Reflection Symmetric Meander Line Protecting against Ultrashort Pulses

Evgeniya B. Chernikova, Anton O. Belousov
Tomsk State University of Control Systems and Radioelectronics, Tomsk, Russia

Abstract – **The paper considers the protection of radio-electronic equipment by means of devices operating on modal filtration technology. The possibility of modal decomposition of an ultrashort pulse in the reflection symmetric meander line (ML) is analyzed for the first time. It consists of two individual turns, in which the conductors are connected pairwise at one end. The work presents the results of quasistatic simulation of the time response of three schematic diagrams of an ML with the length of 1 m. The results showed the improvement of characteristics in comparison to the reflection symmetric modal filter, namely an increased value of the time intervals between decomposition pulses in the absence of resistors at one end of the line.**

Index Terms – **Protection devices, reflection symmetric meander line, multiconductor transmission line, ultrashort pulse, modal filtration.**

I. INTRODUCTION

THE INCREASING PACE of the use of radio-electronic equipment (REE) and the ever increasing complexity of its creation lead to stiffening the requirements for ensuring electromagnetic compatibility (EMC). An important task of the EMC is to comply with the REE susceptibility requirements. This is associated with high sensitivity of modern equipment to electromagnetic interference. A malfunction of normal operation due to interference effects may cause irreparable damage. It especially relates to equipment whose operation is critical in terms of safety, life support, etc [1].

II. PROBLEM STATEMENT

Electromagnetic interference can be radiated and conducted. Conducted interference is dangerous because it penetrates into the REE directly through the conductors, for example, through signal conductors or through the supply circuit [2]. One of the dangerous types of conducted interference is ultrashort pulses (USPs) [3]. Due to the short duration of the USP, the main energy of the generator is spent on increasing its amplitude [4, 5]. The high amplitude of the interfering pulse leads to the breakdown of semiconductor devices [6] and capacitors in traditional noise-suppressing LC- and RC-filters. Moreover, the operating speed of varistors and gas discharge tubes can significantly exceed the duration of a USP [7]. In addition, when a USP impacts equipment, energy has no time to be distributed among the structural elements. Since the energy is localized at one point, the probability of malfunctions in sensitive areas increases significantly [8].

Due to the fact that the application of modern protection devices is difficult because of a number of factors (parasitic parameters of LC- and RC-filter elements, low radiation resistance of semiconductor components, breakdown at high voltages, insufficient operating speed in gas discharge tubes, high cost, etc), the development of new devices for protection against USP is relevant. Therefore, a modal filtration technology has been proposed, which involves decomposing a USP into a sequence of pulses of lower amplitude in structures with inhomogeneous dielectric filling caused by the difference in mode delays [9]. Devices operating in accordance with this technology are implemented as modal filters (MFs) or meander lines (MLs). Their advantages are simple manufacturing technology (e.g in the form of microstrip lines, where the printed conductors are located on a layer of metal-clad glass textolite), low cost, the absence of semiconductor components and lumped circuit elements (which means high service life), radiation resistance and high voltage operation.

A new approach to increase characteristics of such protection devices through the use of reflection symmetry in the cross section of structures has been considered in [10]. A representative example of such structures is a reflection symmetric MF (Fig. 1).

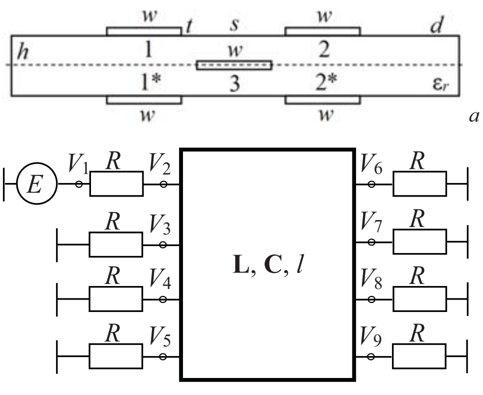

Fig. 1. Cross section (*a*) and schematic diagram (*b*) of the reflection symmetric MF.

MF parameters are *w* (width of the conductors), *s* (separation between them), *t* (thickness of the conductors),

978-1-7281-6846-3/20/$31.00 ©2020 IEEE

Authorized licensed use limited to: Novosibirsk State Technical University. Downloaded on August 08,2020 at 10:15:54 UTC from IEEE Xplore. Restrictions apply.

h (thickness of the dielectric), *d* (distance from the edge to the conductor), ε_r (relative permittivity of the dielectric).

A distinctive feature of the reflection symmetric MF is that it is capable of decomposing a USP into 4 pulses with pairwise equalized voltage and regular intervals between them for certain parameters of the cross section (Fig. 2).

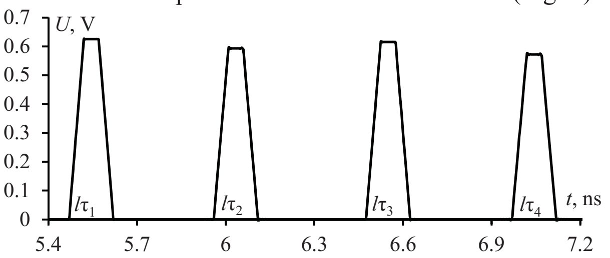

Fig. 2. Voltage waveforms at the output of the reflection symmetric MF.

Meanwhile, when the conductors at one end of the reflection symmetric MF are interconnected with bridges, a reflection symmetric ML is possible to be created. There could be various variants of schematic diagrams. Recently, the diagrams of 2, 3 and 4 cascaded half-turns with resistors at the ends of the remaining conductors have been considered. In such MLs, the signal from the generator to the load passed the path of a length of 2*l*, 3*l*, and 4*l*, respectively [11]. Simulation of the time response of these structures showed the presence of additional pulses in the output signal with delays non-multiple to per-unit-length mode delays, which was not previously observed in the reflection symmetric MF and protective MLs. However, the possibility of decomposing a USP in the reflection symmetric ML of two individual turns, in which the conductors are connected pairwise at one end, has not been previously considered, although this is relevant. The purpose of this work is to carry out such a study.

III. Structure And Schematic Diagram Of Reflection Simmetric ML Under Consideration

At the initial stage of the research into new structures of multiconductor transmission lines (MCTL), a simulation applying a quasi-static approach is preferable to be used. With this type of simulation, only the transverse (T-wave) propagation is assumed. An arbitrary structure diagram is represented as a generalized diagram model, the voltages and currents at any point of which are determined by telegraph equations, to which Maxwell's equations are reduced, for each segment of an MCTL taking into account the boundary conditions at the ends of the segments [12]. The solution of telegraph equations is much simpler and less computational costly, but the accuracy that is ensured with this approach is acceptable, even for solving complex problems [13]. This approach is implemented in the TALGAT software package [14], which will be used to calculate the matrices of per-unit-length coefficients of electrostatic (**C**) and electromagnetic (**L**) induction for segments of the MCTL and to simulate time responses. The matrices of per-unit-length resistances **R** (for losses in conductors) and conductivities **G** (for losses in dielectrics) are taken equal to zero and were not taken into account at this stage of the research.

We considered 3 variants of a reflection symmetric ML consisting of two individual turns. Its cross section with the numbered conductors is shown in Fig. 1*a*. Conductors 1 and 2 are located on one side of the dielectric layer, the third (reference) is located between them in the center, and conductors 1* and 2* are reflection-symmetrical on the reverse side of the dielectric layer, and can be paired together at the end in three ways: on one layer (1-2 and 1*-2*); on different layers (1-1* and 2-2*); diagonally (1-2* and 2-1*). The parameter values are chosen the same as in the reflection symmetric MF (*s*=510 μm, *w*=1600 μm, *t*=18 μm, *h*=500 μm, *d*=1600 μm, ε_r=4.5).

Fig. 3 shows the schematic diagrams of the ML under research. The ML consists of four (except for the reference) conductors of length *l* equal to 1 m, two on each side of the dielectric layer, pairwise interconnected at the far end by bridges with three methods of connection. The first conductor of the turn is connected at one end to a USP source, represented on the diagram by an ideal EMF source *E* with an amplitude of 5 V, durations of rise, fall and flat top of 50 ps each and internal resistance R_1. At the other end, the second conductor of the same turn is connected to a protected circuit represented by the equivalent resistance R_2. Resistors *R* are connected to reference conductor at the beginning and end of the passive turn. The values of all resistances are taken equal to 50 Ω.

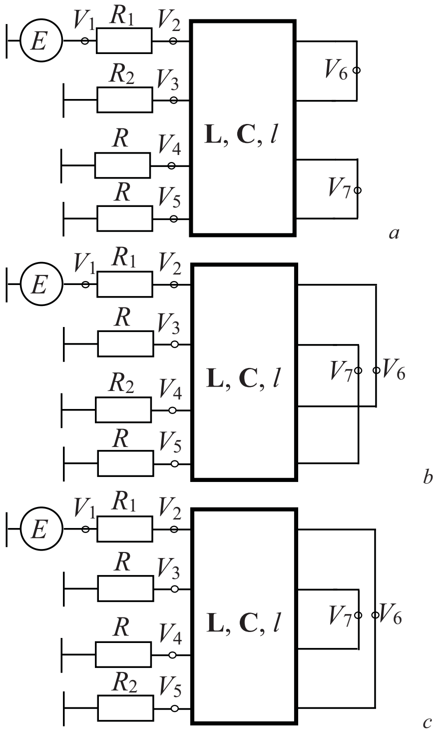

Fig. 3. Schematic diagrams: 1 (*a*), 2 (*b*) and 3 (*c*).

Authorized licensed use limited to: Novosibirsk State Technical University. Downloaded on August 08,2020 at 10:15:54 UTC from IEEE Xplore. Restrictions apply.

IV. Simulation Results

Fig. 4 shows the waveforms of the output voltage for three diagrams of the reflection symmetric ML. The amplitudes of pulses, their delays and time intervals between them are summarized in Table I.

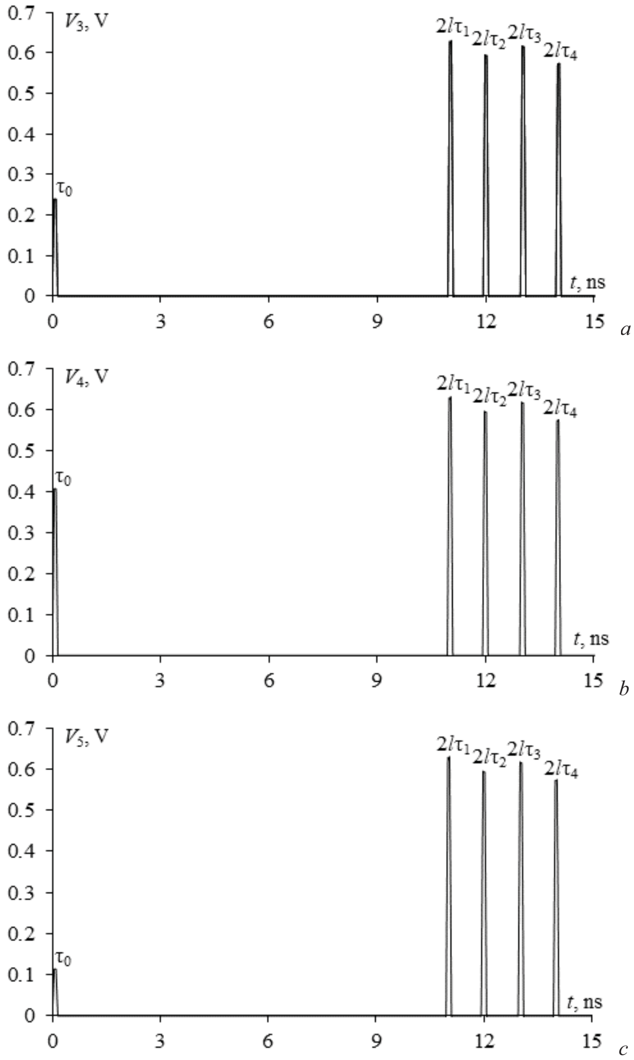

Fig. 4. Voltage waveforms at the output of diagrams: 1 (*a*), 2 (*b*) and 3 (*c*).

TABLE I
Pulse Characteristics For Diagrams 1–3

Parameter	Diagram 1	Diagram 2	Diagram 3
U_0, V	0.239	0.406	0.114
U_1, V	0.630	0.630	0.630
U_2, V	0.595	0.595	0.595
U_3, V	0.617	0.617	0.617
U_4, V	0.572	0.572	0.572
$2l\tau_1$, ns	10.951	10.951	10.951
$2l\tau_2$, ns	11.929	11.929	11.929
$2l\tau_3$, ns	12.959	12.959	12.959
$2l\tau_4$, ns	13.940	13.940	13.940
Δt_1, ns	0.977	0.977	0.977
Δt_2, ns	1.030	1.030	1.030
Δt_3, ns	0.981	0.981	0.981

The USP decomposes into 4 pulses with delays of $2l\tau_1$, $2l\tau_2$, $2l\tau_3$, $2l\tau_4$, which twice propagates along the ML from its input to output (Fig.4). The pulse with a zero delay is crosstalk at the near end of the line.

V. Discussion Of Results

From the analysis of the simulation results of the reflection symmetric ML of two individual turns it follows that this line can decompose a USP, similarly to the reflection symmetric ML, into a sequence of pulses with pairwise equalized voltage amplitudes of the pulses (U_1 and U_3; U_2 and U_4). The maximum amplitude at the output of the line is determined by the pulse U_1 and is equal to 0.63 V, which is slightly higher than the maximum output voltage obtained by simulating the reflection symmetric MF (0.625 V) [10]. The attenuation of the USP in devices is comparable and equals about 4 times, in relation to half the EMF.

In addition, in the reflection symmetric ML (as in the reflection symmetric MF), we observed close values of time intervals between decomposition pulses. However, their values are twice as large as reflection symmetric MF, which allows for the decomposition of a USP of 2 times longer.

The parameters of the cross section and the length of the ML provide condition

$$\min|\Delta\tau_i|2l \geq t_r + t_d + t_f \quad (1)$$

where $\min|\Delta\tau_i|$ is the minimum absolute value of the difference in the per-unit-length mode delays of the ML; i=1, 2, 3, and t_r, t_d, t_f are the durations of the rise, flat top and fall, respectively.

The fulfillment of condition (1) ensures that the initial pulse is decomposed into mode pulses. The value of the difference in the pulse delays is about 1 ns, therefore, the complete decomposition of an USP of duration t_Σ in a segment of this transmission line of length l is possible when

$$t_\Sigma / l < 1 \text{ ns/m}. \quad (2)$$

Authorized licensed use limited to: Novosibirsk State Technical University. Downloaded on August 08,2020 at 10:15:54 UTC from IEEE Xplore. Restrictions apply.

Considering conditions (1) and (2), with the indicated values of the ML parameters, the maximum duration of the input pulse signal t_{Σ} with l=1 m is about 1 ns.

VI. CONCLUSION

Thus, the paper shows the possibility of modal decomposition of a USP in three variants of the reflection symmetric ML of two individual turns, in which the conductors are interconnected pairwise at one end. It is important to note that such an ML requires only 2 resistors, while a similar MF – 6. The results showed the improvement of characteristics in comparison to the reflection symmetric MF, namely, doubled time intervals between decomposition pulses. It is noteworthy that such a structure can also be used with modal reservation [15], i.e. when one turn refers to the reserved circuit, and the other to the reserving circuit.

In the future, a prototype is planned to design and an experimental research into the possibility of USP decomposition in such structures of reflection symmetric MLs will be conducted. Note that the experimental implementation of the reflection symmetric MF, which showed the comparability of measurement and simulation results, is presented in [16].

ACKNOWLEDGMENT

The reported study was funded by Russian Science Foundation (project №19-19-00424).

REFERENCES

[1] V.M. Loborev, "The modern research problems. Plenary lecture," Proc. of AMEREM Conference, Albuquerque, 1996, pp. 121–127.
[2] Z.M. Gizatullin, R.M. Gizatullin, "Investigation of the immunity of computer equipment to the power-line electromagnetic interference," Journal of Communications Technology and Electronics, no. 5, pp. 546–550, 2016.
[3] N. Mora, F. Vega, G. Lugrin, F. Rachidi, M. Rubinstein, "Study and classification of potential IEMI sources," System and assessment notes, Note 41, 8 July 2014.
[4] R. Gaynutdinov, S. Chermoshentsev, "Immunity research of the electronic systems elements at the influence of intentional ultrashort electromagnetic pulses," 17th international conference on micro/nanotechnologies and electron devices EDM 2016, pp. 214–218.
[5] C. Mojert, "UWB and EMP susceptiblity of microprocessors and networks," Proc. of the 14th Int. Zurich Symp. on EMC, Zurich, Switzerland, February 20–22, 2001, pp. 47–52.
[6] H. Rong, Z. Mohammadi, Y.K. Sharma, F. Li, M.R. Jennings, P.A. Mawby, "Study of breakdown characteristics of 4H-SiC Schottky diode with improved 2-step mesa junction termination extension," 16th European Conference on Power Electronics and Applications, 2014, pp. 10.
[7] S. Brown, "High-Frequency Gas-Discharge Breakdown. Proceedings of the IRE," 1951, vol. 39, no. 12, pp. 1493–1501.
[8] A.B. Egorov, A.M. Sotnikov, I.F. Rybalko, "Vozdejstvie moshchnogo elektromagnitnogo izlucheniya na radioelektronnye sredstva," Sbornik nauchnyh trudov DonIZHT, 2012, no. 29, pp. 49-54 (In Russian).
[9] A.T. Gazizov, A.M. Zabolotsky, T.R. Gazizov, "UWB pulse decomposition in simple printed structures," IEEE Transactions on Electromagnetic Compatibility, vol. 58, no. 4, pp. 1136–1142, 2016.
[10] E.B. Chernikova, A.O. Belousov, T.R. Gazizov, A.M. Zabolotsky, "Using reflection symmetry to improve the protection of radio-electronic equipment from ultrashort pulses," Symmetry, 2019, vol. 11(7), no. 883, pp. 1–25.
[11] E.B. Chernikova, A.O. Belousov, "Method for detecting additional pulses in the time response of structures with modal decomposition," 2019 International Multi-Conference on Engineering, Computer and Information Sciences (SIBIRCON), Russia, Tomsk, Oct. 23–24, 2019, pp. 0245–0249.
[12] J.D. Jackson, "Classical electrodynamics," New York: John Wiley & Sons, 1962, pp. 641.
[13] P.E. Orlov, E.N. Buichkin, "Quasistatic and electromagnetic simulation of interconnects of printed circuit boards with modal reservation," 18th International Conference of Young Specialists on Micro/Nanotechnologies and Electron Devices, Erlagol, Altai, June 29–July 3, 2017, pp. 54–58.
[14] S.P. Kuksenko, "Preliminary results of TUSUR University project for design of spacecraft power distribution network: EMC simulation," IOP Conf. Series: Materials Science and Engineering, 2019, vol. 560, no. 012110, pp. 1–7.
[15] V.R. Sharafutdinov, T.R. Gazizov, "Analysis of reservation methods based on modal filtration," Systems of Control, Communication and Security, 2019, no. 3, pp. 117-144 (In Russian).
[16] Y.S. Zhechev, E.B. Chernikova, A.O. Belousov, T.R. Gazizov, "Experimental research of a reflection symmetric modal filter in the time and frequency domains," Systems of Control, Communication and Security, 2019, no. 2, pp. 162-179 (In Russian).

Evgeniya B. Chernikova was born in 1996. She received a Master's degree of TUSUR in 2019. Currently, she is a first year postgraduate student and is working as an engineer at TUSUR. She has over 3 years of experience working with electromagnetic compatibility issues and designing USP protection devices. Her research interests are electromagnetic compatibility, protection devices based on modal filtration, and, in particular, the research into reflection symmetric structures. She is the author of 24 scientific papers.

E-mail: chiernikova96@mail.ru

Anton O. Belousov was born in 1994. He received a B.Sc. degree of TUSUR in 2015 and a Master's degree in 2017. Currently, he is a third year postgraduate student and is working as a Junior Researcher at TUSUR. He is the author of 56 scientific papers.

E-mail: ant1lafleur@gmail.com

Authorized licensed use limited to: Novosibirsk State Technical University. Downloaded on August 08,2020 at 10:15:54 UTC from IEEE Xplore. Restrictions apply.