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Abstract. The article considers the protection of radio-electronic equipment against ultrashort pulses (USP) by means of modal filters (MFs). The reflection symmetric MF structure is analyzed. The results of a quasi-static and electrodynamic analysis of reflection symmetric MF under influence of the USP, without consideration and taking into account losses in conductors and dielectrics, are presented. The maximum deviation for output pulses during simulation using different methods was 5 % for amplitudes and 2.5 % for delays. The necessity of careful consideration of frequency dependence of parameters of the MF materials has been revealed.

1. Introduction

Today's radio-electronic equipment (REE) has extended functionality but, at the same time, it is susceptible to electromagnetic interference. Conducted interference is considered to be the most harmful one, as it can penetrate into devices directly through conductors [1]. Modern generators of ultrashort pulses have very high capabilities [2]. Such ultrashort pulses are able to penetrate and disturb the electronics due to the high power output and short duration [3]. Therefore, it is necessary to do research into the new ways of improving the protection of electronics against ultrashort pulses. A technique of modal filtration [4–6] was proposed for the protection of REE against ultrashort pulses. This technique is based on pulse signal modal decomposition which occurs due to a difference between the modal delays.

In the simulation of the modal filters (MFs), two approaches are most often used: electrodynamic and quasi-static [7]. In general, the first approach is based on a solution of Maxwell's equations. It takes into account all types of waves, however, the computational costs are extremely high even in the analysis of simple configurations. Therefore, this approach, as a rule, is applied only at high frequencies. When using the second approach, there is a simplifying assumption that in the structure only the transverse electromagnetic wave propagates, and the higher types of waves are absent. Maxwell's equations are reduced to telegraph equations, the solution of which is less computationally expensive and gives a good accuracy in solving practical problems [8].

In [9], reflection symmetric MF parameters were optimized according to two criteria in the 50 Ω path. However, in the analysis problem, the quasi-static approach was used [10]. Meanwhile, it is useful to compare time responses of reflection symmetric MF to excitation of an ultrashort pulse, obtained with the help of quasi-static and electrodynamic approaches. However, such task previously was not solved. The aim of this paper is to fill this gap.

2. Structures under simulation

A general cross-section, schematic diagram, as well as waveforms of EMF and input voltage for the reflection symmetrical MF, are shown in Figure 1.

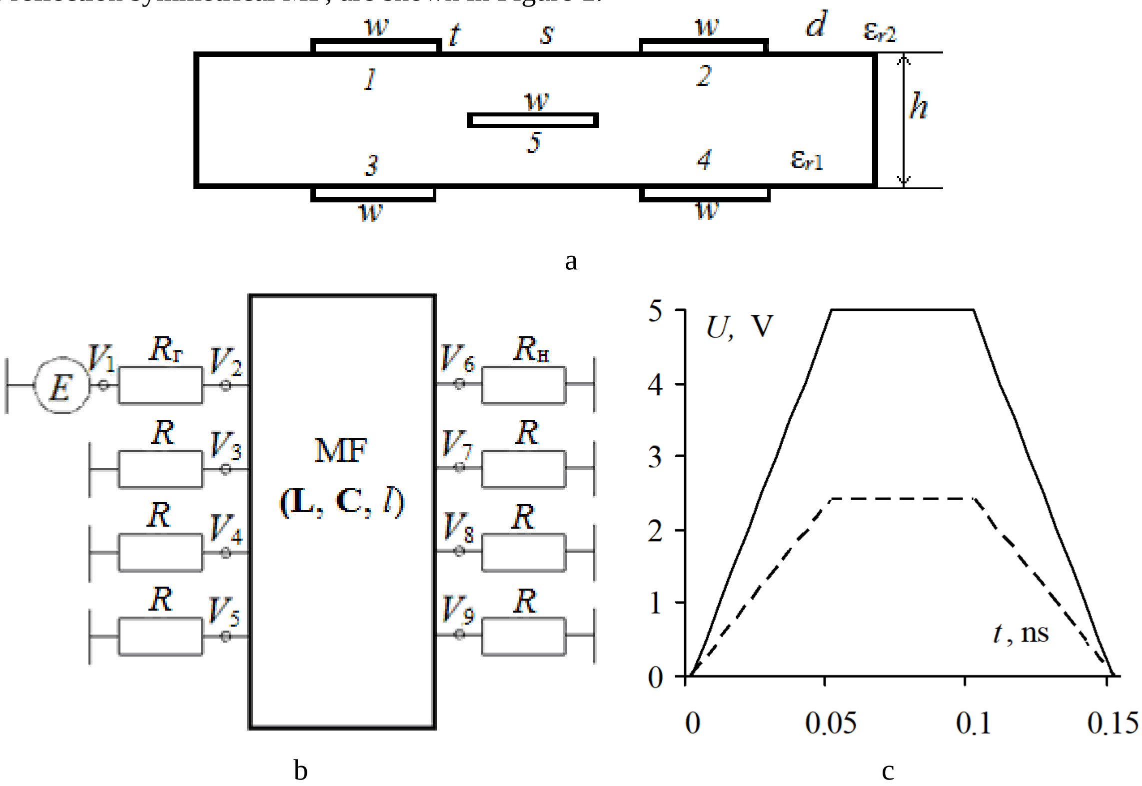

Figure 1. Cross-section (a), schematic diagram (b), exciting electromotive force (——) and input voltage (– – –) waveforms (c).

The MF was modeled with the following parameters: the width of the conductors w=1600 μm, the separations between them s=510 μm, the thickness of conductors t=18 μm, the thickness of the dielectric h=500 μm, the permittivity of the dielectric ε_r=4.5, length of the line l=1 m and R=50 Ω. (The line parameters were chosen from the condition of best matching: using the criterion of the input voltage level to be equal to half the EMF.)

3. Simulation results

The voltage waveforms at the output of the reflection symmetric MF for quasi-static and electrodynamic approaches are shown in Figure 2. Table 1 summarizes the amplitudes of the decomposition pulses, as well as the time delays of each pulse for quasi-static and electrodynamic analysis, without taking into account the losses. Table 1 shows that the maximum deviation in pulse amplitudes is 4.9 % and for delays 2.5 %, which can be considered acceptable. The difference in the waveforms of the decomposition pulses and the difference in the delays obtained in the quasi-static and electrodynamic analysis are explained, first of all, by the different account of the frequency dependence of ε_r [11], as well as the possible effect of radiation losses, taken into account only in electrodynamic analysis.

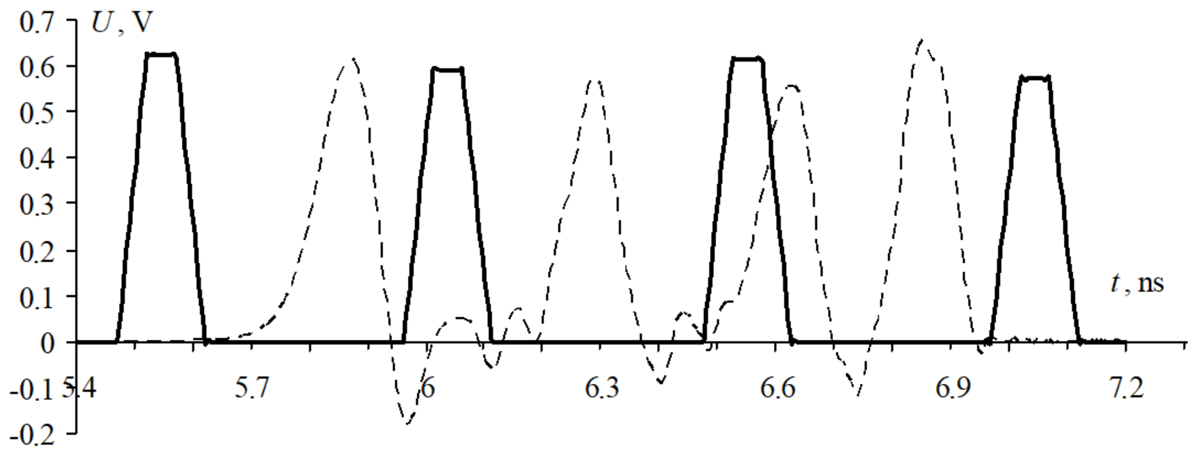

Figure 2. Voltage waveforms at the output of reflection symmetric MF under quasi-static (——) and electrodynamic (– – –) analysis without taking into account the losses.

Table 1. Comparison of amplitudes (U) and delays (t) of four pulses with different types of analysis without taking into account the losses.

Parameter	Electrodynamic	Quasi-static	Deviation, %
U_1, V	0.63	0.62	0.8
U_2, V	0.60	0.58	1.7
U_3, V	0.62	0.56	5
U_4, V	0.58	0.64	4.9
t_1, ns	5.75	5.47	2.5
t_2, ns	6.22	5.97	2
t_3, ns	6.55	6.58	0.2
t_4, ns	6.84	6.97	0.9

A similar simulation taking into account the losses in conductors and dielectrics was performed (Figure 3). In this case, the authors calculated the matrices of per-unit-length resistances **R** (for the losses in the conductors with account of skin effect, proximity effect and losses in the ground plane by the method proposed in [12]) and conductance **G** (for the losses in the dielectrics with constant values of ε_r=4.5 and dielectric loss tangent tgδ=0.017). The consistency of the results is also acceptable. In the quasi-static analysis, non-causality constituting a premature arrival of the output signal is observed. Thus, for simulation without taking into account the losses, the first pulse comes to the output in time of 5.75 ns, whereas taking into account the losses, the arrival time of the pulse signal to the end of the line shifts to 5 ns. It is explained by neglecting the frequency dependence of ε_r and tgδ under quasi-static analysis.

Table 2 summarizes the amplitudes of the decomposition pulses for quasi-static and electrodynamic analysis taking into account the losses.

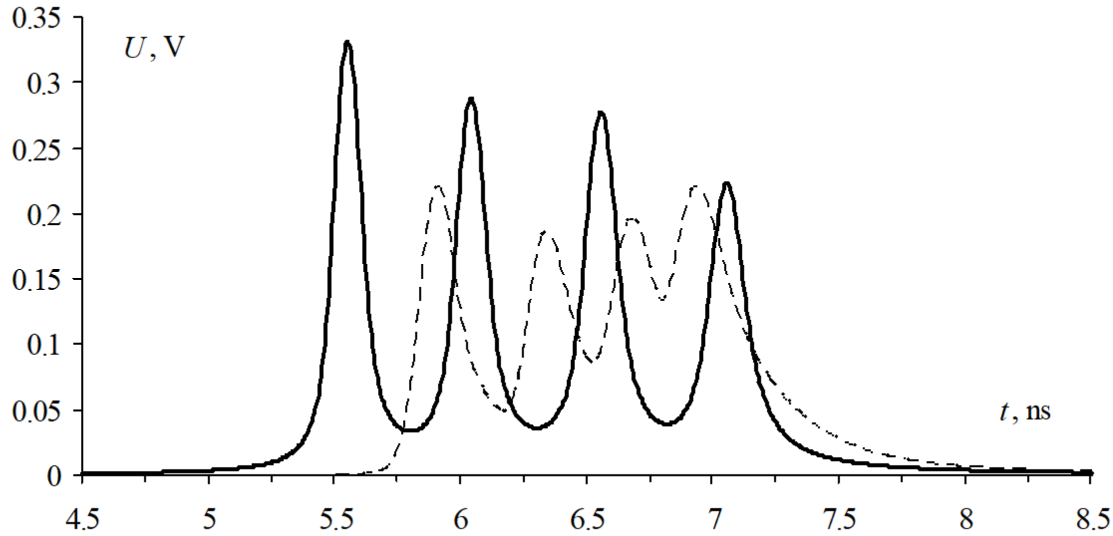

Figure 3. Voltage waveforms at the output of a reflection symmetric MF under quasi-static (——) and electrodynamic (– – –) analysis taking into account the losses.

Table 2. Comparison of amplitudes (U) of four pulses with different types of analysis taking into account the losses.

Parameter	Electrodynamic	Quasi-static	Deviation, %
U_1, V	0.22	0.33	20
U_2, V	0.19	0.29	20.8
U_3, V	0.20	0.28	16.7
U_4, V	0.22	0.22	0

The losses accounting showed a significant (2-fold) decrease in the amplitude of the pulses. However, the difference in accounting the frequency dependence of losses in a quasi-static and electrodynamic analysis led to an increase in the deviation of up to 20 %. Considerable overlapping of the decomposed pulses does not permit to define accurately their delays. Therefore, the evaluation of the pulse delays was not performed.

4. Conclusion

Thus, the results obtained in modeling using quasi-static analysis are generally supported by electrodynamic analysis. This fact is important since it allows us to assume that the implementation of the layout of the printed circuit board of a reflection symmetrical MF and its measurement will show similar results. An important conclusion is also the need for a more accurate account of the frequency dependence of the parameters of materials. Obviously, results of MF optimization will be considerably affected by an approach using for simulation and proper accounting for losses.

5. Acknowledgments

This research was supported by the Russian Federation President grant №14.256.18.356MD.

References

[1] Gizatullin Z M and Gizatullin R M 2006 *Journal of Communications Technology and Electronics* **61**(**5**) 546–50

[2] Mora N, Vega F, Lugrin G, Rachidi F, Rubinstein M 2014 *System and assessment notes* Note 41

[3] Chermoshentsev S F and Gaynutdinov R R 2016 *International Conference on Actual Problems of Electron Devices Engineering, APEDE* **2** 1–6

[4] Gazizov A T, Zabolotsky A M, Gazizov T R 2016 *IEEE transactions on electromagnetic compatibility* **58**(**4**) 1136–42

[5] Samotin I E 2010 *Technology of electromagnetic compatibility* **4(35)** 31–4

[6] Samotin I E 2010 *Dokladi Tom1sk. gos. un-ta sist. upr. i radioelectroniki* **2**(**20**) 169–171

[7] Orlov P E, Buichkin E *N 2017 18th International conference on micro/nanotechnologies and electron devices EDM* 54–8

[8] Kuksenko S P, Khazhibekov R R, Gazizov T T 2017 *Technology of electromagnetic compatibility* **1(60)** 13–20

[9] Chernikova E B and Belousov A O 2017 *Scientific session TUSUR* 95–7

[10] Kuksenko S P, Zabolotskiy A M, Melkozerov A O, Gazizov T R 2015 *Dokladi Tom1sk. gos. un-ta sist. upr. i radioelectroniki* **2**(**36**) 45–50

[11] Belousov A O and Gazizov T R 2018 *Moscow seminar on electronic and network technologies in conjunction with international Siberian conference on control and communications* (*SIBCON–2018*) 1–4 (to be published).

[12] Matthaei G L, Chinn G C 1992 *Microwave Symposium Digest* 1353–4