2019 International Siberian Conference on Control and Communications (SIBCON)

Comparative Analysis of Microstrip and Reflection Symmetric Four-Conductor Modal Filters

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***Abstract*—The paper presents a comparative analysis of two new devices for protection against high-power ultrashort pulses (USPs): a four-conductor microstrip modal filter (MF) and a reflection symmetric MF, performed for the first time. These structures were simulated using a quasistatic approach with an increase of the separation between conductors from 200 to 800 µm. We provide a comparison of time and frequency characteristics and give the results of the qualitative comparison of the presented MFs by a number of attributes, which allow us to determine the advantages and disadvantages of each device. The results are useful for further research and proper use of protection means against USPs, which are based on stripe structures.**

***Keywords*— protection device, modal filtration, multiconductor microstrip line, reflection symmetry, time response, frequency response.**

I. Introduction

Currently, radio-electronic equipment (REE) is massively introduced in almost all industries, including military, nuclear, space, medical and telecommunication. Such a tendency leads to the aggravation of the electromagnetic compatibility (EMC) problem due to vulnerability of equipment to electromagnetic effects. One of the EMC problems is to protect equipment against conductive interference, which can be fed and penetrate into the REE directly through the the conductors [1]. A powerful ultrashort pulse (USP) seems to be especially dangerous [2]. Traditional devices are used as protection against impulse interference, for example, voltage suppressors, varistors, passive RC- and LC-filters. However, such protecting devices have a number of disadvantages (low radiation resistance, short service life, failure to operate at high voltages, insufficient operating speed, etc.), making it difficult to protect against powerful USP. New devices based on modal filtration technology have been proposed to protect against USP in [3]. They have no these disadvantages but have several advantages (absence of semiconductor components, as a result, high radiation resistance and long service life; operation at high voltages; small dimensions and low cost). There are various configurations of such devices, including coupled, multiconductor, reflection symmetric modal filters (MF). However, their comparison has not previously been performed. Meanwhile, it would be useful to perform it, for example, in the same way as comparing a modal filter and a meander line [4]. Such a comparison will determine the advantages and disadvantages of each device, which can help designers to choose the necessary means of protection against USP. The purpose of the work is to perform such a research.

II. Structures and Schematic Diagram of MFs under Consideration

For a comparative analysis, it is advisable to perform a simulation of MFs with the identical parameters. For this purpose, we selected the four-conductor microstrip [5] and reflection symmetric [6] MF structures. Cross sections of these structures are presented in Fig. 1, where w is the width of the conductors, s is the separations between them, t is the thickness of the conductors, h is the thickness of the dielectric, ε_r is the relative permittivity of the dielectric. The schematic diagram for these MFs is presented in Fig. 2.

Per-unit-length parameters and responses were calculated with quasistatic approach in TALGAT software [7] using the schematic diagram of Fig. 2. In our study we developed geometric models of the investigated MFs' cross sections, calculated matrixes of the per-unit-length coefficients of electrostatic (**C**) and electromagnetic (**L**) inductances, worked out a schematic diagram for simulation, set loads and excitation pulse values, and calculated time and frequency responses to the excitation in the parameter range. The resistance values (R) were taken equal to 50 Ohm while the MF length was l=1 m. It was assumed that a T-wave was propagating along the MF. Losses in conductors and dielectrics were not taken into account, since this is not fundamental in the task of comparing two devices, i.e. the per-unit-length entries of the of resistance matrix (**R**) and conduction matrix (**G**) were accepted to be equal to zero. Simulation of the frequency response of the MFs was perfomed with the harmonic excitation of EMF source of 2 V in the frequency range from 1 MHz to 3.5 GHz. To simulate the time response, we used a source of pulse signals represented by an ideal EMF source with amplitude – 1 V with durations of rise, fall and flat top of 30 ps each, so that t_Σ=90 ps (Fig. 3).

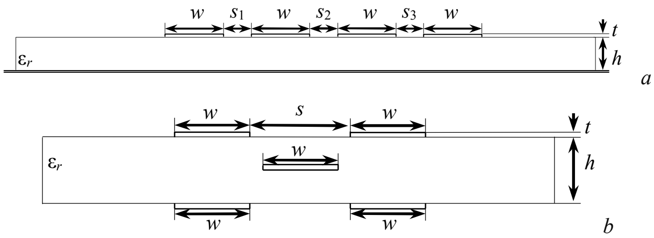


Fig. 1. Cross sections of microstrip (a) and reflection symmetric (b) four-conductor MFs

Research was carried out at the expense of the Russian Federation President grant № MD–365.2018.8

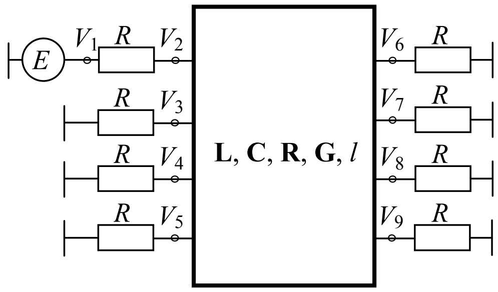


Fig. 2. Schematic diagram of microstrip and reflection symmetric four-conductor MFs

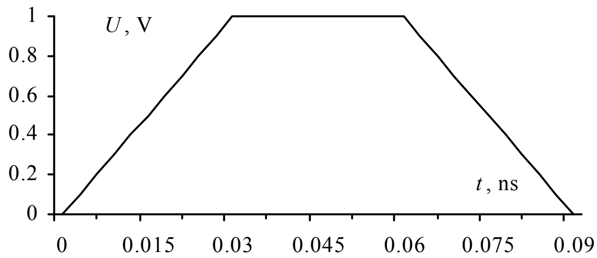


Fig. 3. EMF waveform of pulse excitation

III. Simulation Results

The MFs were simulated with the following parameters: w=1000 µm, t=18 µm, h=500 µm, ε_r=5, s=200, 500, 800 µm. The changing of s was caused by its large effect on the signal characteristics resulted from the change in the conductor coupling.

The frequency responses of the investigated MFs are presented in Fig. 4, and the bandwidth values for the level of 0.707 – in Table I.

TABLE I. Bandwidths (GHz) of Microstrip (MS) and Reflection Symmetric (RS) MFs

s, µm	**MS**	**RS**
200	0.3610	0.1847
500	0.4567	0.1991
800	0.5857	0.2080

It can be seen from Table I that for s=200 µm, the value of bandwidth of a microstrip MF is 1.95 times more than the similar value of reflection symmetric MF, for s=500 µm – 2.9 times and for s=800 µm – 2.8 times.

The simulation results of MFs in the time domain (the amplitudes of each pulse, as well as the values of the time intervals between decomposition pulses) are presented in Table II, and the resulting waveforms at the output of the MF – in Table III.

TABLE II. Parameters of Output Voltage Waveforms for Microstrip (MS) and Reflection Symmetric (RS) MFs

	s, µm					
	200		500		800	
	MS	RS	MS	RS	MS	RS
U_1, V	0.043	0.124	0.051	0.124	0.055	0.125
U_2, V	0.144	0.121	0.156	0.123	0.162	0.124
U_3, V	0.205	0.125	0.197	0.126	0.194	0.125
U_4, V	0.102	0.105	0.093	0.102	0.088	0.098
Δt_1, ns	0.166	0.353	0.158	0.535	0.135	0.719
Δt_2, ns	0.349	0.73	0.286	0.588	0.231	0.476
Δt_3, ns	0.571	0.752	0.432	0.647	0.335	0.495

It follows from Table II that for the microstrip MF for s=200 µm, the maximum voltage at the end of the active conductor is 2.43 times less than half of the EMF (0.5 V), for s=500 µm – 2.53 times and for s=800 µm – 2.57 times.

In the case of the reflection symmetric MF for s=200 µm, the maximum voltage at the end of the active conductor is 4 times less than U=0.5 V, for s=500 µm – 3.96 times and for s=800 µm – 4 times.

It follows from the obtained results, that with an increase of s parameter, the value of the maximum voltage changes insignificantly for both MF structures. However, the reflection symmetric MF is able to decompose the input signal almost twice as good as microstrip MF. This can be explained by the fact that, in a reflection symmetric MF, pairwise equalized decomposition pulses are observed at the output, which minimizes the maximum amplitude while in a microstrip MF, each pulse has a different amplitude. Note that both MFs are close to pseudo-matching for the given parameters [5].

It can also be seen that in a microstrip MF, with the increase of s parameter, the minimum time interval between decomposition pulses decreases. The total duration of decomposition pulses is also reduced (Δt_Σ=1.087 ns, Δt_Σ=0.877 ns, Δt_Σ=0.702 ns for s=200, 500 and 800 µm, respectively). In the reflection symmetric MF, with an increase in s, the total duration also decreases (Δt_Σ=1.835 ns, Δt_Σ=1.771 ns, Δt_Σ=1.692 ns for s=200, 500 and 800 µm, respectively), but it is about twice as big as in the microstrip MF. Also, reflection symmetric MFs are characterized by relatively equal time intervals between decomposition pulses, which helps to prevent possible pulse pile up caused by an increase in the duration of the input pulse excitation.

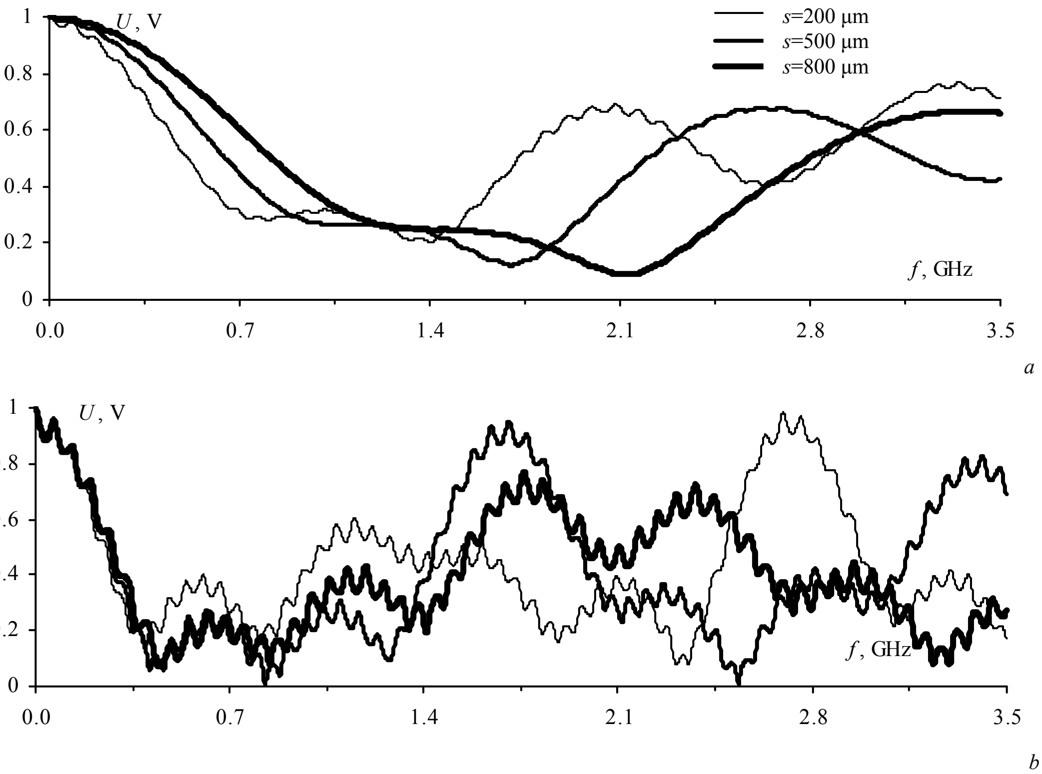
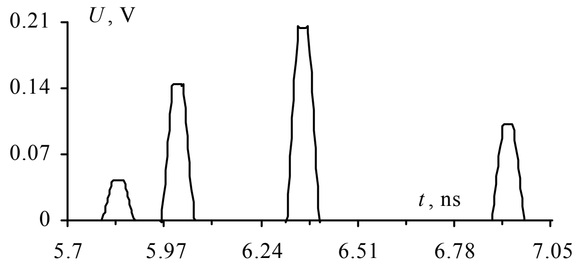
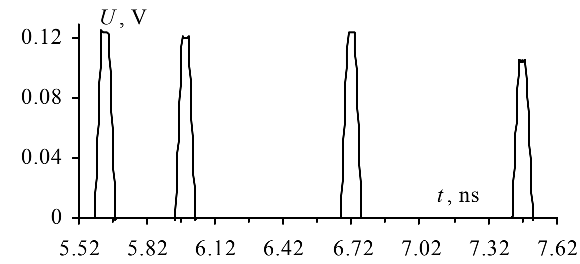
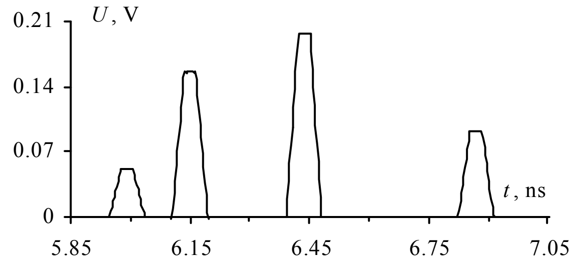
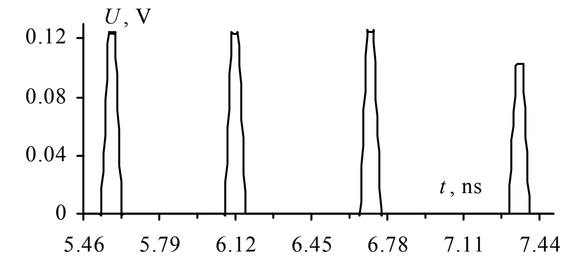
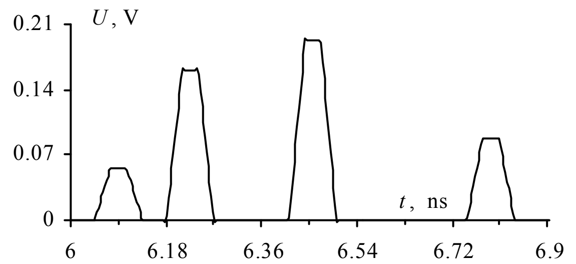
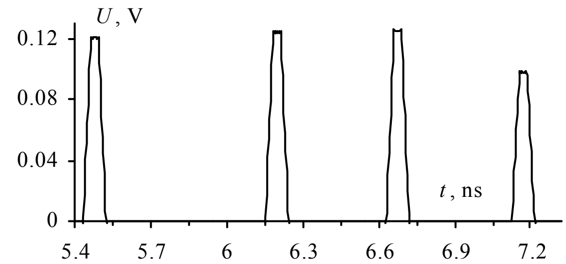


Fig. 4. Frequency responces of microstrip (*a*) and reflection symmetric (*b*) MFs

TABLE III. VOLTAGE WAVEFORMS AT THE OUTPUT OF MICROSTRIP (MS) AND REFLECTION SYMMETRIC (RS) MFS

***s*, μm**	**MS**	**RS**
200		
500		
800		

IV. SUMMARIZED MF COMPARISON RESULTS

The results of a qualitative comparison of microstrip and reflection symmetric MFs by a number of attributes are presented in Table IV. The following are clarifications for each of the points.

TABLE IV. COMPARISON OF A FOUR-CONDUCTORS MICROSTRIP (MS) AND REFLECTION SYMMETRIC (RS) MFS. SIGNS: (+) SUITABLE; (0) MEDIUM SUITABLE; (–) NOT SUITABLE

№	Attribute	MS	RS
1	Input signal attenuation by decomposing a sequence of smaller amplitude pulses	+	+
2	The presence of both broad-side and edge couplings	0	+
3	The ability to align the time intervals between decomposition pulses	0	+
4	The possibility to increase the types of structures and the range of optimized parameters.	+	0
5	Absence of necessity to use additional optimization	0	+
6	High bandwidth	+	0
7	The possibility to increase the input pulse duration.	0	+
8	Simplicity of implementation	+	0

1. Microstrip and reflection symmetric MFs are able to reduce the amplitude of the input signal due to its modal decomposition into four smaller amplitude pulses at the output.
2. The constructive position of the conductors relative to the grounded conductor in the reflection symmetric MFs provides both broad-side and edge couplings.
3. Equalized time intervals between decomposition pulses can be obtained for both structures by optimizing the parameters. However, due to the specific character of the reflection symmetric MF structure, the process of optimization by this criterion is easier.
4. A microstrip MF has both a larger set of parameters for optimization and a range for their optimization, since it is not limited to maintaining symmetry, unlike a reflection symmetric MF.
5. To optimize a reflection symmetric MF, it is sufficient to use a heuristic search [6], whereas when optimizing a microstrip MF, it may be necessary to use other approaches (for example, genetic algorithms) [5].
6. A microstrip MF has a wider bandwidth than a reflection symmetric MF.
7. For s=200, 500 and 800 µm, a reflection symmetric MF is capable to decompose the input signal with a duration of up to 345, 540, 465 ps, respectively, whereas a microstrip – of only up to 165, 150, 135 ps.
8. A distinctive feature of a microstrip MF is the ease of fabrication (single-layer PCB) and low cost, whereas the fabrication of a reflection symmetric MF is laborious and expensive.

V. CONCLUSION

Thus, we performed a comparative analysis of two new devices for protection against USP: a microstrip and a reflection symmetric four-conductor MFs. The comparison revealed a number of advantages and disadvantages of each device by a number of features. The comparison results showed the importance of such work, since it can be used for further research and use of various configurations of protection devices.

In conclusion, we note that some of the features discussed in Table IV are related to each other. For example, the greater the attenuation of the filter, the lower the bandwidth. However, this relation was not considered here.

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