Quasistatic Simulation of a New PCB-integrated Sensor of Conductive Emissions

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Abstract— **The relevance of controlling a level of conductive emissions of a modern radioelectronic equipment is noted. A description of the new device for monitoring the level of conductive emissions, which is distinguished by the absence of galvanic connection with the controlled line and by the integration into a printed circuit board is given. The possibility of determining the voltage spectrum of an interference signal is demonstrated.**

Keywords— Conductive emissions, sensor, EMC, printed circuit boards.

I. INTRODUCTION

With the development and wide extension of electronic devices of various applications, it is necessary to ensure electromagnetic compatibility (EMC). Interference immunity and system fault tolerance of critical electronic devices are very important, as radio electronic devices are vulnerable to electromagnetic interference and its malfunctioning may lead to major losses. Moreover, there is currently growing threat of intentional electromagnetic interference on electronic devices. So the impact may lead to breakdown or malfunction of electronic devices. In particular, the effect of ultrashort pulses is especially dangerous. One of the parts of effective protection of radio electronic devices from ultrashort pulses is the detection and monitoring of the parameters of the interference signal.

A radiator of pulsed electromagnetic field with high intensity and a frequency spectrum from 0.1 GHz to 10 GHz and an asymmetric two-conductor sensor of the electric field are offered [1]. A new approach to the creation of devices, which are providing detection of dangerous deliberate electromagnetic interference, is presented [2]. It is based on recording of key parameters of pulsed electrical disturbances such as amplitude, Joule integral, energy and repetition frequency of electric distortions which are induced in the device circuit. Common mode and differential mode interferences were investigated by using in-circuit measurement and an analysis of conducted measurements of the effect of conductive interference without a line impedance stabilization network were also presented [3]. A compact system for measuring electromagnetic interference in the time domain is presented [4]. The system is suitable for measuring interference caused by transient processes, interference from lightning strikes to wires and antennas which are located in missile carriers, aircraft and unmanned aerial vehicle.

The concept of controlling the level of conductive emissions [5, 6] is suggested, which is distinguished by the absence of galvanic connection with the controlled line that is providing the lower level of distortions inserted by the sensor. However, for obtaining the parameters of the interference signal, approaches to the analysis of crosstalk in the structures of coupled lines are needed, since initially only the detection of impulse noise was assumed.

The aim of this paper is the analysis of the conductive emissions in the time and frequency domains at the near and far ends of the detector of the conductive emissions.

II. DEVICE FOR CONTROL OF CONDUCTIVE EMISSIONS LEVEL

The scheme of the conductive emissions level control device [6] in printed circuit boards (PCB) is shown on Fig. 1. The device operation principle is that information on conductive emissions propagating along a controlled line can be obtained though the waveform of crosstalk in a passive line that acts as a detector. The parameters of the interference signal propagating along the controlled line are extracted by processing the conductive emissions in the signal processing unit. The main feature of the device is that, the role of sensors is performed by traces integrated into the PCB layers. The installation of such devices (sensors) on an already designed circuit board will require only a change in the PCB trace, without changing the PCB arrangement. For implementation of this method is necessary to monitor the electrical and magnetic couplings between the controlled and passive lines.

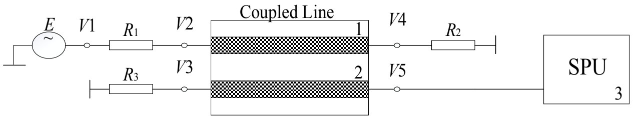

Fig. 1. The scheme of the conductive emission level control device: controlled line (1), passive line (detector) (2), signal processing unit (3)

The principle of operation of the device is demonstrated by the example of a quasi-static simulation of the structure of coupled lines. The simulation was performed in the TALGAT system [7]. The TALGAT software is based on the method of moments and allows to make 2D quasistatic analysis of arbitrary complexity structures. The algorithm implemented in the system allows calculating the matrices **L**, **C**, **Z** and mode delays of a structure. Using the modified node-potentials method in the

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frequency domain, it is possible to calculate the time response through a fast Fourier transform.

Consider the structure of coupled lines, where the passive (P) line performs a function of a detector, and the active (A) line is monitored. Cross section of coupled lines is shown in Fig. 2*a*. Parameters of the cross sections: $h = 0.25$ mm, $t = 0.105$ mm, $w = 1$ mm, $s = 0.5$ mm, $d = 6$ mm, $\varepsilon_{r1} = 5$. The length of the structure (l) is 1 m. A schematic diagram of the structure is shown in Fig. 2*b*. The calculated parameters of the structure are given in Table I.

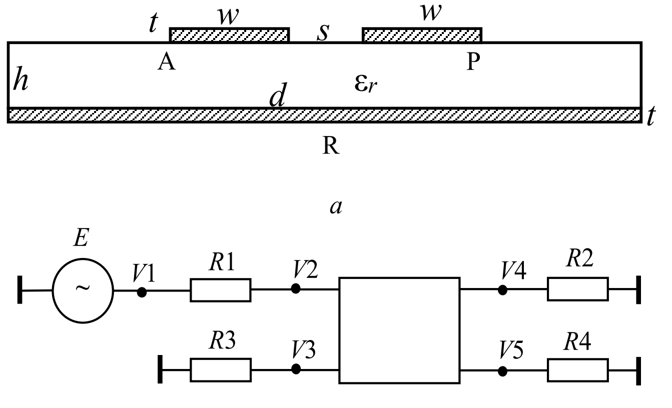

Fig. 2. Cross section of coupled lines (*a*), circuit diagram (*b*) of the simulated structure

TABLE I. MATRIXES **L**, **C**, **Z**, PER-UNIT-LENGTH DELAY OF EVEN (τ_E) AND ODD (τ_O) MODES AND THEIR DIFFERENCE

Matrices			**Per-unit-length mode delays and their difference**		
L, *nH/m*	**C, *pF/m***	**Z, Ω**	***τe*, *ns/m***	***τo*, *ns/m***	**Δτ, *ns/m***
179 19 19 179	232 -8 -8 232	27.76 1.93 1.93 27.76	6.65	6.2	0.45

The resistance values R of all the resistors are chosen from the condition [8]

$$R = \sqrt{Z_o \cdot Z_e} \tag{1}$$

where $Z_e = Z_{11} + Z_{21}$ - even mode impedance, $Z_o = Z_{11} - Z_{21}$ - odd mode impedance. Because the $Z_e = 29.69$ Ω, and $Z_o = 25.83$ Ω, then $R = 27.7$ Ω.

III. TIME-DOMAIN CONSIDERATION

The simulation results for time response of the considered circuit to the trapezoidal excitation having the total durations of 0.3, 3, 30 ns (rise, flat top and fall times are equal) and EMF amplitude of 2 V are shown in Fig. 3.

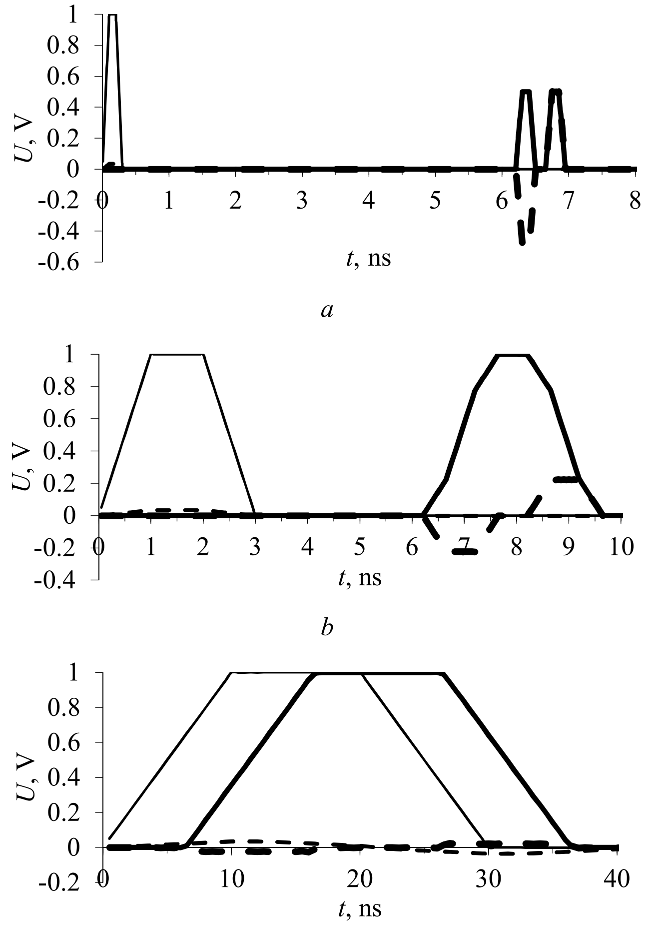

Fig. 3. Time responses at the near (——$V2$, – –$V3$) and far (——$V4$, – –$V5$) ends of the monitored and passive lines with trapezoidal signal durations: 0.3 (*a*), 3 (*b*), 30 (*c*) ns

The above responses show that as the pulse duration increases, the crosstalk level decreases from 0.5 V (50% of the signal level at the beginning of the active conductor) to 0.023 V (2.3%). When the duration of the detected pulses is greater than the difference of mode delays of the structure formed by the pair of conductors (monitored and the detector), the overlapping pulses are observed in the passive line for trapezoidal pulse widths of 3 and 30 ns in Fig. 3 *b, c*. This leads to a decrease in the peak value of the crosstalk amplitudes in the passive line, which makes it difficult or impossible to detect it. On this basis, the level of interference for a 0.3 ns pulse allows us to use the passive line of this structure as a detector of conductive emissions.

IV. FREQUENCY-DOMAIN CONSIDERATION

Such an analysis of signals in the time domain allows only detecting the propagation of impulse interference in the line, while the voltage spectrum of the interference signal makes it possible to determine the possible origin and source of the interference signal. For this, it is necessary to find the amplitude-frequency characteristics of the structure. Using the quasistatic and electromagnetic simulation software, it is possible to obtain the transfer functions of the structures formed by the controlled line and the detector. Consider the frequency responses at the near and far ends of the structure in the frequency range from 0 to 10 GHz (Fig. 4, 5).

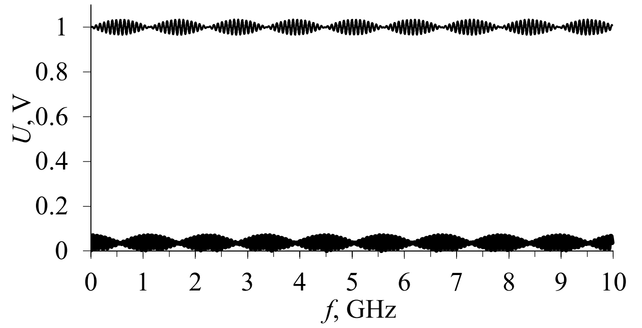

Fig. 4. Frequency responses to harmonic excitation at near end of the monitored (—— *V*f2) and passive (—— *V*f3) lines

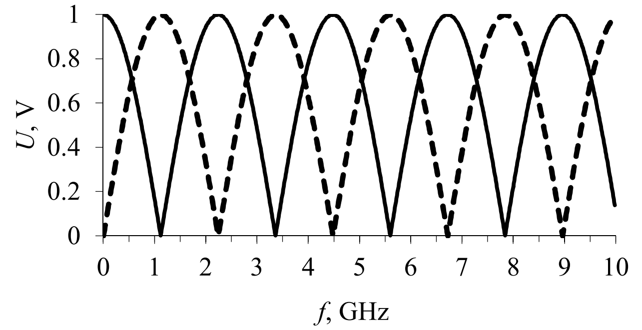

Fig. 5. Frequency response to harmonic excitation at far end of the monitored (—*V*f4) and passive (– – *V*f5) lines

Fig. 4, 5 show that the form of frequency responses at the near and far ends of the structure is periodic, the period equals $2{\cdot}f_0$ where

$$f_0=\frac{1}{2l\left|\tau_e-\tau_o\right|}\cdot \tag{2}$$

The maxima and minima of the signal amplitudes alternate with the frequency f_0. Substituting the values of the per-unit-length mode delays from Table I, we get

$$f_0=\frac{1}{2\times1\,\text{m}\times\left|6{,}65\times10^{-9}\text{ s/m}-6{,}2\times10^{-9}\text{s/m}\right|}=1111\text{ MHz.}$$

Calculating the voltage amplitude spectrum at the ends of the passive line, it is possible to restore the form of the original interference signal acting on the monitored line. Let $U_i(\omega)$ be the voltage amplitude spectrum at the node *Vi*, and $Uj\ (\omega)$ be the voltage amplitude spectrum at the node *Vj*. Then the magnitude of the transfer function of the nodes *Vi* and *Vj*

$$K_{ij}(\omega)=U_i(\omega)/U_j(\omega)\,. \tag{3}$$

We introduce the function of the inverse magnitude of the transfer function (FIMTF)

$$K_{ij}^{-1}(\omega)=1/K_{ij}(\omega)\,. \tag{4}$$

Knowing the transfer function and the voltage amplitude spectrum of the signals at the ends of the passive line (the spectrum of the output signal), it is possible to determine voltage amplitude spectrum of the original signal

$$U_i(\omega)=U_j(\omega)\times K_{ij}^{-1}(\omega)\cdot \tag{5}$$

We denote FIMTF for the nodes *V*2, *V*5 as $K_{25}^{-1}(\omega)$, then for voltage amplitude spectrum at node *V*2 of monitored line we have

$$U_2(\omega)=U_5(\omega)\times K_{25}^{-1}(\omega).$$

For nodes *V*2 and *V*3 we have similarly

$$U_2(\omega)=U_3(\omega)\times K_{23}^{-1}(\omega).$$

The calculated FIMTF for the structure under consideration are shown in Fig. 6, 7. From Fig. 6 we see that the FIMTF for the nodes *V*2 and *V*5 at frequencies of multiple $2{\cdot}f_0$ reaches a maximum value. From Fig. 7 we see that the transfer function for the nodes *V*2 and *V*3 does not exceed the value 1165 in the whole considered frequency range.

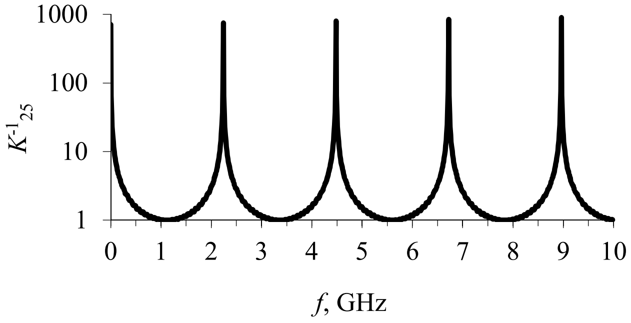

Fig. 6. FIMTF for nodes *V*2 and *V*5

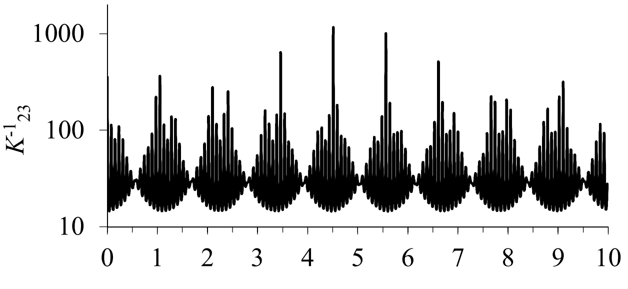

Fig. 7. FIMTF for nodes *V*2 and *V*3

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V. CONCLUSION

The approach to the control of conductive emissions is considered. Quasistatic simulation in the time and frequency domains for the microstrip coupled line structure is performed. A method for reconstructing the amplitude spectrum of the interference signal voltage is proposed. It consists in using the calculated FIMTF of the controlled and passive lines to reconstruct the input spectrum. However, the proposed approach requires the simulation of each individual system. For the structure used as a test model of the proposed device the FIMTF is calculated and given. It is shown that these functions take values greater than one on a number of frequencies and reach a maximum value of 1165.

It should be noted that in order to implement the proposed method, it is necessary to develop a hardware part, namely, to select the components for receiving and processing the interference signal, which will be included in the signal processing unit.

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