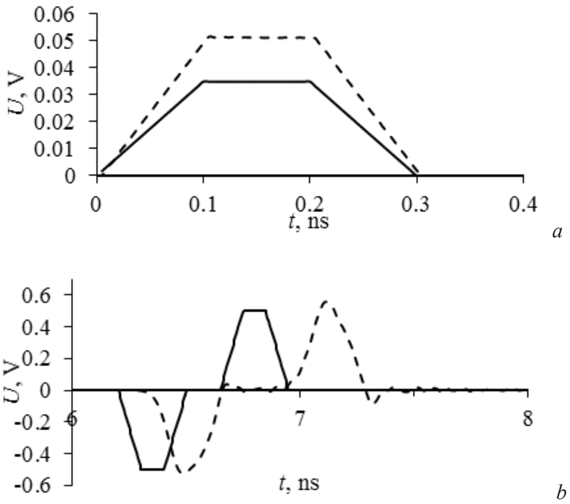

Fig. 5. Waveforms at near (*a*) and far (*b*) ends of passive conductor for structure of Fig. 3

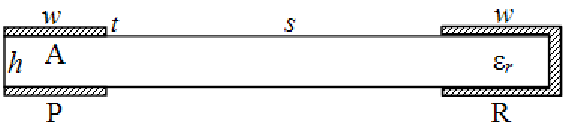

Fig. 6. Cross section of coupled line with broadside coupling

A structure of symmetrical lines with broadside coupling is shown in Fig. 9. The upper and lower ground planes are simulated as a rectangular cross-section conductor. (Preliminary simulation has shown the correctness and efficiency of this model.) The corresponding traces of the reserving and reserved circuits are parallel to each other and located one above another, and also are isolated by the dielectric layer [13].

Parameters of the cross sections: w = 0.3 mm, t = 0.065 mm, d = 3w, d_1 = 4w, h_2 = 0.1 mm, h_1 = 0.2 mm, ε_{r1} = 5, ε_{r2} = 25. The simulation results are shown in Fig. 10, 11, the parameters are given in Table I.

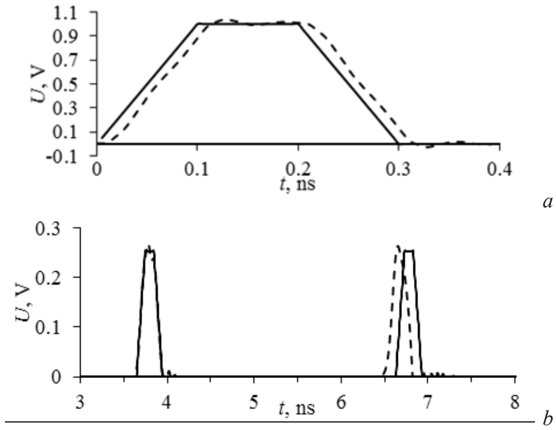

Fig. 7. Waveforms at near (*a*) and far (*b*) ends of active conductor for structure of Fig. 6

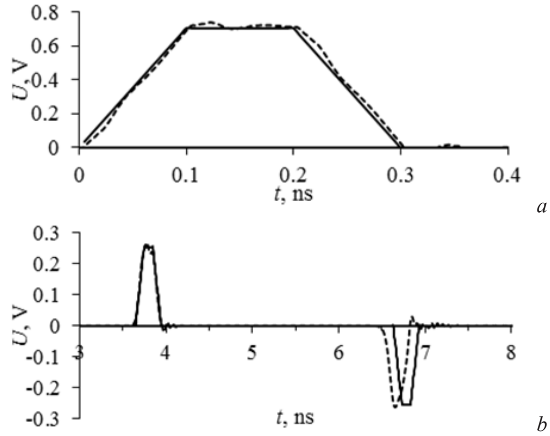

Fig. 8. Waveforms at near (*a*) and far (*b*) ends of passive conductor for structure of Fig. 6

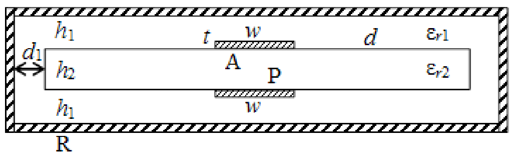

Fig. 9. Cross section of coupled line with broadside coupling

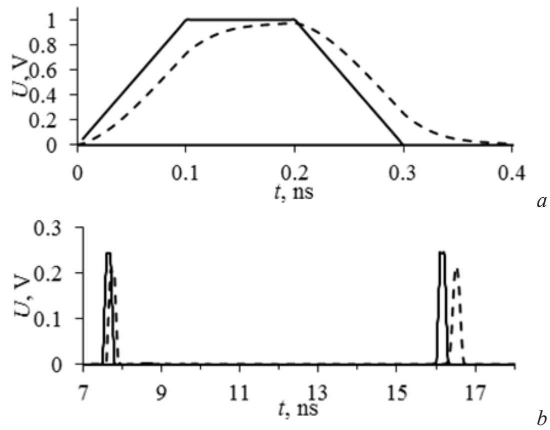

Fig. 10. Waveforms at near (*a*) and far (*b*) ends of active conductor for structure of Fig. 9

TABLE I
VALUES OF DELAYS AND AMPLITUDES OF PULSES AT NEAR AND FAR ENDS OF ACTIVE AND PASSIVE CONDUCTORS, OBTAINED IN TALGAT AND CST MWS

	Active conductor						Passive conductor					
	TALGAT			CST MWS			TALGAT			CST MWS		
	Near end pulse	Far end Pulse 1	Far end Pulse 2	Near end pulse	Far end Pulse 1	Far end Pulse 2	Near end pulse	Far end Pulse 1	Far end Pulse 2	Near end pulse	Far end Pulse 1	Far end Pulse 2
Coupled microstrip line	Time delay, ns											
	–	6.2	6.6	–	6.3 (1%)	6.9 (4%)	–	6.2	6.6	–	6.3 (1%)	6.9 (4%)
	Value of amplitude, V											
	1	0.5	0.5	1.07 (6%)	0.52 (4%)	0.56 (10%)	0.03	-0.5	0.5	0.05 (40%)	-0.52 (4%)	-0.56 (10%)
	Calculation time, s											
	4.3			2208			4.3			2208		
Coupled line with broadside coupling	Time delay, ns											
	–	3.6	6.6	–	3.6 (0%)	6.5 (1%)	–	3.6	6.6	–	3.6 (0%)	6.5 (1%)
	Value of amplitude, V											
	1	0.25	0.25	1.03 (3%)	0.25 (0%)	0.25 (0%)	0.7	0.25	-0.25	0.73 (4%)	0.26 (4%)	-0.26 (4%)
	Calculation time, s											
	4.2			1106			4.2			1106		
Symmetrical lines with broadside coupling	Time delay, ns											
	–	7.5	16	–	7.6 (1%)	16.3 (2%)	–	7.5	16	–	7.6 (1%)	16.3(2%)
	Value of amplitude, V											
	1	0.24	0.24	0.97 (3%)	0.2 (20%)	0.2 (20%)	0.71	0.24	-0.24	0.74 (4%)	0.2 (20%)	-0.21 (14%)
	Calculation time, s											
	4.9			6181			4.9			6181		

TABLE II
VALUES OF MATRICES OF PRIMARY PARAMETERS, DELAYS OF EVEN AND ODD MODES AND THEIR DIFFERENCE, OBTAINED IN TALGAT

Structure	L_{11}, nH/m	L_{12}, nH/m	C_{11}, pF/m	C_{12}, pF/m	Z_{11}, Ω	Z_{12}, Ω	τ_o, ns/m	τ_e, ns/m	Δτ, ns/m
Coupled microstrip line	178.94	186.06	232.05	-8.09	28	2	6.652	6.205	0.446
Coupled line with strong broadside coupling	1041.86	931.65	204.68	-197.93	279	262	6.631	3.647	2.984
Symmetrical lines with broadside coupling	170.27	151.55	6932	-6757	22	21	16.008	7.501	8.507

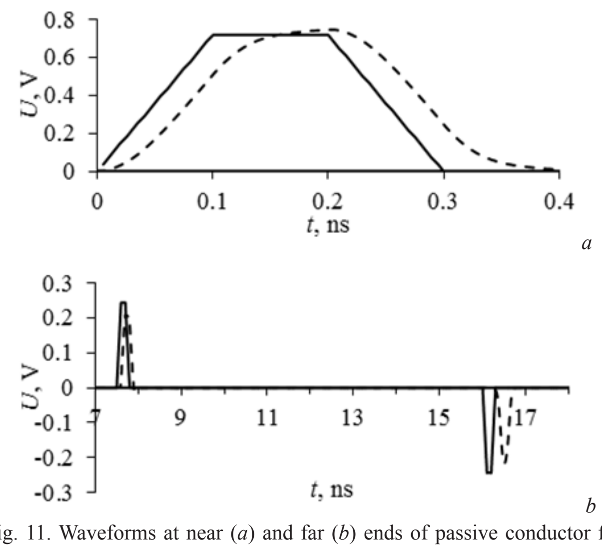

Fig. 11. Waveforms at near (*a*) and far (*b*) ends of passive conductor for structure of Fig. 9

V. CONCLUSION

Present results show generally good compliance of the results of quasistatic and electromagnetic analysis. A small difference of the results is explained by different methods, by which the calculation was carried out (MOM and FIT). Time spent on the calculation differs in 263-1261 times. The maximum difference was 4% for delays and 40% for amplitudes of pulses.

For the upper frequency of signal spectrum (10 GHz) the wavelength in vacuum equals to 3 cm and it is somewhat smaller with the dielectric. When width of the structure is more than 0.1λ, quasistatic simulation results can be inaccurate. However, we observe the overall coincidence of quasistatic and electromagnetic analysis results that allows us to conclude the correctness of the quasistatic analysis for structures of this type. Given this, we can say that the quasistatic analysis is more suitable for these structures, as it requires less computational efforts.

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