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Method of Lay-Out of a Multilayer PCB for Circuits with Triple Reservation

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***Abstract*—A new method of lay-out of a multilayer PCB for circuits with triple reservation is considered. Simulation of four-conductor structure is performed. In this structure UWB pulse decomposed to 4 pulses with smaller amplitudes. These results demonstrate that the proposed method allows to increase interference immunity of PCB circuits with triple reservation.**

Keywords—modal filtration, reservation, interference immunity, communication systems

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 to 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]. In these papers only duplex reservation are considered, i.e. multiplicity factor (m) of reservation is equal to 1. However, in many systems of critical infrastructure, the duplex reservation does not provide the required reliability, therefore, to increase the fault tolerance of these systems the reservation with $m> 1$ is used. For example, a multiplicity factor of reservation of safety systems of modern nuclear power plants [6] is at least of 3.

The aim of this paper is to introduce a new method of lay-out of a multilayer PCB for circuits with triple reservation. At first, principle of the method is described. Then, parameters and time and frequency responses are simulated.

I. Principle of Method

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 [7–9]. 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, up to decomposition 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 existence of resonant frequencies (with zero magnitude), thus, interfering signal can be attenuated till zero in a particular range of frequencies.

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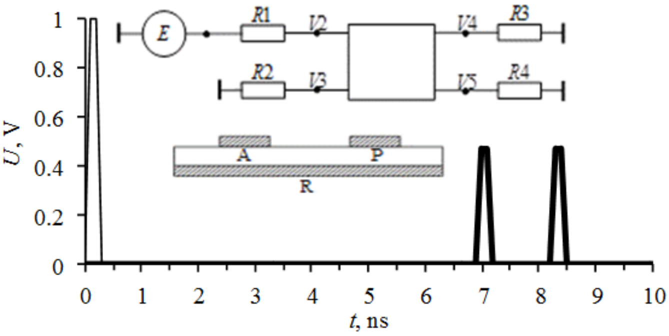

Fig. 1. Signal at the near (–) and far ends (**–**) of active conductor

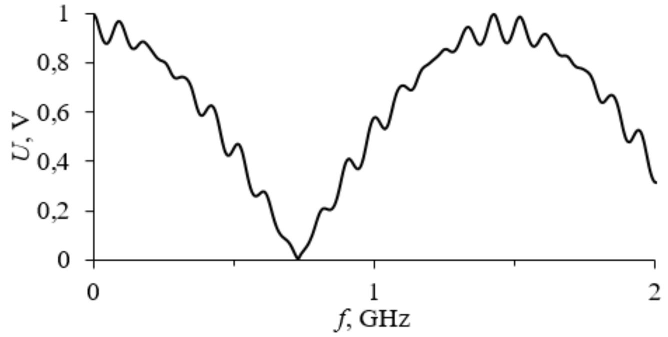

Fig. 2. Frequency response to harmonic excitation

However, as noted above, previous research have been performed for reservation circuits with m =1. Thus, to extend the range of applications in which the modal reservation can be used the method with m=3 is provided.

In the proposed method of triple reservation (Fig. 3) the reference conductor consists of separate layers, while two PCBs are conglutinated by dielectric layer with relative dielectric constant higher, than one of dielectric substrate of these PCBs. Reserving and one reserved circuits in conglutinating layer of dielectric are placed on one of PCBs, while two other reserved circuits are placed on another PCB. Traces of these reserved circuits are arranged on one level and at equal distances from each other and have identical sizes. Electronic components are placed on sides of PCBs that are opposite to the conglutinated sides.

As a result, reserving circuit becomes less sensitive to conducted emissions, and the level of conducted emissions from the reserving circuit is reduced. It is achieved because the interfering pulse, with duration that is less than the difference between delays of modes in the structure, is decomposed into pulses with smaller amplitudes. Interference at a predetermined frequency can be significantly attenuated.

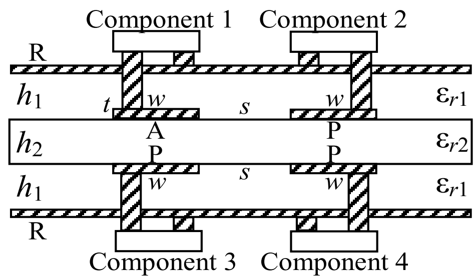

Fig. 3. Method of lay-out of a multilayer PCB for circuits with redundancy, where conductors: A - active, P - passive, R - reference.

II. Simulation Results

Simulation was executed in the TALGAT (time response) and CST MWS (frequency response) software without accounting the losses. In CST MWS a combination of the perfect boundary approximation with the Finite Integration Technique is used [10]. 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 entries 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 [11].

Achievability of results is illustrated on the example of a quasistatic and electrodynamic analysis. The model of a cross-section of a structure is shown in Fig. 4 (*a*). 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.) A geometrical model of the structure, built for simulations in TALGAT, is shown in Fig. 4 (*b*).

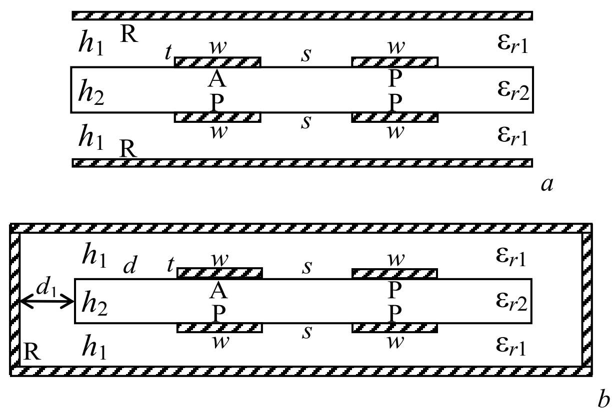

Fig. 4. Cross-section of a multilayer PCB (*a*) and its model in TALGAT (*b*)

In general, the structure is considered as a four-conductor transmission line with inhomogeneous dielectric filling in cross section. Consequently, four modes can propagate in the structure, and the interference signal is subjected to modal distortion, up to the decomposition into a sequence of four pulses. However, the amplitude of these pulses is largely dependent on the boundary conditions at the ends of the conductors. Since each of the modes has own impedance, matching of structure becomes more complicated. Accordingly, loads at the ends of the line were defined by the condition

$$R = (Z_{11}\, Z_{21})^{0.5}.$$

Then, we calculate the matrix coefficients of per-unit-length electrostatic (**C**) and electromagnetic (**L**) inductions, delay modes (τ) and the matrix of impedances (**Z**) for $w = 430$ µm, $t = 105$ µm, $s = 50$ µm, $d = 50$ µm, $d_1 = 4w$, $h_2 = 130$ µm, $h_1 = 1000$ µm, $\varepsilon_{r1} = 4.25$, $\varepsilon_{r2} = 20$.

$$\mathbf{L} = \begin{bmatrix} 381.5 & 272.1 & 265.4 & 237.4 \\ 272.1 & 381.5 & 237.4 & 265.4 \\ 265.4 & 237.4 & 381.5 & 272.1 \\ 237.4 & 265.4 & 272.1 & 381.5 \end{bmatrix}, \text{ nH/m},$$

$$\mathbf{C} = \begin{bmatrix} 863.1 & -616.3 & -167.9 & -37.6 \\ -616.3 & 863.1 & -37.6 & -167.9 \\ -167.9 & -37.6 & 863.1 & -616.3 \\ -37.6 & -167.9 & -616.3 & 863.1 \end{bmatrix}, \text{ pF/m},$$

$$\tau = \begin{bmatrix} 13.6 \\ 6.9 \\ 8.3 \\ 11.5 \end{bmatrix}, \text{ ns/m},$$

$$\mathbf{Z} = \begin{bmatrix} 50.7 & 42.1 & 38.1 & 36.6 \\ 42.1 & 50.7 & 36.6 & 38.1 \\ 38.1 & 36.6 & 50.7 & 42.1 \\ 36.6 & 38.1 & 42.1 & 50.7 \end{bmatrix}, \Omega.$$

The circuit from Fig. 5 was used during simulation of the waveform in the structure with length of 1 m. Impulse interference with EMF of 2 V and rise, flat top and fall times of 100 ps was excited between the active (reserved) and the reference conductors. The reserving conductors are functioning as passive conductors. Waveforms at the near ($V2$) and the far ($V6$) ends of the active (reserved) conductor are shown in Fig. 6, which also shows that there are four pulses with amplitude of 0.12, 0.24, 0.16 and 0.19 V. Decomposition of the impulse interference into four pulses with lower amplitudes (and consequently a decrease in susceptibility of a reserved circuit to external conducted emissions) is caused by the difference of delays of modes in the structure formed according to this method of PCB lay-out.

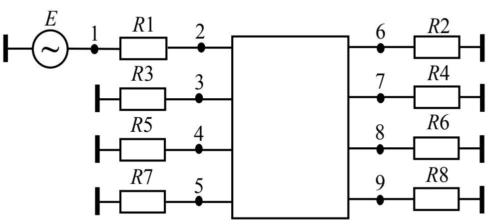

Fig. 5. Circuit diagram of the simulated structure.

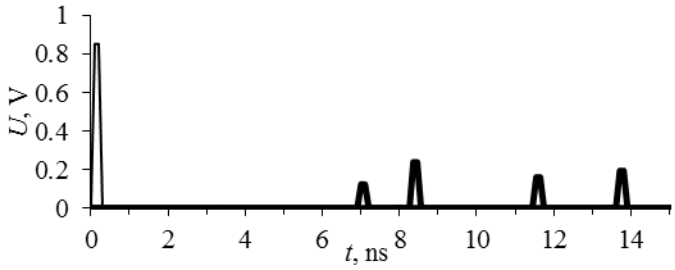

Fig. 6. Simulated waveforms at near (–) and far (—) ends of reserved conductor.

Fig. 7 shows the propagation ratio of the active conductor of structure. The figure shows that the maximum attenuation occurs at a frequency of about 2 GHz. Spectrum bandwidth which attenuation is less than 3 dB is 10 MHz.

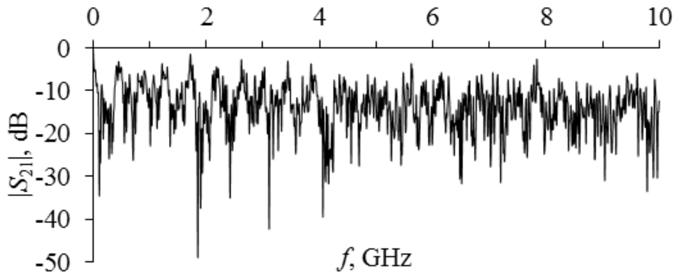

Fig. 7. Propagation ratio of the active conductor of structure

III. Analysis of the Results

The simulation results showed that this method of lay-out provides a significant reduction of amplitudes of interfering signal. The maximum and minimum differences of per-unit-length delay of modes are 6.7 ns/m and 1.4 ns/m accordingly. Due to the increasing number of conductors, in such a structure it is more difficult to get a full matching and to minimize pulse magnitudes.

Furthermore, the choice of sizes and ε_r of structure permits to control maximum and minimum difference of per-unit-length delay of modes, changing interference signal duration (when considering the time domain) for which the complete modal decomposition is possible, and the resonance frequency (when considering the frequency domain).

IV. Conclusion

Thus, in this paper a structure of a multilayer PCB for circuits with triple reservation is simulated. Compared to coupled line with duplex reservation, in this structure the pulse is decomposed into four pulses instead of two pulses. As seen from the above results, it can allow to attenuate the interfering signal. Also worth noting that the pulses are divided into two groups, one of which comes with less delay. It should be noted that a more detailed investigation of the boundary conditions at the ends of lines to align the pulses amplitudes is required.

The proposed method of tracing of printed conductors of circuit with reservation provides reduction of susceptibility of reserved circuit to external conducted emissions, as well as reduction of the level of conducted emissions generated by the reserved circuit.

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