Modal Filter for Spacecraft Busbar Protection Against Ultrashort Pulses

Roman Khazhibekov, Alexander Zabolotsky, *Member, IEEE*
Tomsk State University of Control Systems and Radioelectronics, Tomsk, Russia

Abstract **– Protection of onboard equipment of a spacecraft against electromagnetic interference is an actual problem. One of the most dangerous effects is an interfering ultrashort pulse. The use of known devices for protection against conducted interference is hampered by a number of conflicting requirements, for example, protection of as many circuits as possible, small mass of a protective device, and the ability to function effectively for 15 years in space conditions. The protection of equipment against the ultrashort pulse, based on modal filtering is proposed. The paper presents the results of the development of a modal filter prototype with a broad-side coupling. When choosing a structure, such parameters as the maximum bus current, insulation breakdown voltage, wave impedance of the line and the duration of the interfering ultrashort pulse were taken into account. To substantiate the choice of structure, quasi-static and electrodynamic simulations were performed. The simulation results showed that the modal filter effectively attenuate the 0.45-ns ultrashort pulse by 7 times. A modal filter prototype without resistors has been implemented, which showed a greater level of attenuation of the ultrashort pulse than the resistive construction.**

Index Terms **– Modal filter, ultrashort pulse, protection device, DC busbar, spacecraft.**

I. INTRODUCTION

BUSBARS ARE USED to transmit electrical current in various types of electrical and electronic equipment. They are installed where high current is used, for which other conductive methods, such as the use of multilayer printed circuit boards (PCB) or wires, are not suitable due to the conductors heating [1–3].

One of the objectives of the project "Theoretical and experimental studies on the synthesis of an optimal high-voltage power supply network for spacecraft", conducted in accordance with the contract FTP-2017-TUSUR-2 dated 09/26/2017, is the development of a prototype of the device for the spacecraft busbar protection against ultrashort pulse (USP).

The dangers of USP are extensively researched [4, 5]. However, increasing the lifetime of the spacecraft to 15 years, leading to the degradation of the properties of the used materials, and also difficult to predict changes in the properties of new materials used in prospective spacecraft, can create conditions for increasing the dangerous effects. The use of known protective devices to solve this problem is hampered by a number of conflicting requirements, for example, the protection of as many circuits as possible, the small mass of the protective device, the ability to function effectively for 15 years in space. Therefore, the creation of new elements and protection devices against USP is very important. Protection against USP, based on modal filtering is proposed [6 – 8]. The physical principle of such protection is based on the effect of the decomposition of an interfering pulse in a segment of a coupled line into modes, each of which propagates with its own delay.

In [9], it was shown that an asymmetric modal filter (MF) with a broad-side coupling has an amplitude of decomposition pulses less than for structures with an edge coupling. In addition, the difference of mode per unit lenght delays in this structure is about 3 ns/m, while in structures with an edge coupling it does not exceed 1 ns/m. Therefore, the use of MF with broad-side coupling is appropriate, and the purpose of the work is to develop the prototype of MF with a broad-side coupling to protect the spacecraft busbar against the USP.

II. CHOOSING AND SUBSTANTIATION OF THE MODAL FILTER STRUCTURE

When developing the MF for busbar protection against USP, the following requirements were taken into account: the maximum current is 10 A, the maximum allowable voltage is 600 V, the wave impedance of line is 50 Ω, the duration of the interference USP is 0.45 ns. According to these requirements, and IPC-2221B [10] the minimum width of the conductor is calculated. In the inner layer (when PCB is covered by compound) it is 2.589 mm. Under specified conditions, the allowable distance between the conductors is 2 mm (according to GOST R 55490-2013 and GOST 23751-86) [11, 12]. As the material of the dielectric we used fiberglass. According to GOST 12652-74, the guaranteed value of breakdown voltage for 1 mm thick fiberglass is 28 kV [13]. The relative dielectric constant of fiberglass is 5, and the loss tangent is 0.035 at a frequency of 1 MHz.

In accordance with the requirements described, the structure of the MF with a broad-side coupling has been developed. In the TALGAT program, optimal value of geometrical parameters were found, for which the geometric mean of wave impedance of even and odd modes is 49.84 Ω: w=5.5 mm, s=2 mm, t=0.105 mm, h=0.79 mm. The cross-section of structure is shown in Fig. 1, and the connection scheme in Fig. 2.

978-1-7281-1753-9/19/$31.00 ©2019 IEEE

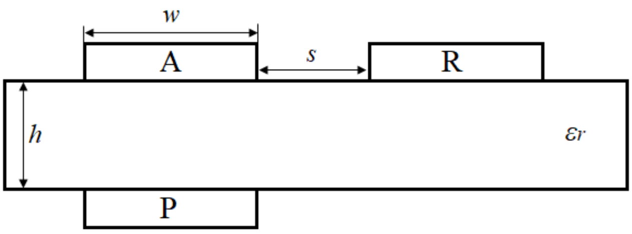


Fig. 1. Cross-section of the MF with a broad-side coupling for the protection of spacecraft busbar, where the conductors: A is active, P is passive, and R is the reference.

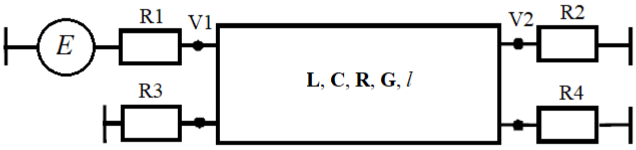


Fig. 2. Connection scheme of the MF.

Using quasi-static analysis, the voltage waveforms at the input and output of the MF with a length of 1 m were calculated under the influence of the USP with a rise, hold and a fall times of 0.15 ns and an EMF amplitude of 1 kV. The simulation results with the matched passive conductor (R3=R4=50 Ω) are shown in Fig. 3. From the diagram it can be seen that the amplitude of the USP has reduced from 0.5 kV to 0.12 kV or 4.17 times. In this case, the difference in delays of the MF modes is 2.8 ns.

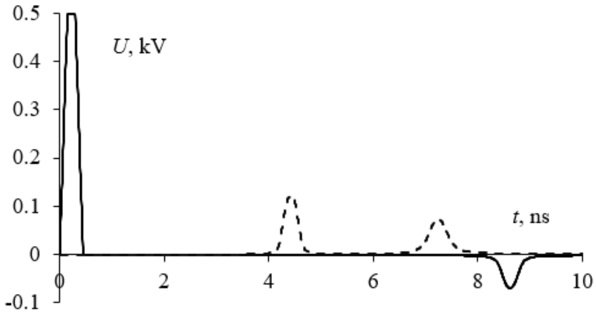


Fig. 3. Voltage waveforms at the input (——) and output (- - -) of the MF under the influence of the USP with EMF amplitude of 1 kV.

III. Development of the Modal Filter Layout

Based on the simulation results and requirements, the construction of the MF layout is proposed. To reduce the size of the PCB, the conductors are made in the form of half-turns. The length of the conductors of the layout is 0.276 m and the size of the PCB is 105×45 mm. A top and a bottom views of the MF layout are shown in Fig. 4.

Initially, the simulation was performed in the TALGAT system without taking into account the effect of half-turns (the conductors were supposed to be straight). Voltage waveforms at the input and output of the MF were calculated under the excitation of the USP. Resistances at the ends of the active conductor were assumed to be 50 Ω.

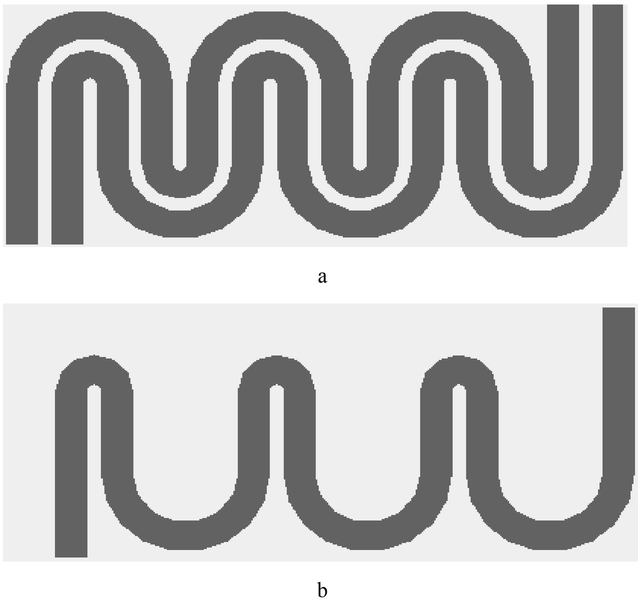


Fig. 4. Top (*a*), and bottom (*b*) views of the MF layout.

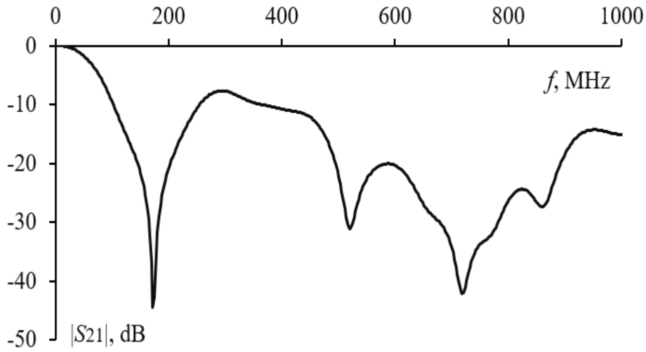
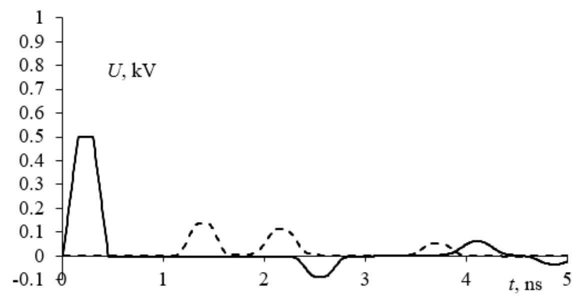
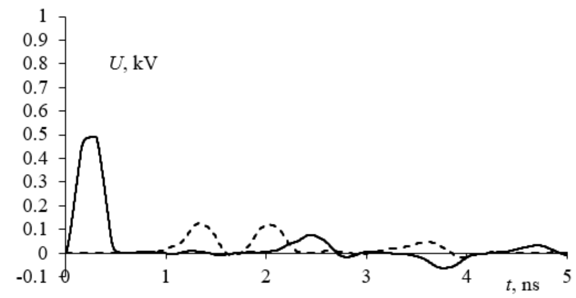
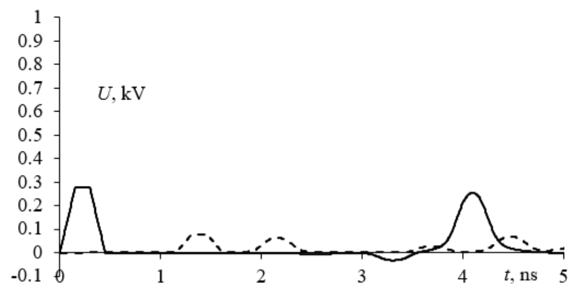
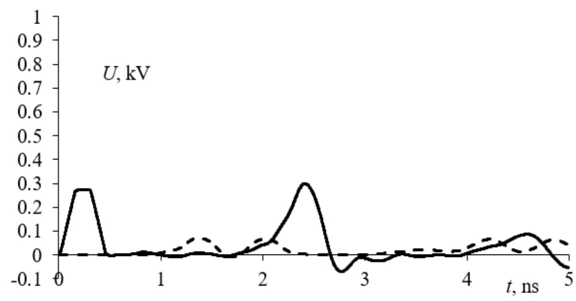
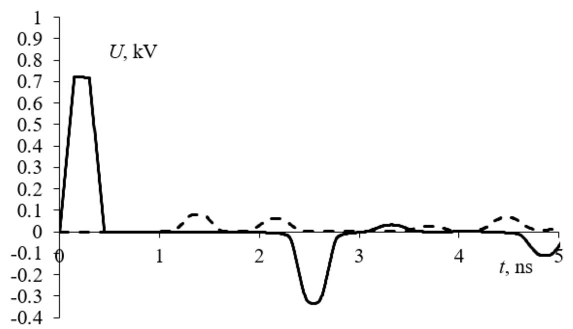
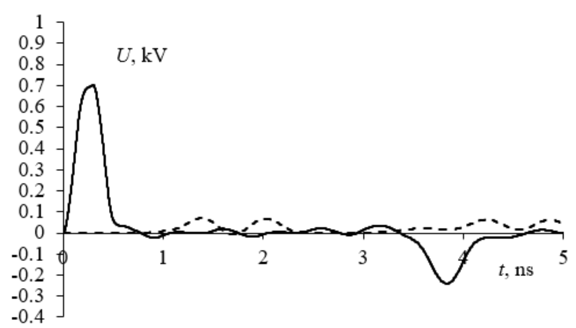


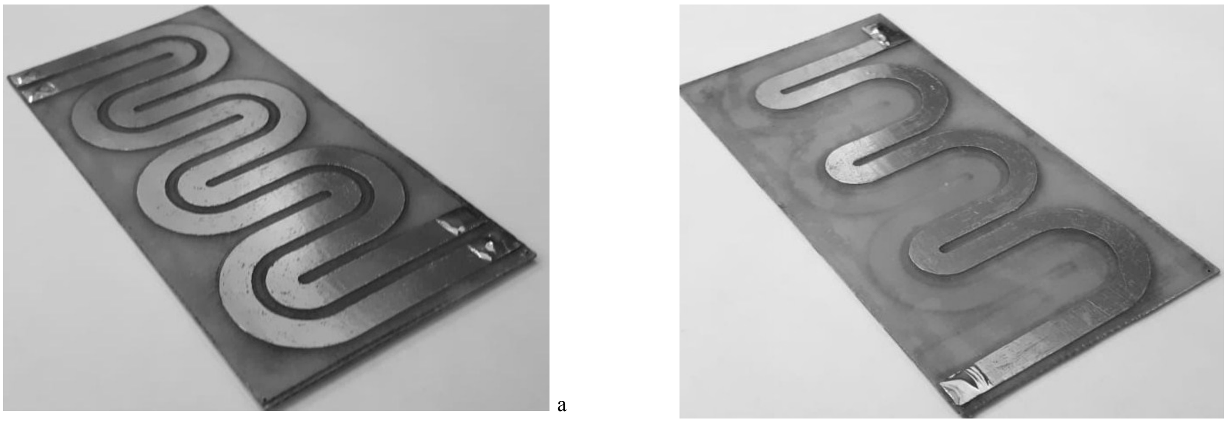
Fig. 5. The $|S_{21}|$ frequency dependences (coinside) of the MF when the passive conductor is in SC-OC and OC-SC modes.

The passive conductor of MF was considered on in three different modes: 50 Ω at both ends, short circuit (SC)-open circuit (OC) and OC-SC. The simulation results are shown in Table. From the diagrams, the attenuation of the USP amplitude at the MF output was determined as 0.5*E*/V2. When the passive conductor was matched, the attenuation was 3.65. When SC-OC and OC-SC modes were used, the attenuation was equal to 6.41. The results of electrodynamic simulation of the same structure, taking into account the effect of the turns (forms of conductors as in Fig. 4), also are shown in table. The matched mode of the passive conductor, attenuation 4 was obtained, and in the SC-OC and OC-SC modes – 7.14.

The $|S_{21}|$ frequency dependences of the MF with SC-OC and OC-SC modes of the passive conductor were calculated (Fig. 5). These dependencies are identical. The graph shows that the MF bandwidth is 63 MHz, and the first resonance frequency is 172 MHz.

TABLE
VOLTAGE WAVEFORMS AT THE INPUT (V1) (—) AND OUTPUT (V2) (- - -) OF THE MF WITH FOR DIFFERENT MODES OF THE PASSIVE CONDUCTOR

<table>
<tr><th>Mode</th><th>Quasi-static analysis</th><th>Electrodynamic analysis</th></tr>
<tr><td>Matched</td><td>
</td><td>
</td></tr>
<tr><td>SC-OC</td><td>
</td><td>
</td></tr>
<tr><td>OC-SC</td><td>
</td><td>
</td></tr>
</table>



a b

Fig. 6. The prototype of the MF PCB: top (*a*), and bottom(*b*) views.

IV. CONCLUSION

Thus, a MF prototype for the spacecraft busbar protection against USP was developed. The device has a small weight (7 g) and small dimensions (105×45×1 mm) to be compactly placed along spacecraft busbar. In addition, the MF is implemented without components, which allows for a required service life. The simulation results showed that the MF effectively attenuate the USP with the attenuation of 0.45 ns. So, the quasi-static analysis showed that the MF attenuate the USP by 6.41 times, and electrodynamic by 7.14 times. From the $|S_{21}|$ frequency dependences it can be seen that the cutoff frequency of the MF is 63 MHz. The prototype of the PCB is implemented. Further experimental studies are planned.

ACKNOWLEDGMENT

This work was supported by the Ministry of Education and Science of the Russian Federation on the project RFMEFI57417 X0172.

REFERENCES

[1] J. Roudet, J.-L. Schanen, A. Foutane, “Influence of the cabling geometry on paralleled diodes in a high power rectifier,” IEEE Conf. Record of the Industry Applications Conference, San Diego, CA, USA, 6-10 Oct.1996, Vol. 2, P.993–998.

[2] R.C. Jodoin, “Using busbars for efficient power distribution,” Electron. Packaging Prod., 33 (2), 46-47, 1993.

[3] F. D. Jones, P. B. Schubert (eds.), “Engineering Encyclopedia. 3rd ed.,” New York, Industrial Press, 1963.

[4] N Mora, F. Vega, G. Lugrin, F. Rachidi, M. Rubinstein, “Study and classification of potential IEMI sources,” System and assessment notes, 2014, Note 41.

[5] Testing and measurement techniques - Measurement methods for high-power transient parameters, IEC 61000-4-33, Electromagnetic compatibility (EMC), Part 4-33, 2005.

[6] A.M. Zabolotsky, A.T. Gazizov, “New approach to the power network protection against ultrawide band pulses,” 2014 International Conference on Energy, Environment and Material Science (EEMAS 14), Russia, Saint Petersburg, State Politechnical University, 2014, P. 104-107.

[7] T.R. Gazizov, I.E. Samotin, I.E. Zabolotsky, A.O. Melkozerov, “Design of printed modal filters for computer network protection,” 2010 30th international conference on lightning protection (iclp), 2010, p. 1-3.

[8] A.O. Belousov. “Multi-conductor microstrip line as a modal filter for protection against ultrashort pulses,” *Doklady TUSUR,* 2015, no 3(37), P. 124–128 (In Russian).

[9] I.E. Samotin. (2011). Protection devices for computers and control systems by modal decomposition of interference pulses in cable and strip structures (PhD thesis, TUSUR, Tomsk, Russia), 199 p.

[10] IPC-2221B, Generic standard on printed board design, developed by IPC-2221 Task Group (D-31b) of the Rigid Printed Board Committee (D-30) of IPC, 2012.

[11] GOST R 55490-2013, Printed boards. General technical requirements for the construction and acceptance, 2014, 24 p.

[12] GOST 23751-86, Printed circuit boards. Basic parameters of structure, 1986, 7 p.

[13] GOST 12652-74, Electrotechnical glass-cloth-base laminate. Specifications, 2008, 14 p.

Roman Khazhibekov was born in Almaty region of Kazakhstan in 1994. He was received the master’s degree in TUSUR university in 2018.

Currently, R. Khazhibekov is an engineer of the laboratory "Safety and electromagnetic compatibility of radioelectronic means" and graduate student of the TUSUR university. The main occupation is the development of protection devices against ultrashort pulses. R. Khazhibekov is the author of 18 scientific papers.

E-mail: r300994@mail.ru

Alexander Zabolotsky was born in Kemerovo region of Russia in 1982. He was received an engineering degree in 2004, the Ph.D. degree in 2010 and doctor degree in 2017

Currently, he is head of the laboratory "Safety and electromagnetic compatibility of radioelectronic means" and TUSUR university professor. A.M. Zabolotsky is the author of 190 scientific papers.

E-mail: zabolotsky_am@mail.ru