Ultrashort pulse decomposition in the turn of a meander microstrip line with a passive conductor

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Ultrashort pulse decomposition in the turn of a meander microstrip line with a passive conductor

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Abstract. The paper presents the results of evaluating the effect of changing the cross-section parameters of a meander microstrip line (MSL) with a passive conductor on the ultrashort pulse (USP) waveform and amplitude. The study revealed the occurrence of additional pulses in the structure under investigation in addition to cross-talk and main mode pulses. The delays of each pulse were determined and the conditions for USP decomposition in a meander MSL with a passive conductor into a sequence of seven pulses were formulated. By means of heuristic search optimization according to the criteria for fulfilling formulated conditions and the criterion of the minimum amplitude, we obtained the optimal parameters of the line cross-section, at which the USP is decomposed into a sequence of seven pulses with attenuation of 5.38 times relative to half of the electromotive force.

1. Introduction

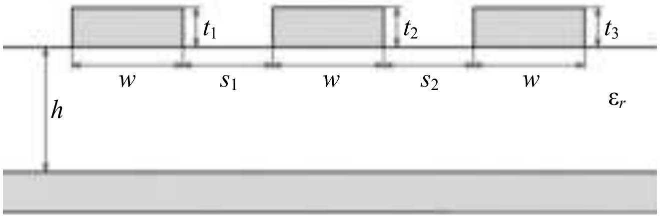
One of the urgent tasks of electromagnetic compatibility (EMC) is to ensure the protection of radio electronic equipment (REE) against electromagnetic interferences (EMI) which can be both natural (electrostatic discharge, secondary manifestations of a lightning discharge) and intentional (electromagnetic weapons). The steady increase in the number and integration degree of REE increases the risk of its damage from pulsed [1] and continuous [2] EMI, even with small amplitude of the field strength. Dangerous is a powerful ultrashort pulse (USP) which can penetrate into REE and disable sensitive circuits due to a wide spectrum and high power [3, 4]. Well-known protection means (such as voltage limiters, varistors, passive RC and LC filters) have a number of disadvantages, the main of which are low power and speed, as well as low radiation resistance and, as a consequence, short operating life [5, 6]. All this makes it difficult to provide adequate REE protection.

There are many stripline devices for protecting against USPs and filtering signals [7-12]. Noteworthy are protection devices based on modal decomposition technology [13, 14], which are devoid of the indicated disadvantages, and also have a number of advantages (absence of semiconductor components, long operating life, operation at high voltages and low cost). Another approach based on modal decomposition technology is signal decomposition in a turn of a meander microstrip line (MSL) into a sequence of pulses of lower amplitudes (cross-talk, odd and even modes) [15]. Conditions that ensure such decomposition have been formulated. The maximum USP attenuation of 2.42 times (relative to half the electromotive force (e.m.f.)) in the turn of the meander MSL has been demonstrated [15]. However, as the attenuation coefficient is too low, the approach needs to be improved. For example, by integrating one additional passive conductor close to the turn of the meander MSL, the USP can be decomposed into four pulses since there are three modes propagating in such a structure. It is also noteworthy that asymmetric structures contain additional pulses [16], the number of which depends on the number of linear combinations of line modes. Since three modes propagate in the meander MSL with an additional conductor, three additional pulses also appear in such line. Considering this, a USP in the line under investigation can be decomposed now into seven main pulses of lower amplitudes including the cross-talk pulse.

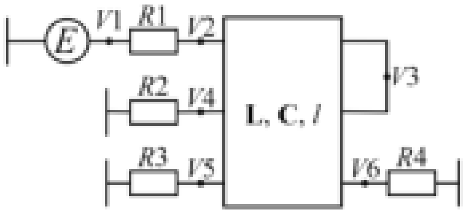
The aim of this work is to study the possibility of USP decomposition into a sequence of seven pulses of lower amplitude. To do this, first, it is necessary to analyze the influence of changes in the geometric parameters of the line under investigation on the USP waveform and amplitude, to formulate the conditions for USP decomposition into a sequence of seven pulses, and to optimize the parameters of the cross-section of the line according to the criteria for ensuring the formulated conditions and the criterion of the minimum amplitude at the output.

2. Initial data and preliminary analysis

The cross-section and circuit diagram of the meaner MSL with a passive conductor are shown in figure 1.



(*a*)



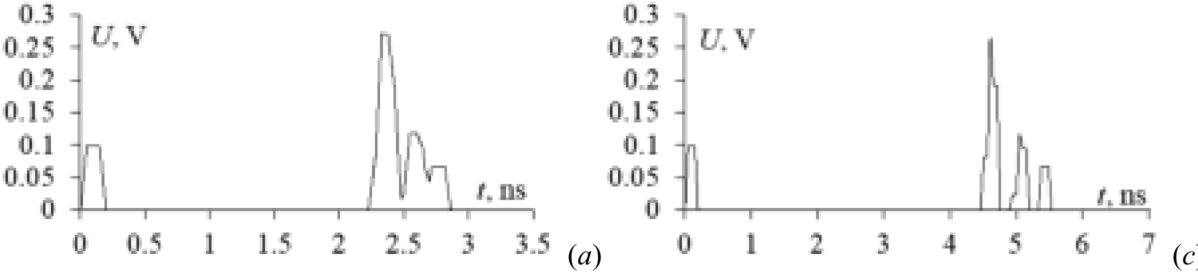
(*b*)

Figure 1. Cross-section (*a*) and circuit diagram (*b*) of the line under investigation.

Initial parameters of the line are the following: the width and thickness of conductors are w=300 µm and t_1=t_2=t_3=18 µm, respectively; the space between the conductors is s_1=50 µm and s_2=50 µm; the relative permittivity of the substrate is ε_r=5.4; the thickness of the substrate is h=300 µm; the distance from the edge of the structure to the conductor is d=3w; the line length is l=200 mm. The loads $R1$–$R4$ are taken equal to 50 Ohm. A trapezoidal USP with the following parameters was chosen as the excitation: the amplitude of the e.m.f. is 1 V, the flat top 100 ps, and the rise and fall times are 50 ps each.

3. Simulation results

The quasi-static simulation was performed in the TALGAT software [17]. Figure 2 shows the USP waveform at node $V4$ with the initial line parameters and a sequential increase of l up to 500 mm with a step of 100 mm.



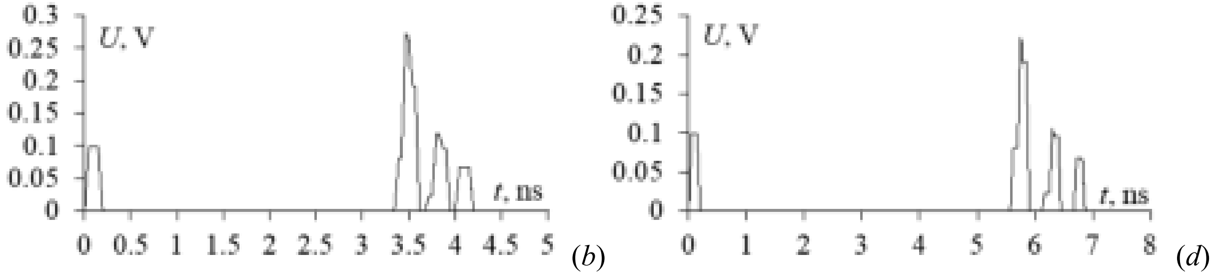


Figure 2. Voltage waveform at node *V*4 with *l*=200 (*a*), 300 (*b*), 400 (*c*) и 500 (*d*) mm.

It can be seen from figure 2 that as the line length increases, the USP at the end of the line gradually falls into three pulses, and then two more pulses begin to appear at the rises of the second and third pulses. The USP amplitude at the end of the line at *l*=200 mm is 0.273 V, and at *l*=500 mm – 0.207 V. Then, the analysis of the waveform change at node *V*4 was performed with the initial parameters of the line cross-section at *l*=500 mm and a sequential decrease in s_1 from 40 to 10 µm with a step of 10 µm. This was made to enhance the electromagnetic coupling between the passive conductor and the signal conductors of the turn (figure 3).

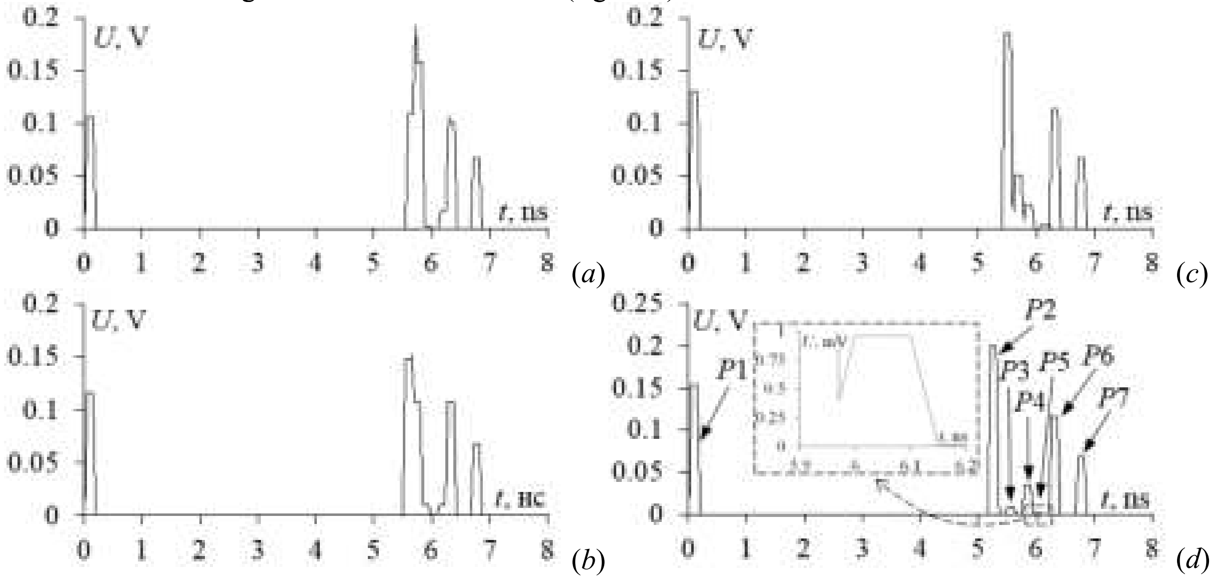


Figure 3. Voltage waveform at node *V*4 with s_1=40 (*a*), 30 (*b*), 20 (*c*) и 10 (*d*) µm.

As can be seen from figure 3, the USP at the end of the line under investigation is gradually decomposed into more pulses when the coupling is enhanced. Let us consider the waveform in Fig. 3*d* in detail. It can be seen that in node *V*4, the USP is represented by a sequence of seven pulses (*P*1–*P*7) with amplitudes not exceeding 0.2 V. The first pulse is cross-talk and three of the six subsequent ones are mode pulses of the line. Three more pulses are additional and arise due to the influence of asymmetry in the cross-section [16].

We then determined the delay of each pulse. For this task, we used the TALGAT software to calculate the per-unit-length delays of the line modes with the initial parameters at *l*=500 mm and s_1=10 µm (hereinafter, we will call this set of parameters the initial one): τ_1=5.16 ns/m, τ_2=5.77 ns/m and τ_3=6.73 ns/m. Then the times when the mode pulses arrive are determined as: $\tau_1 2l$, $\tau_2 2l$ and $\tau_3 2l$. Substituting the known variables we obtain t_{P2}=5.16 ns, t_{P4}=5.77 ns and t_{P7}=6.73 ns. Thus, pulses *P*2, *P*4 and *P*7 are pulses of the line modes, and pulses *P*3, *P*5 and P6 are additional. We note that pulse *P*5 has the minimum amplitude, not exceeding 1 mV, and its front is superimposed on the fall of pulse *P*4. Taking into account [16], the delays of pulses *P*3, *P*5 and *P*6 are defined as:

t_{P3}=(t_{P2}+t_{P4})/2=5.46 ns, t_{P5}=(t_{P2}+t_{P7})/2=5.94 ns and t_{P6}=(t_{P4}+ t_{P7})/2=6.25 ns. Considering the results obtained in this paper and the results from [15, 16], it is possible to formulate the conditions for the USP decomposition in a meander MSL with an additional passive conductor. For this, it is necessary that the delay of each subsequent pulse (except the first one) be no less than the delay of the previous pulse summed up with the total USP duration. Then the conditions for the complete USP decomposition in the line under study will have the following view

$$t_{P2} \geq t_{\mathrm{USP}}, \tag{1}$$

$$t_{P3} \geq t_{P2} + t_{\mathrm{USP}}, \tag{2}$$

$$t_{P4} \geq t_{P3} + t_{\mathrm{USP}}, \tag{3}$$

$$t_{P5} \geq t_{P4} + t_{\mathrm{USP}}, \tag{4}$$

$$t_{P6} \geq t_{P5} + t_{\mathrm{USP}}, \tag{5}$$

$$t_{P7} \geq t_{P6} + t_{\mathrm{USP}} \tag{6}$$

where t_{USP} is the total USP duration. Thus, condition (1) ensures that pulse $P2$ arrives as soon as pulse $P1$ ends, condition (2) – pulse $P3$ arrives as soon as pulse $P2$ ends and so on. After the substitution of known and algebraic transformations, condition (1) takes the view

$$\tau_1 \times 2l \geq t_{\mathrm{USP}} \tag{7}$$

conditions (2), (3) and (5) take the equal view

$$\tau_2 l \geq \tau_1 l + t_{\mathrm{USP}} \tag{8}$$

conditions (4) and (6) take the view

$$\tau_1 l + \tau_3 l \geq \tau_2 \times 2l + t_{\mathrm{USP}}, \tag{9}$$

$$\tau_3 l \geq \tau_2 l + t_{\mathrm{USP}}. \tag{10}$$

We note that when substituting known variables, conditions (7), (8), (10) are satisfied, but condition (9) is not satisfied (this is also seen in figure 3*d* where the rise of pulse $P5$ is superimposed on the fall of pulse $P4$). In this regard, the optimization of the geometric parameters of the line under investigation was carried out by means of a heuristic search according to the criteria for fulfilling conditions (7)–(10) and the criterion of the minimum amplitude. For this, an analysis was made of the influence of changes in geometric parameters on the pulse delays and the signal amplitude at the end of the line. As a result of analysis, the optimal parameters fulfilled the above criteria were found. The obtained optimal parameters of the line are the following: w=1000 µm, t_1=22 µm, t_2=140 µm, t_3=76 µm, s_1=9 µm, s_2=5 µm, ε_r=5,8, h=390 µm and l=300 mm. We note that the obtained parameters are far from the capabilities of PCB manufacturers, but they most clearly demonstrate the USP decomposition into 7 pulses with minimum amplitudes, and so were used for academic purposes. The per-unit-length delays were calculated in the TALGAT software with optimal parameters: τ_1=4.19 ns/m, τ_2=5.37 ns/m and τ_3=7.31 ns/m. Thus, when substituting the obtained per-unit-length delays of the line modes into conditions (7)–(10), they are satisfied with a margin. The USP waveform at the line output at optimal parameters is shown in figure 4.

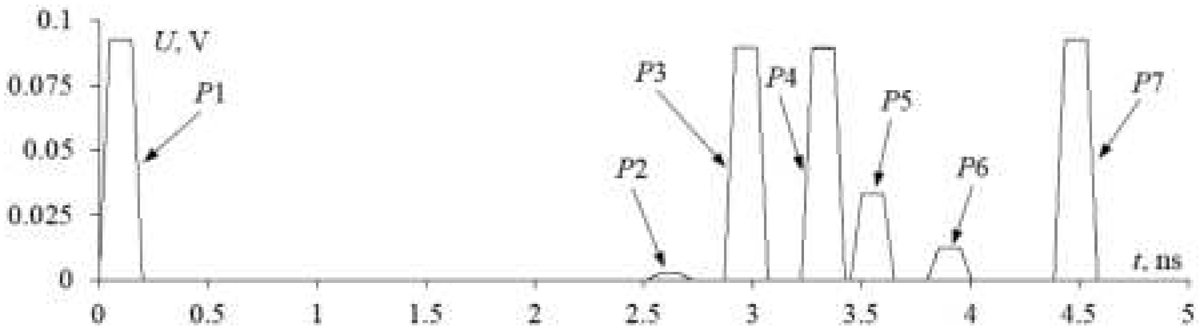


Figure 4. Voltage waveform at node *V*4 at optimal geometric line parameters which ensure the fulfillment of conditions (7)–(10)

As can be seen from figure 4, the USP at the line output is represented by a sequence of 7 pulses with the amplitudes not exceeding 93 mV. Pulses *P*1 and *P*7 have equal and maximum amplitudes at the line output. Further, the end of the line sees lower amplitude pulses which are caused by reflections.

4. Conclusion

In this study, we have evaluated how the change in the parameters of the cross-section of a meander MSL with a passive conductor influences the USP waveform and amplitude. It was demonstrated that, in addition to cross-talk and main mode pulses, the line under investigation contains additional pulses, which are an additional resource for minimizing the amplitude of the interference pulse. The delays of each of the decomposition pulses were determined and the conditions for USP decomposition in a meander MSL with a passive conductor into a sequence of seven pulses were formulated. The optimization of the geometric parameters of the line was carried out according to the criteria for fulfilling the formulated conditions and the criterion of minimal amplitude. As a result, the maximum USP attenuation was 5.38 times relative to half the e.m.f.

Acknowledgments

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