New Concept of Critical Infrastructure Strengthening

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Abstract. Strengthening of critical infrastructure is considered. Modal reservation of electronics is proposed as a new concept of the strengthening. The concept combines a widely used cold backup and a recently proposed modal filtration. It makes electronics reliable as well as protected against electromagnetic interference, especially the ultra-wide band pulses. New printed circuit board structure is suggested for implementation of the proposed concept. Results of simulation in time and frequency domains are presented for the suggested structures. Considerable attenuation of dangerous excitations shows that the new concept and structure are promising.

Keywords: Critical Infrastructure, electromagnetic interference, ultra-wide band pulse, cold backup, modal filtration, modal reservation.

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INTRODUCTION

Safety of critical infrastructure is very important for our society because its improper functioning may result in considerable accidental loss. Therefore, necessary strengthening of the infrastructure is the main concern of those who are responsible for reliable work of the infrastructure. Global trend of proliferation of electronics in our life is fully seen for the critical infrastructure. However, electronics are vulnerable to an electromagnetic interference. Moreover, nowadays, there is an increasing threat of deliberate electromagnetic impact on electronics [1]. Such impact can result in malfunction or failure of electronic equipment [2]. Particularly, the impact of ultra-wideband (UWB) pulses is especially dangerous, because existing surge protectors do not protect against it [3]. There are known only some industrial devices that protect against UWB pulses but have large dimensions and a high cost. Thus, currently there is no both low-cost and effective protection against UWB pulses. However, the increasing role of electronics in the critical infrastructure functioning makes this protection essential. Representative reflection of the importance of this problem can be found in AMEREM/EUROEM/ASIAEM conferences. For example, in recent ASIAEM 2015 the separate technical topic "IEMI Threats, Effects and Protection" and the important special sessions (Design of Protective Devices and Test Methods. Evaluation of HEMP/IEMI Impacts on Critical Infrastructure.) were organized.

It is worth noting that the technique called as backup, redundancy or reservation is widely used, as it is an efficient way to overcome fault of electronics. It allows to use the similar idle part of electronic equipment in case of fault in the operating part. However, it doubles hardware. Necessity of proper protection against UWB pulses considerably complicates all the parts and, as a result, the final design. Therefore, a search for new principles of design of the critical infrastructure electronics strengthening is important.

The idea of modal filtration has been suggested, and several devices based on modal filtration principle have been developed. Among them there are symmetrical structures of modal filters (MF) for protection of Fast Ethernet network against lightning [4] and electrostatic discharge [5]. The asymmetrical MF based on PCB technology has been considered recently, and it has been shown, that the MF with special resistors can 7 times attenuate the UWB pulse [6], while the MF without resistors – up to 55 times [7]. The physical principle of a MF operation is based on the phenomenon of decomposition of interference pulse into modes with different propagation delays in the coupled line. The difference between these delays can be longer than the duration of the interference pulse if there is nonhomogeneous dielectric filling in the cross section of the line. Then, one pulse applied between the active and the reference conductors at the near end of the line is decomposed into two pulses at the far end of the line. However, to convert a transmission line (an interconnect) into MF, at least one conductor should be added to each transmission line. It considerably complicates the implementation of the protection in case of numerous interconnects.

The aim of this paper is to present the new concept of "modal reservation" for the strengthening of critical infrastructure electronics. This concept combines a widely used cold backup and a recently proposed modal filtration.

PROPOSED APPROACH

Cold backup is a widely used way to enhance reliability of electronics, for example, when a reserved circuit is placed on one part of a printed circuit board, while the reserving one is placed on neighboring part. However, the sheer fact of existence of a reserving circuit can be used not only for the reserving but also for the protection of reserved circuit during operation. Indeed, use of coupling between reserved and reserving conductors of the circuits can improve the protection against electromagnetic interference.

We propose such implementation of reserved and reserving circuits, wherein (according to modal filtration terminology) each conductor of the reserved circuit is active (excited by a signal), each conductor of the reserving circuit is passive (without the exciting signal), while the reference conductor (signal ground plane) is shared between reserved and reserving circuits. On that basis, we suggest the technique of printed interconnect routine, wherein the reserved and reserving circuits have the same reference conductor in form of separate layer, the reserved and reserving conductors having the same name are routed by pairs and parallel to each other with minimum permissible gap between the reserved and reserving conductors.

As a result, we have the decreased susceptibility of a reserved circuit to external conducted emissions and reduced level of conducted emissions from the reserved circuit. In case of failure of a reserved circuit, the similar results are achieved in the reserving circuit. They are achieved due to the fact that the interfering signal, the duration of which is less than the difference between the delays of even and odd modes of coupled line structure formed by reserved and reserving conductors, undergoes modal distortions in the form of decomposition into lower amplitude pulses (when considering the interfering signal in the time domain).

Reachability of the results is demonstrated by simulation of propagation of the pulse (with electromotive force of 2 V with rise, fall and a flat top times of 100 ps) in the structure of coupled line with a length of 1 m (Fig. 1 *a*). Geometrical parameters of conductors: $w = 300$ µm, $s = 100$ µm, $t = 65$ µm. Thickness of a dielectric substrate $h = 510$ µm, a dielectric constant $\varepsilon_r = 10$. Value of the resistors R is equal to the geometric mean of the impedances of even and odd modes.

The TALGAT software is used for simulations [8]. The system is based on the method of moments and it allows to carry out the two-dimensional quasi-static analysis of structures of any complexity. The software-based algorithms allow to calculate elements of a moment matrix with the application of analytical expressions [9]. Firstly, geometrical model of the coupled line is created. Then, each boundary of the cross section is segmented and matrixes **L** and **C** are calculated by a method of moments. Square roots of eigenvalues of the **L** and **C** matrices product are calculated to obtain per unit of length delays for preliminary analysis. At last, response to pulse excitation is calculated using the approach based on modified nodal admittance matrix for formulation of network equations including the transmission line and terminal networks in frequency domain. Voltages in the time domain are obtained by applying the inverse fast Fourier transform.

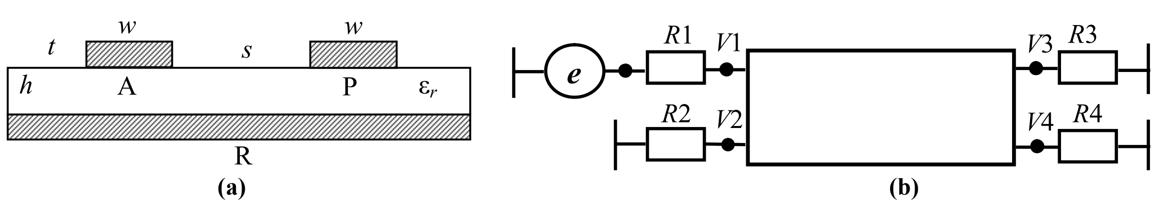

FIGURE 1. Cross section of coupled microstrip line structure, where **A** stands for the active (reserved), **R** for the reference, and **P** for the passive (reserving) conductors (a). Schematic diagram of the simulated structure (b)

A pulse is excited between the active and reference conductors, while the passive conductor performs the function of a reserving one. The results of the quasi-static simulation of time domain response at the near and far ends of the reserved conductor (*V*1 and *V*3 in Fig. 1 *b*) show two pulses with amplitudes of 0.5 V (Fig. 2 *a*), which is half the pulse level (1 V) at the near end of the reserved conductor. The decomposition of the pulse into the two pulses of smaller amplitude (and therefore the decreased susceptibility of reserved circuit to external conducted emissions) occurs due to the difference in delays of even and odd modes of the coupled lines structure. In case of pulse excitation between reserving and reference conductors, there is a similar response. Comparison of the frequency responses (Fig. 2 *b*) for the structures of single and coupled microstrip lines shows the attenuation of spectral components of the original signal and existence of the resonant frequencies (the spectral components with zero amplitude), which can significantly weaken the interference signals at predetermined frequencies.

Thus, the simulation results show that the proposed routing approach for printed circuits with redundancy allows reducing the susceptibility of the circuits to external conductive emissions and the level of conducted emissions from the circuits. In conclusion, it is worth noting that the considered simple cross section is only one of possible cross sections. In the extended version of this paper we will discuss other cross sections of printed circuit boards for more effective implementation of "modal reservation".

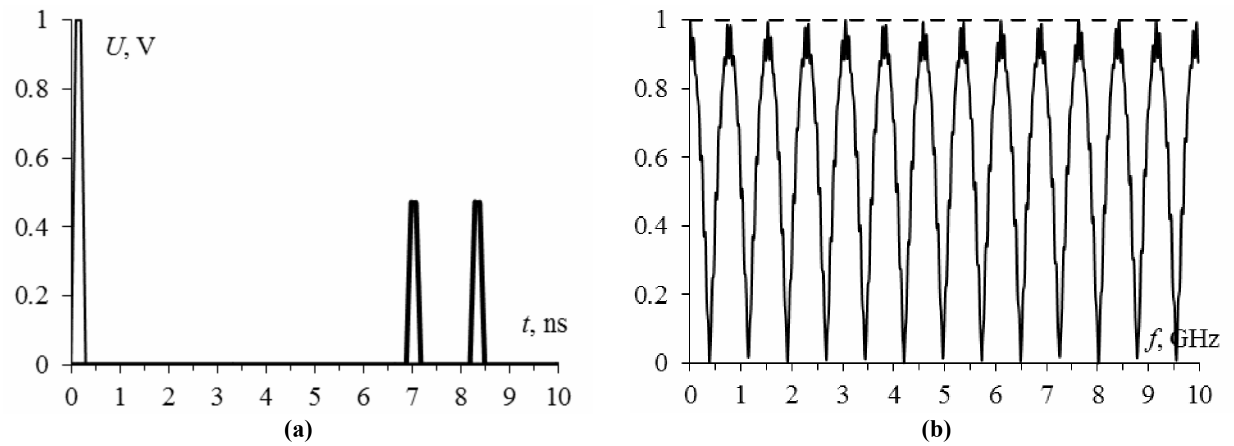

FIGURE 2. Simulated waveforms at near (–) and far (—) ends of reserved conductor (a), frequency response (b) of single (- -) and coupled (—) microstrip lines on harmonic excitation

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