Ultrashort pulse decomposition in reflection symmetric meander lines of two cascaded half-turns

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Ultrashort pulse decomposition in reflection symmetric meander lines of two cascaded half-turns

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Abstract. The paper presents the analysis of the time response of reflection symmetric meander lines of two cascaded half-turns to the excitation of an ultrashort pulse (USP). The analysis is based on simulating 3 circuit diagrams of half-turns connections for a length of 1 m. The simulations revealed the possibility of additional pulses in the time response to appear at the output. It is shown that the delay values of the additional pulses are equal to the arithmetic mean values of the two mode delays in different versions. The results of the work are useful for further study of additional pulses in the time response and to establish the nature of their occurrence.

1. Introduction

When creating radioelectronic equipment (REE), much attention is paid to reliability and electromagnetic compatibility (EMC) due to the vulnerability of REE to electromagnetic interference. Non-compliance with EMC requirements can lead to improper operation of REE and may entail to undesirable consequences, for example, regular malfunctions of critical installations [1]. Therefore, it is relevant to carefully observe EMC requirements in the development of critical systems.

One reason of REE malfunctioning can be conducted interference, which can penetrate into REE directly through the conductors [2]. A bright example of such excitation is an ultrashort pulse (USP) [3, 4], which, due to the wide spectrum and short duration, can penetrate into REE and disable it. Meanwhile, protection devices connected to the equipment input have a number of disadvantages (low power, insufficient operating speed, spurious parameters and short service life) that make it difficult to protect equipment against powerful USPs. Therefore, the search and study of new ways for effective protection are necessary. Such is a modal filtration effect, which implies decomposition of a USP into pulses of lower amplitude due to differences in mode delays. It is implemented by using corresponding protection devices: modal filters (MF) and meander lines (ML) [5].

In addition, a new approach to improve modal filtration using a reflection symmetric MF has been proposed (Figure 1). It is noteworthy since, by providing both the edge and broad-side couplings between the conductors at certain parameters, it allows obtaining USP decomposition pulses at the line output with nearly equal values of the pulse amplitudes and the time intervals between the pulses (Figure 1).

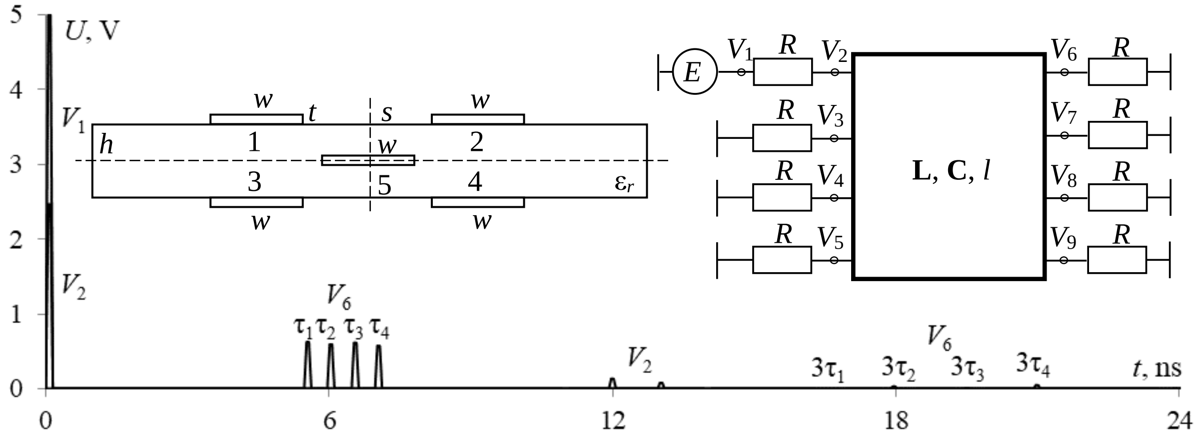

Figure 1. Schematic diagram, cross section and waveforms of EMF (V_1), input (V_2) and output (V_6) voltages of a reflection symmetric MF

Earlier [6], the configuration of a reflection symmetric ML of 4 cascaded half-turns has been considered, where a signal propagates the maximum path (from the generator to the load) for a length of 4*l*. Meanwhile, the analysis of the reflection symmetric MF diagram allows us to identify other options for connecting half-turns. For example, a signal can pass from the generator to the load path of 2*l*, i.e. along 2 cascaded half-turns, with resistors connected to the ends of the two remaining conductors. The purpose of this work is to investigate the possibility of USP decomposition in such structures.

2. Structures under investigation

As a result, we obtained the 3 options of half-turns connections. Their schematic diagrams, when half-turns are pairs of conductors located on top, side and diagonally (cross section in Figure 1), are presented in Figure 2.

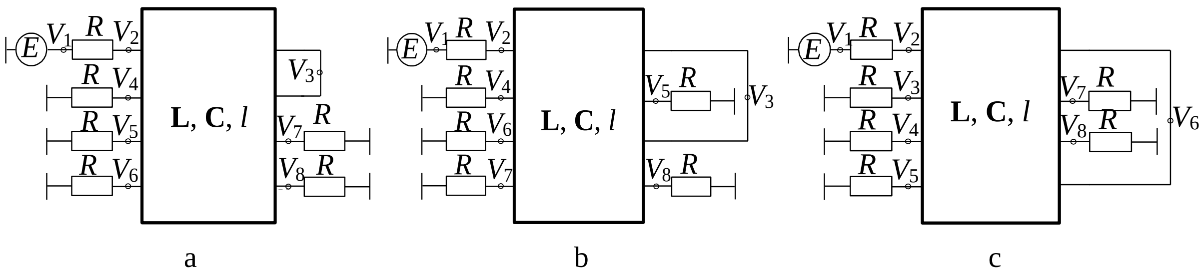

Figure 2. Schematic diagrams of half-turns connections: 1 (a), 2 (b) and 3 (c)

The construction of a cross-sectional geometric model with optimal values of the parameters (s=510 μm, w=1600 μm, t=18 μm, h=500 μm, ε_r=4,5), the calculation of matrices of per-unit-length coefficients of electrostatic (**C**) and electromagnetic (**L**) inductions, the construction of a diagram for simulation, the assignment of terminations and excitation, as well as the calculation of the time response were made similarly to the simulation of 4 cascaded half-turn structures [6] in the TALGAT software [7] used for its acceptable accuracy and low computational costs [8].

3. Simulation results

Figure 3 shows the voltage waveforms obtained at input (nodes V_2 in Figure 2) and output (nodes V_4 in Figure 2*a*, V_6 in Figure 2*b* and V_5 in Figure 2*c*), respectively.

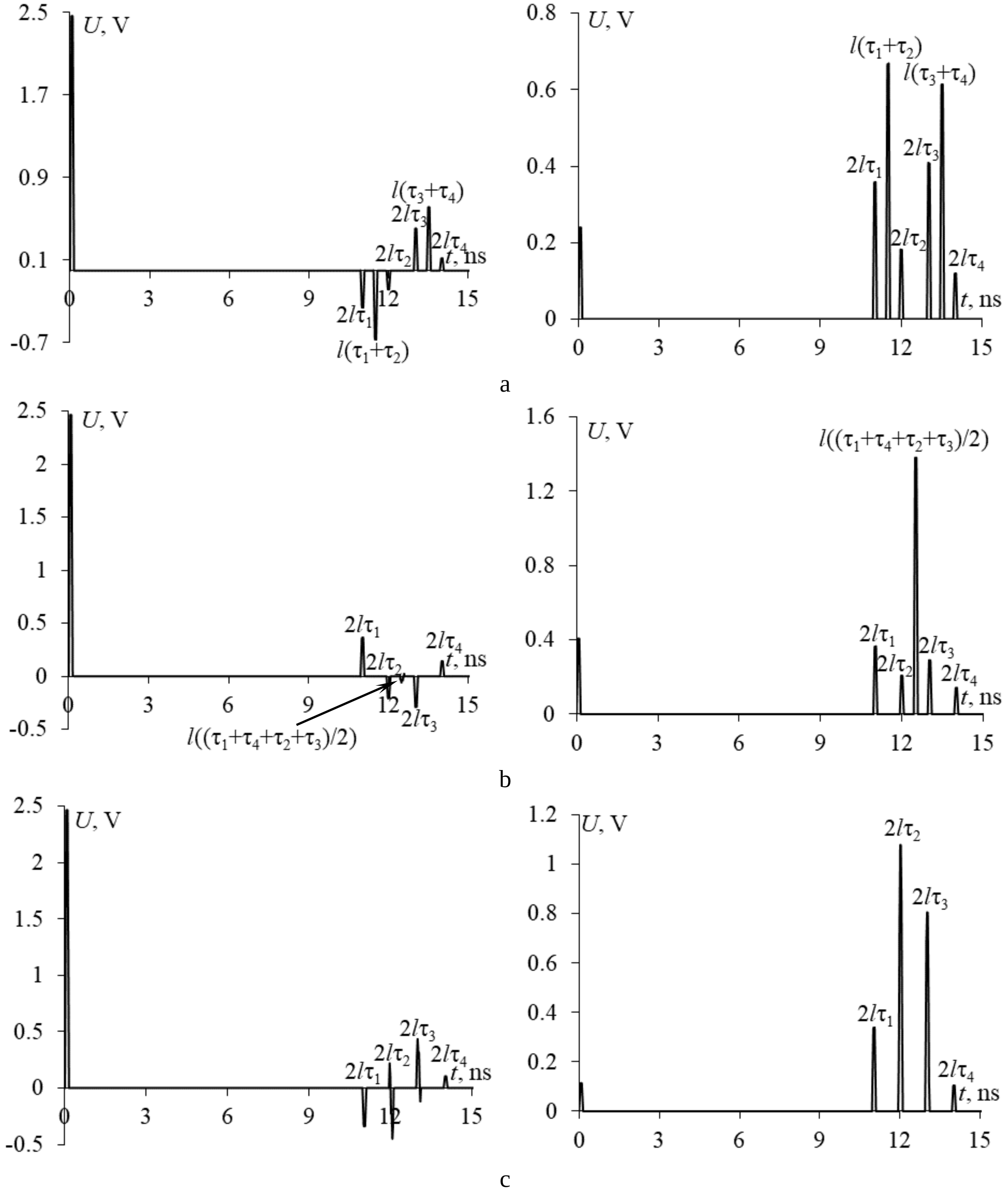

Figure 3. Voltage waveforms at the input (left) and at the output (right) of schematic diagrams 1 (a), 2 (b) and 3 (c)

On the resulting voltage waveforms, there is a group of pulses whose time delays are multiples of 2 per-unit-length time delays. At the input of all diagrams, pulses of negative polarity are observed.

Note the presence of additional pulses with other delay values. In explicit form, this is shown only for diagram 1 (Figure 3*a*). It can be assumed that such pulses exist also for diagrams 2 and 3, but they come almost simultaneously with the main pulses. For diagram 2, this is confirmed by the increase in the total amplitude of the pulse between the pulses of modes 2 and 3, and for diagram 3 – modes 2 and

3. To perform additional verification of this assumption, we increase the value of l from 1 to 10 m for diagrams 2 and 3. The fragments of time responses at the output of diagrams 2 and 3 with pulses whose delays are multiples of 20 per-unit-length time delays are shown in Figure 4.

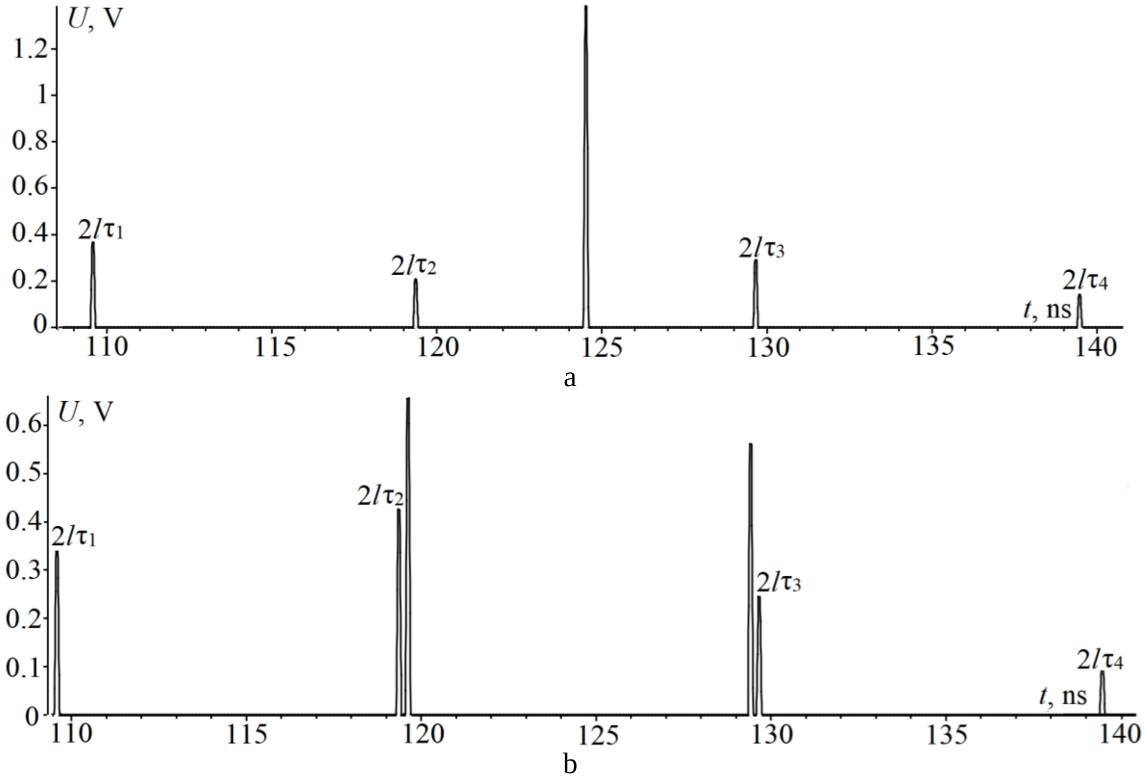

Figure 4. Voltage waveforms at the output of diagram 2 (a) and diagram 3 (b) for l=10 m

The simulation results confirm the assumption about the presence of additional pulses in diagram 3, whereas for diagram 2 it was not possible to expand the pulses by increasing the line length because the time intervals between the decomposition pulses in the reflection symmetric MF are equalized. Therefore, it is necessary to change the cross section parameters for diagram 2: s=510 μm, w=1600 μm, t=18 μm, ε_r=4.5 are constant, while the value of h is increased from 500 μm to 1000 μm. The voltage waveforms at the output of diagram 2, with two additional pulses rather than one, are shown in Figure 5.

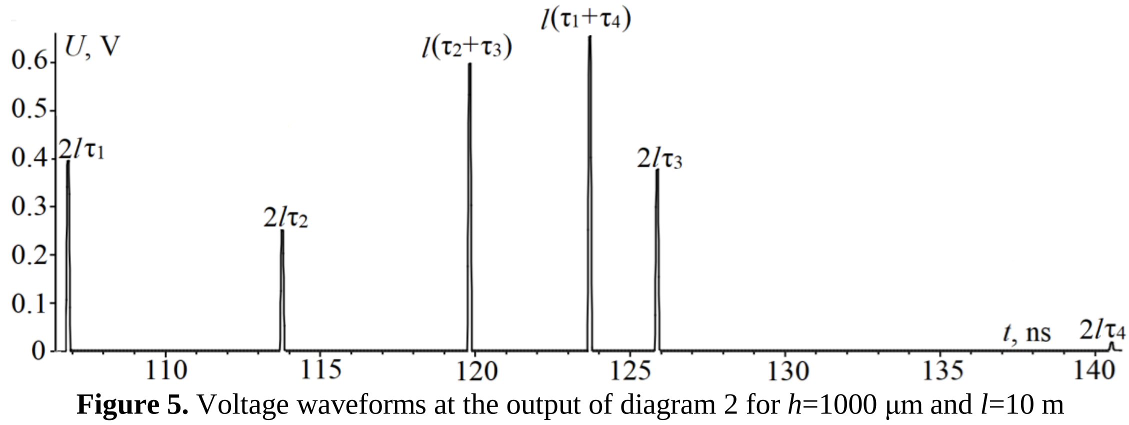

Figure 5. Voltage waveforms at the output of diagram 2 for h=1000 μm and l=10 m

Table 1 shows the values of per-unit-length time delays of modes 1–4 multiplied by 1, 2, 4 and 20, since the time delays of the pulses at the input and output of the reflection symmetric ML are multiples of 2 per-unit-length time delays for l=1 m and 20 for l=10 m.

Table 1. Values of per-unit-length time delays (ns/m) of modes 1–4, multiplied by 1, 2, 4, 20

Multiplie	1	2	3	4
1	5.4698	5.9591	6.4746	6.9687
2	10.9398	11.9183	12.9493	13.9376
20	109.517	119.294	129.595	139.406
20 (h=1000 μm)	106.792	113.705	125.805	140.47

From the analysis of Table I and Figures 3–5 it can be seen that the time delays of additional pulses are equal to the arithmetic means of two per-unit-length time mode delays in different versions. For example, these delays are $(2\tau_1+2\tau_2)/2=\tau_1+\tau_2$ and $(2\tau_3+2\tau_4)/2=\tau_3+\tau_4$ for diagram 1, $(2\tau_1+2\tau_4)/2=\tau_1+\tau_4$ and $(2\tau_2+2\tau_3)/2=\tau_2+\tau_3$ for diagram 2, and $(2\tau_1+2\tau_3)/2=\tau_1+\tau_3$ and $(2\tau_2+2\tau_4)/2=\tau_2+\tau_4$ for diagram 3. But due to the symmetry, the delays of additional pulses can coincide with each other (as in diagram 2) or with the main ones (as in diagram 3).

4. Conclusion

Thus, the possibility of USP decomposition in a reflection-symmetric ML of two cascaded half-turns is shown. When simulating the time response in 3 considered diagrams, additional pulses were detected in the output signal. Depending on the way how conductors are connected, the additional pulses have delay values that are equal to the arithmetic mean value of the two pulse delays.

The maximum amplitude at the output of the reflection symmetric ML for all diagrams is determined precisely by the amplitude of the additional pulses, which is a new resource for optimization. Based on this, it is useful to optimize the reflection symmetric ML according to the criteria for equalizing time intervals between all (including additional) decomposition pulses and minimizing the maximum amplitude at the ML output to increase the attenuation of the USP.

Regarding the provided attenuation at the output of the reflection symmetric ML in the cases considered, the minimum amplitude value (0.661 V) was obtained for diagram 1. It is noteworthy that it is almost the same as that of the reflection symmetric MF (0.625 V). Meanwhile, to implement such circuit, we need 4 rather than 6 resistors at the ends of passive conductors.

A similar decomposition is possible for other signals, for example, for a Gaussian pulse, as well as for more complex types of pulses, such as electrostatic discharge. Note, however, that the duration of a decomposable part of the input signal must be lower than the minimum MF mode delay difference, and even half of this value, if we take into account additional pulses.

5. Acknowledgments

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