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Investigation of Possibility of Protection against Electrostatic Discharge Using Meander Microstrip Line

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Abstract. The possibility of protection against electrostatic discharge (ESD) by means of a turn of the meander microstrip line was investigated. It was estimated that the required length of the line should be 66 m for the decomposition of the whole ESD with duration of 100 ns, which is unacceptable. Therefore, the authors investigated the possibility of decomposing only ESD peak surge with duration of 4 ns. As a result, the decomposition of the peak surge into a sequence of smaller pulses was demonstrated. The attenuation of 1.33 times for the ESD amplitude in the turn of the meander microstrip line with a length of 3 m was obtained.

1. Introduction

Modern trends in the development of radio electronic equipment (REE) force the designers to pay special attention to electromagnetic compatibility (EMC). First of all, this is due to the increase in performance, the decrease in working voltages and the geometric size of the elements of the REE. All this significantly decreases the stability of REE to overvoltages. One of the current problems of EMC is the protection of REE against various electromagnetic interferences (EMI), which can be both internal (due to failures in the work of REE) or external (natural or intentional). The most dangerous pulses for REE are those with short duration and high power: ultrawideband pulses (UWB), electrostatic discharges (ESD), as well as a lightning discharge. Such influences penetrate in the critical nodes of the REE and disturb its sensitive circuits. There are many protective devices against such influences, but often their use is unacceptable because of their insufficient speed and low power [1]. Therefore, for protection in a wide frequency range, complex multistage devices are required. Meanwhile, in practice, simplicity and cheapness of protection devices are required. Therefore, it is necessary to identify and explore new approaches to protection, as well as to find ways to implement it effectively.

There are many studies of different devices based on strip lines for protection against UWB pulse (including ESD protection) and signal filtering in frequency domain [2–7]. There is a method of protection against UWB pulse, based on the use of modal distortions in multiconductor microstrip lines [8]. However, a more simple method based on the decomposition of the UWB pulse in a turn of meander line into a sequence of pulses of small amplitude is also proposed recently [9]. The decomposition is achieved by such a choice of parameters of the turn which provides a number of simple conditions. Full-scale testing of devices based on this approach has been performed, and as a result the possibility of REE protection against the UWB pulse by the turn of the meander line has been proved experimentally.



At the next stage of these studies, the investigation of the REE protection from ESD can be considered, since it is one of the examples of dangerous pulses. Such study can expand the application domain of meander delay lines as devices for protection against electromagnetic threats. The turn of the meander microstrip line, which has been investigated experimentally in [9], is suitable for such studies.

The purpose of this paper is to investigate the possibility of REE protection from ESD using a turn of a meander microstrip line. To achieve this purpose, it is necessary to draw a cross-section using real geometric parameters, to set the ESD as exciting pulse and to calculate the response to the ESD excitation.

2. Formulation of the problem

Similarly to previous studies [9], it is necessary to satisfy two simple conditions for the decomposition of ESD in a turn of a meander line. The first condition provides the propagation of a pulse along the turn without distortion of the pulse by the near-end crosstalk:

$$2l\tau_{min} \geq t_{\Sigma} \quad (1)$$

where l – length of a half turn, τ_{min} – the smallest value among per-unit-length delays of the even (τ_e) and odd (τ_o) modes of the line, and t_{Σ} – the total duration of the pulse. The second condition ensures the decomposition of the pulse into pulses of the odd and even modes of the line:

$$2l|\tau_e - \tau_o| \geq t_{\Sigma}. \quad (2)$$

Thus, in order to implement protection against ESD by a turn of a meander line, it is necessary to meet conditions (1) and (2) by choosing the line parameters. If cross section parameters of the line are given, it is advisable to fulfill conditions (1) and (2) by choosing the line length, without changing the real geometric parameters of the line cross-section.

3. Initial data for simulation

Having been investigated experimentally, the real meander microstrip line was chosen for the study (Figure 1a). The cross-sectional parameters of the line are as follows: width and thickness of the signal conductor are $w=2450 \mu\text{m}$ and $t=45 \mu\text{m}$ respectively; the distance between conductors is $s=300, 250, 100, 150 \mu\text{m}$; dielectric substrate thickness is $h=2000 \mu\text{m}$; permittivity of the substrate is $\epsilon_{rc}=5.4$.

The circuit of the connections of the investigated line consists of two parallel conductors of length l connected to each other at one end (Figure 1b). One of the line conductors is connected to a signal generator represented in the circuit by ideal current source I and parallel resistance $R1$. The second conductor of the line is connected to the receiving device represented in the diagram by resistance $R2$. To minimize reflection of the signal at the ends of the line conductors, the values of $R1$ and $R2$ are accepted to be equal to the average geometric mean of the even and odd modes impedance. The geometric parameters of the line cross-section are chosen so that $(Z_e Z_o)^{0.5} \approx 50 \text{ Ohm}$.

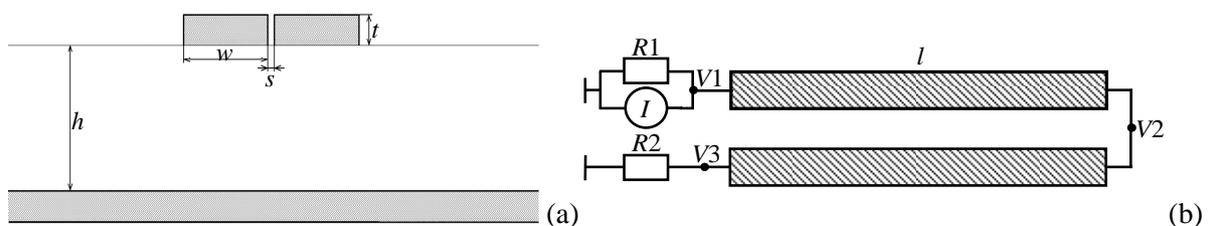


Figure 1. The cross section (a) and circuit of the connections (b) of the microstrip meander line

As an excitation, ESD having the form of current accepted by standard IEC 61000-4-2 [10] is used. Figure 2 shows the voltage waveform at the beginning of the line (at node V1) for $l=0.1 \text{ m}$.

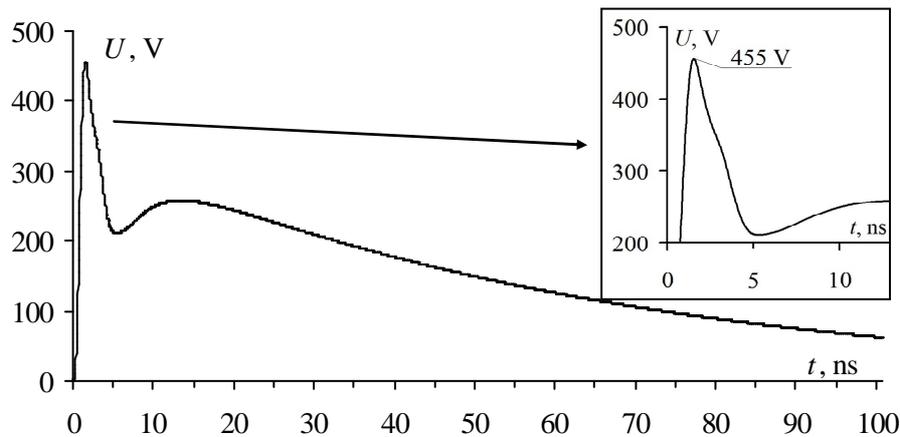


Figure 2. The voltage waveform at the beginning of the line for $l=0.1$ m and ESD peak surge with a duration of about 4 ns

4. Simulation of waveforms at the end of the meander line

Simulation of the investigated line is performed using the TALGAT system [11]. Elements of matrices **C** and **L** for a structure in Figure 1a for $s=300, 250, 200$ and $150 \mu\text{m}$, obtained using the method of moments, are presented in Table 1.

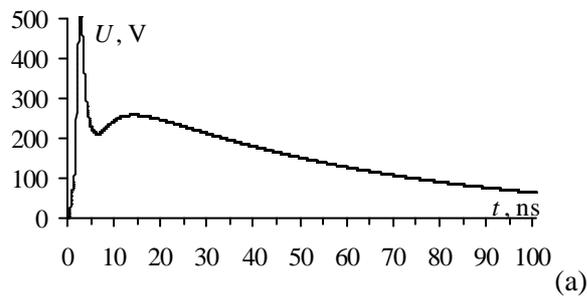
Table 1. The calculated elements of matrices **L** and **C**

| $s, \mu\text{m}$ | 300 | | 250 | | 200 | | 150 | |
|------------------|-------|----------|-------|----------|-------|----------|-------|----------|
| | diag | off-diag | diag | off-diag | diag | off-diag | diag | off-diag |
| L, nH/m | 352.9 | 151.6 | 350.1 | 157.3 | 346.4 | 163.6 | 341.7 | 171.3 |
| C, pF/m | 130.1 | -42.4 | 132.9 | -45.8 | 136.7 | -50.1 | 141.8 | -55.6 |

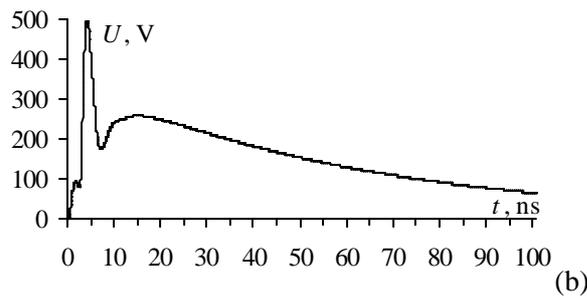
The calculated per-unit-length delay of the odd and even modes for the structure under study with $s=300 \mu\text{m}$ are $\tau_e=6.65$ ns/m, $\tau_o=5.89$ ns/m. Thus, to decompose completely the ESD with a duration of 100 ns in the turn of the meander microstrip line, it is necessary to ensure its length $l=66$ m. Obviously, a line of this length is unacceptable for using in practice. To reduce the size turn, it is proposed to decompose the ESD incompletely, and to decompose only its peak surge with a duration of about 4 ns, whose amplitude is 455 V (Figure 2).

For simplicity, let us introduce the definitions: the first part of the ESD is ESD peak surge with a duration of 4 ns (Figure 2), the second part of the ESD is a long part of the ESD after the peak surge. To understand the change of the ESD waveform in the turn of a meander microstrip line, detailed simulation is performed with a consecutive increase in the length of the line (l). The simulated waveforms at the end of the line (at node V3) with $s=300 \mu\text{m}$ for $l=0.1, 0.2, 0.3, \dots, 1$ m are shown in Figures 3, 4, and for $l=1.5, 2, \dots, 3$ m – in Figure 5.

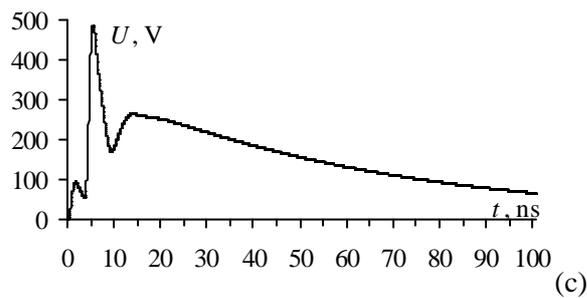
Figures 3 and 4 show the appearance of a near-end crosstalk pulse (the first pulse) on the front of the main signal (ESD peak surge) and the increased delay of the main signal, as the line length increases. It is worth noting minor increase (in 1.1 times at $l=0.1$ m) of the amplitude of the signal at the output of the line under study. This is due to the overlapping of a peak surge propagating through the turn, over the near-end crosstalk from it. It is seen from Figure 5 that when the line length is increased to $l=3$ m, the decomposition pulses of the odd and even modes are more clearly observed.



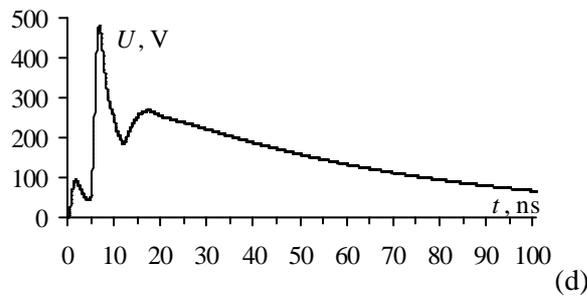
(a)



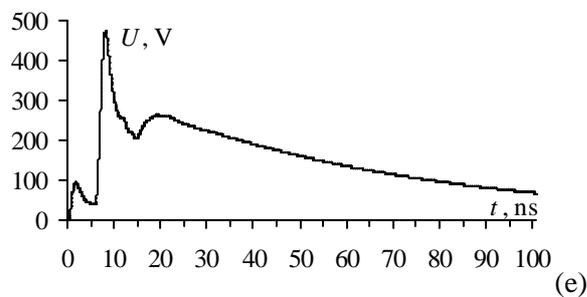
(b)



(c)

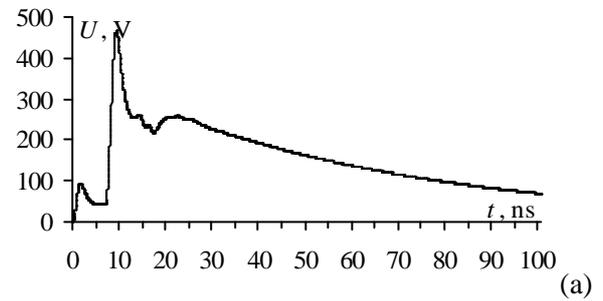


(d)

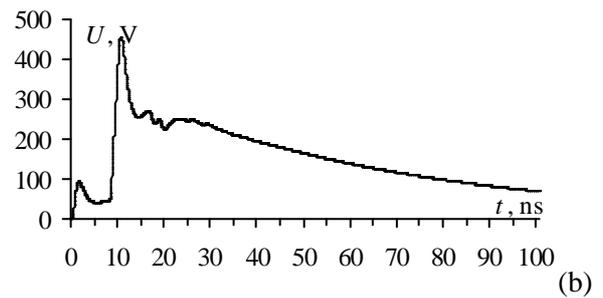


(e)

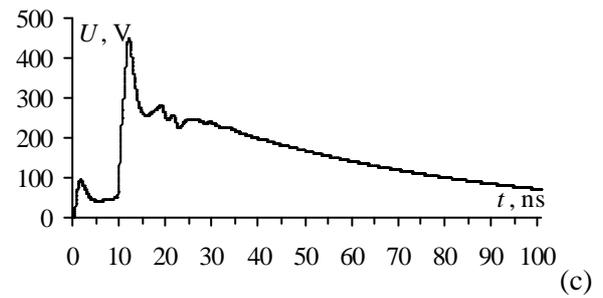
Figure 3. Voltage waveforms at the output of the meander microstrip line for $l=0.1$ (a), 0.2 (b), 0.3 (c), 0.4 (d), 0.5 (e) m



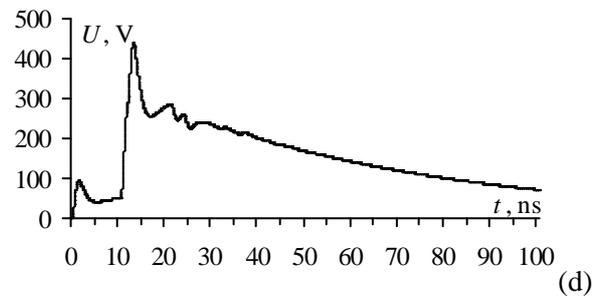
(a)



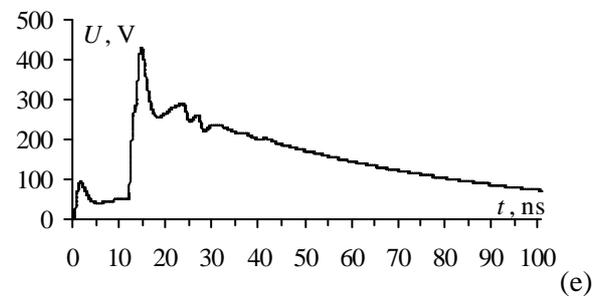
(b)



(c)



(d)



(e)

Figure 4. Voltage waveforms at the output of the meander microstrip line for $l=0.6$ (a), 0.7 (b), 0.8 (c), 0.9 (d), 1 (e) m

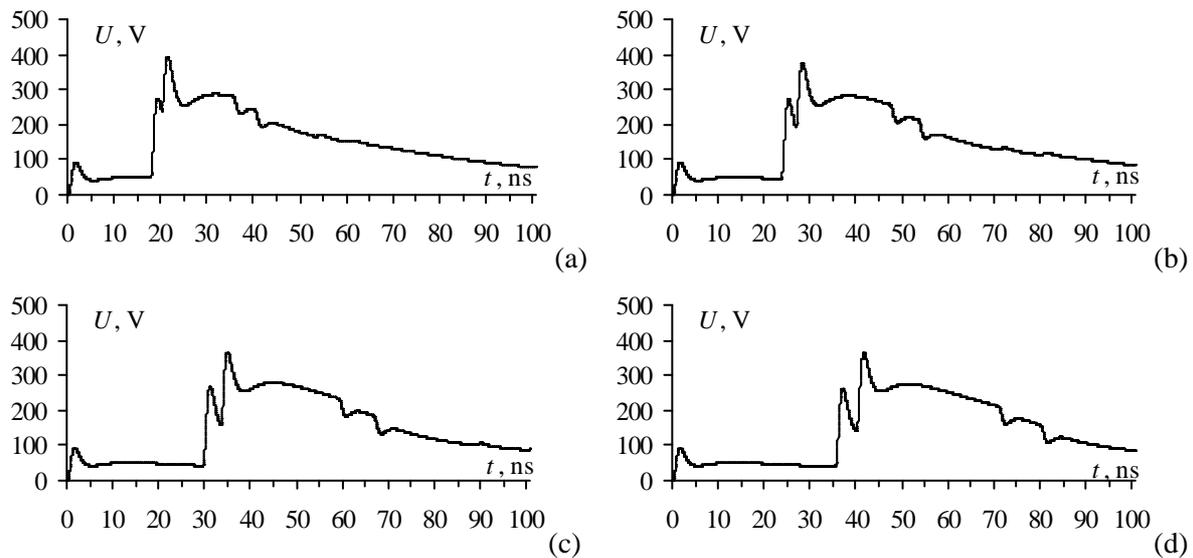


Figure 5. Voltage waveforms at the output of the meander microstrip line for $l=1.5$ (a), 2 (b), 2.5 (c), 3 (d) m with $s=300 \mu\text{m}$

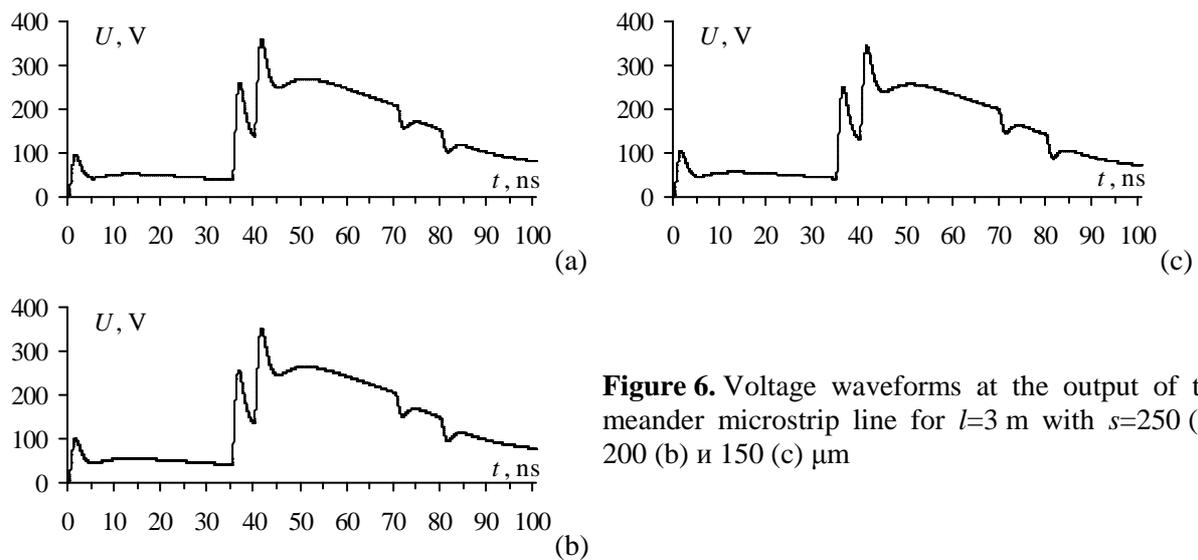


Figure 6. Voltage waveforms at the output of the meander microstrip line for $l=3$ m with $s=250$ (a), 200 (b) и 150 (c) μm

The peak output voltage values are 393.6, 374.6, 366.4 и 364 V for $l=1.5$, 2, 2.5 и 3 m, respectively. Thus, the maximum attenuation of the ESD is 1.25 times. It is also worth noting that the amplitude of cross-talk (the first pulse) with a decrease in the length of the line remains unchanged and does not exceed 93 V.

As it was shown earlier [9], an increase in the coupling between conductors leads to an increase in the amplitude of the crosstalk pulse and a decrease in the peak value of the pulses of the odd and even modes of the line. Therefore, in order to minimize the ESD amplitude at the line output, a similar simulation of the meander microstrip line turn with decreasing distance between conductors $s=250$, 200 and 150 μm is performed for $l=3$ m.

The obtained waveforms at the output of the investigated line are shown in Figure 6. It is seen that the decrease in value of s does not affect the ESD output waveform. However, the output amplitude decreases with decreasing s . Thus, the amplitudes at the output of the line are 358.6, 352, and 343.5 V for $s=250$, 200, and 150 μm , respectively. As a result, the maximum attenuation of the ESD (1.33 times) for the structure under study is obtained for $l=3$ m and $s=150 \mu\text{m}$.

5. Conclusion

The study shows in detail the change in the waveform and amplitude of the ESD in the turn of a meander microstrip line against its length. The peak surge of ESD (the first part of ESD) was minimized. As a result, the decomposition of the peak surge on a pulses sequence of smaller amplitude was demonstrated. The voltage amplitude at the line output of 75.5% of the signal level at the line input (attenuation 1.33 times) is obtained for length of 3 m and 150 μm separation. The cross-section parameters were fixed. However, there is a potential to reduce the ESD amplitude by changing other cross-section parameters: w , t , h and ε_{rC} . In this paper, the simulation has been performed without accounting for losses, which can also have a significant effect on the shape and amplitude of the ESD at the end of the line.

6. Acknowledgments

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