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Studying the structures of modal filter with circular reflection symmetry

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Abstract. The paper considers the protection of radio-electronic equipment (REE) against ultrashort pulses (USPs) by using the symmetry to decompose a USP into a doubled number of pulses with half as small amplitude. For the first time, we performed a quasistatic simulation of the time response of a 4-conductor and 8-conductor MFs with circular reflection symmetry. It is shown that these MFs are able to decompose the USP into a sequence of pulses of smaller amplitude. However, in order to obtain the required attenuation level, additional optimization by several criteria is required.

1. Introduction

Electromagnetic compatibility (EMC) becomes increasingly important in the development of radio-electronic equipment (REE). This is due to an increase in the concentration of electrical and electron components on a smaller area, an increase in the upper frequencies of signals, and the improvement of the capabilities of generators of intentional electromagnetic effects. As a consequence, the danger of mutual influence and related disruption of normal functioning of REE increases, which is unacceptable, especially for critical systems. One of the directions of EMC is the protection against conductive interferences, which are electromagnetic noise penetrating into the equipment directly through conductors [1]. A particularly dangerous excitation is a powerful ultrashort pulse (USP) [2].

There are devices that are used to protect against pulse interferences. These include voltage suppressors, arresters, varistors, passive RC- and LC-filters. However, they have a number of disadvantages (susceptibility to radiation, failure to operate at high voltages, insufficient operating speed, etc.), which make it difficult to protect REE against powerful USPs. To solve this problem, a new modal filtration technology was proposed, which is based on the phenomenon of modal pulse decomposition into pulses of smaller amplitude [3]. Modal filters (MF) have a number of advantages: high radiation resistance, durability, operation at high voltages, small dimensions and low cost.

2. Problem statement

There are various MF structures based on coupled multiconductor transmission lines. Figure 1a shows the cross-section of the structure of a printed MF [4] with a triangular arrangement of conductors, where conductors 1 and 2 are located on the upper side of the dielectric substrate, and reference conductor 3 is located on the back. This MF is able to decompose a USP into 2 pulses with twice as small the amplitude. A new approach to increase the MF's protection characteristics by means of using reflection symmetry in the cross-section of structures has been proposed [5]. The representative of such structures is a 4-conductor reflection symmetric MF, obtained by adding conductors 1* and 2* to the MF with a triangular arrangement of conductors (Figure 1a). It is able to decompose a USP into 4 pulses of 4 times smaller amplitude. Its cross-section is shown in Figure 1b.

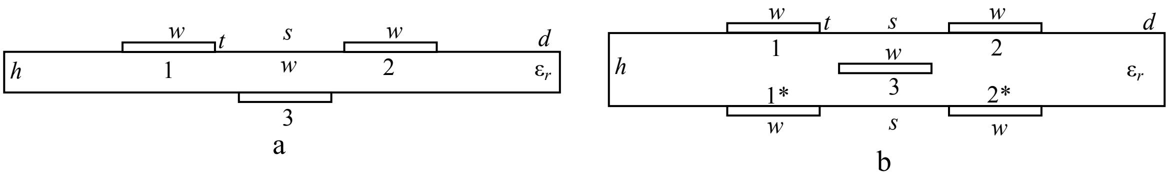

Figure 1. Cross sections of the 2-conductor (a) and reflection symmetric MFs (b).

Meanwhile, reflection symmetric MFs with circular conductors have not been considered before. At the same time, it can be assumed that the use of circular symmetry will allow splitting a USP into a doubled number of pulses with a doubled number of conductors in the MF.

Thus, the purpose of the work is to investigate the possibility of USP decomposition in structures with reflection circular symmetry.

3. Structures and diagram of the MFs under study

At the first stages of investigating the new structures of multiconductor transmission lines, it is reasonable to use a quasistatic simulation. In this case, only transverse T-wave propagation is allowed. The description of wave processes in the quasistatic approach is based on the telegraphic equations to which Maxwell's equations are reduced. Solving these equations is less expensive, and the accuracy provided by this approach is acceptable even for complex problems [6]. This approach is implemented in the TALGAT software [7].

The simulation algorithm includes:

- Construction of geometrical models of cross sections.
- Calculation of matrices of per-unit-length coefficients of electrostatic (**C**) and electromagnetic (**L**) induction. Losses in conductors and dielectrics have not been taken into account.
- Calculation of matrices of characteristic impedance (**Z**) and per-unit-length delays (**τ**).
- Simulation of the schematic diagram; load and excitation determination.
- Calculation of response.

For the study, two structures consisting of 4 and 8 conductors were selected. Their cross sections are shown in Figure 2 (dashed axes of symmetry are marked). The radii of the conductors are 0.4 mm and the dielectrics – 1.6 mm. The relative dielectric permeability (ε_r) is equal to 5.

Figure 2. Cross-sections of the 4- (a) and 8-conductor (b) structures with circular reflection symmetry.

Figure 3a shows the schematic diagram of the 8-conductor structure, and Figure 3b shows the 4- conductor one. The line consists of 8 (apart from the reference) conductors of l length equal to 1 m. The values of all resistances R were assumed to be equal to the arithmetic mean value of elements of matrix **Z** along the main diagonal. The active conductor is connected at one end with the USP source represented in the diagram by an ideal source of EMF E with an amplitude of 5 V, the lengths of rise, fall and flat top of 10 ps each (Figure 3c).

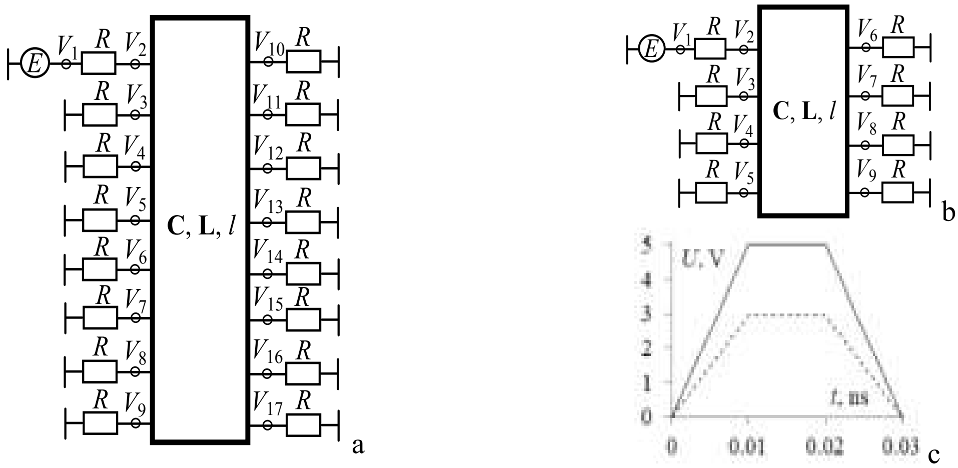

Figure 3. Schematic diagram of the 8-conductor (a) and 4-conductor (b) structures, EMF waveform of pulse excitation (c).

4. Simulation results

4.1. The 4-conductor structure with circular reflection symmetry

In simulation, segmentation plays an important role. To select its optimal value, we estimated the calculation of matrix **τ** as well as the value of maximum voltage at the 4-conductor MF output (U_{max}) obtained at different values of intervals: 100, 200, and 300 (Figure 4) and then compared the results (Table 1).

Figure 4. Conductor segmentation: 100 (a), 200 (b) and 300 (c) intervals.

Table 1. Selection of segmentation for simulation.

Parameters	100 intervals	200 intervals	300 intervals
τ_1, ns/m	4.901	4.922	4.922
τ_2, ns/m	4.932	4.952	4.952
τ_3, ns/m	4.666	4.687	4.687
τ_4, ns/m	4.654	4.666	4.667
U_{max}, V	0.621	0.622	0.622

Table 1 shows that the accuracy of calculating **τ** and U_{max} elements at 200 and 300 intervals is the same, i.e. further increase of intervals is senseless. Meanwhile, the simulation with 200-interval segmentation requires less time. Thus, 200 intervals have been selected for the simulation with optimal segmentation.

The results of calculating the time response of the 4-conductor MF with reflection circular symmetry are shown in Figure 5*a*. It can be seen that this MF decomposes the USP into 4 pulses with paired amplitudes, as in the original reflection symmetric MF. The attenuation coefficient is 4 (U_{max}=0.622 V).

4.2. The 8-conductor structure with circular reflection symmetry

Further, the 8-conductor MF with reflection circular symmetry was studied. It is based on the above described 4-conductor MF with circular conductors. Figure 5*b* shows the time response at the MF output. Seven decomposition pulses are observed on the obtained voltage waveforms. Meanwhile, Table 2 shows that τ_2 and τ_3 almost coincide differing only by 0.01 ns/m. Therefore, pulses 2 and 3 came practically at the same time, which caused their superposition with amplitude summation. To confirm this assumption, the simulation of the MF with the increased value of l from 1 to 4 m was performed (Figure 5c) [8].

As a result, there are 8 pulses with the maximum amplitude of 0.479 V, which is 5.2 times smaller than the amplitude of half the EMF. Thus the first part of hypothesis about the possibility of USP decomposition into a double number of pulses is confirmed. However, in contrast to the 4-conductor reflection symmetric MF, in which attenuation coefficient is equal to 4, the MF under study does not decrease a USP by 8 times. Meanwhile, the maximum amplitude of decomposition pulses at attenuation coefficient 8 should be equal to 0.3125 V. In the time response (Figure 5c), 4 pulses with such amplitude are observed, 3 more pulses have an amplitude less than this value, and the maximum amplitude is only 1.5 times greater, which is natural due to the mismatch of modes and can be eliminated by optimization.

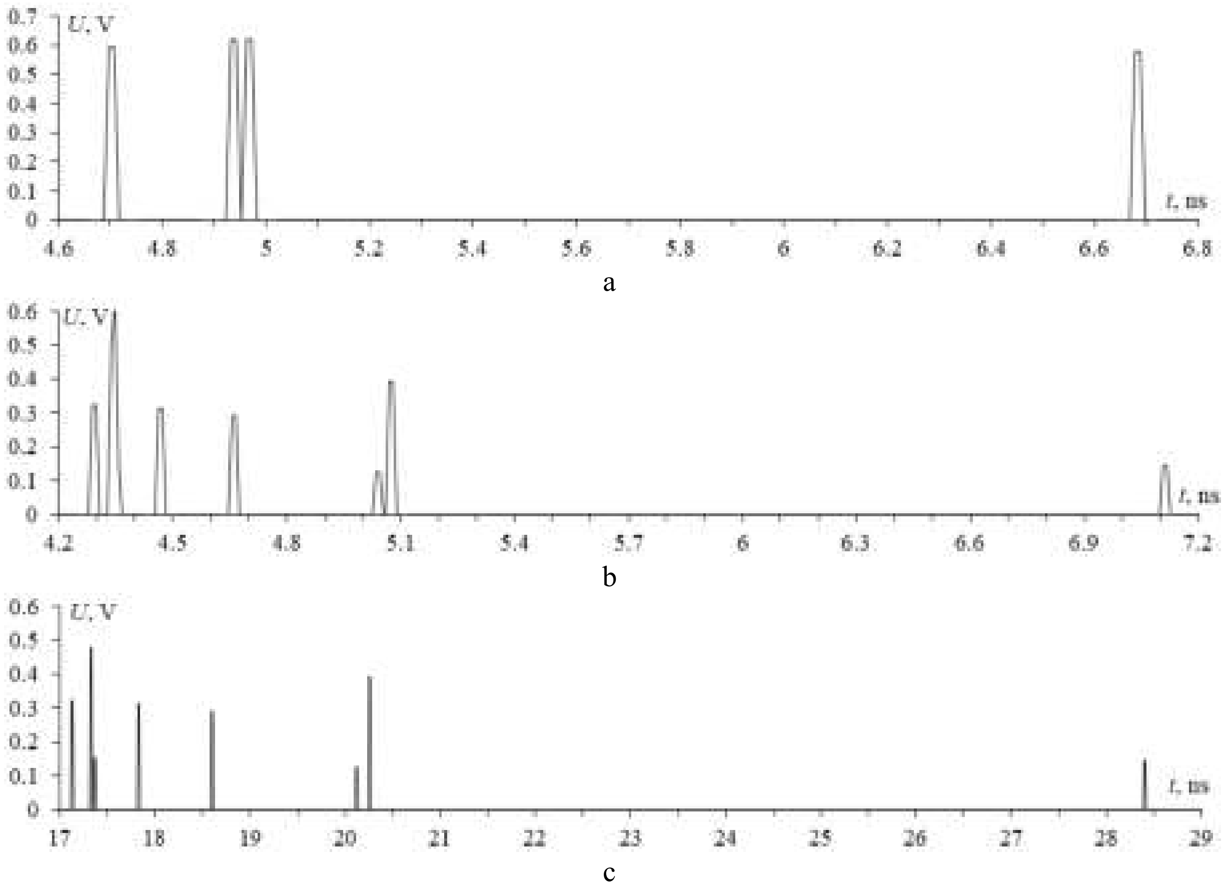

Figure 5. Voltage waveforms at the output of the 4-conductor (a) and 8- conductor circular MF for l=1 m (b) and l=4 m (c).

Table 2. Simulation results (τ_i in ns/m and U_{max} in V) of the 8-conductor MF.

Parameters	τ_1	τ_2	τ_3	τ_4	τ_5	τ_6	τ_7	τ_8	U_{max}
l=1 m	4.278	4.328	4.337	4.453	4.646	5.025	5.060	7.097	0.634
l=4 m	17.114	17.313	17.351	17.813	18.584	20.102	20.242	28.388	0.479

5. Conclusion

Thus, the possibility of USP decomposition in structures with circular reflection symmetry is considered. The results of simulating the 4-conductor and 8- conductor MFs are presented. It is shown that these structures are capable of decomposing a USP into pulses of smaller amplitude with attenuation coefficients of 4 and 5.2 (at l=4 m) times, respectively. Meanwhile, the required attenuation level (by 8 times) could not be achieved only by transition from 4 to 8 conductors. But it is obvious that this can be done by optimization.

In the future, we are planning to optimize these structures according to the criteria of minimizing the output voltage amplitude, as well as ensuring the matching. Due to the peculiarities of USP decomposition in reflection symmetric structures, it is believed that this is possible, first of all, by equalizing the pulse amplitudes at the MF output.

Acknowledgments

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