A Device for an Ultrashort Pulse Attenuation in Common and Differential Modes in the High Voltage Power Supply Circuits of the Spacecraft

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Abstract **– The protection of the on-board electronic equipment components of the spacecraft against electromagnetic interference is an actual problem. One of the most dangerous effects is an interfering ultrashort pulse. Therefore, it is necessary to search for new solutions to reduce the dangerous effects of ultrashort pulse propagating in spacecraft power systems on the on-board radioelectronic equipment. In this article, protection of the equipment against an ultrashort pulse based on modal filtering is proposed. The paper presents the results of the development of a device for the decomposition of the ultrashort pulse in high-voltage power circuits of a spacecraft. The device is based on modal filters with broadside coupling and provides an attenuation of the ultrashort pulse with a duration of 0.3 ns by 24.7 times in common mode and 12.3 times in differential mode.**

Index Terms **– Ultrashort pulse, coupled line, busbar, spacecraft.**

I. INTRODUCTION

IT IS KNOWN THAT, TO TRANSMIT OF ELECTRIC current in spacecraft, power busbars are used [1, 2]. With busbar, the power supply of all on-board radioelectronic equipment (REE) of the spacecraft is provided. Therefore, the conductive interferences propagating in the busbar can penetrate into the REE. One of the most dangerous types of interference is an ultrashort pulse (USP) [3]. A feature of this pulse is that it has a wide frequency spectrum. In this regard, the USP can pass through inductors due to the presence of a parasitic electric capacitance at high frequencies [4]. In addition, due to the high amplitude of the pulse, an electrical breakdown of semiconductor devices occurs [5]. The above factors lead to the fact that the USP can penetrate into the REE, passing through interference suppressing devices and DC-DC converters installed in the power supply systems of the spacecraft. Therefore, it is necessary to search for new solutions to reduce the dangerous effects of USP propagating in spacecraft power systems on the onboard REE. Proposed protection against USP based on modal filtering [6, 7]. The physical principle of such protection is based on the effect of interference pulse decomposition in a segment of a coupled line into modes, each of which propagates with its own delay. And the connected lines in which the interference pulse is decomposed are called modal filters (MF).

When working in spacecraft power systems, the device should not only attenuate the amplitude of the USP, but also have a high direct current throughput. In addition, it is necessary for the MF to function in both common and differential excitation modes. In this work, a device for ultrashort pulse attenuation is proposed for which works common and differential modes in the spacecraft high-voltage power supply circuits and the aim of the work is to study the characteristics of this device.

During the operation of the busbar, the device for USP decomposition is supposed to be placed in a special aluminum case together with an interference suppressing *LC* filter. The appearance of the busbar with the case installed on it is shown in Fig. 1 [8].

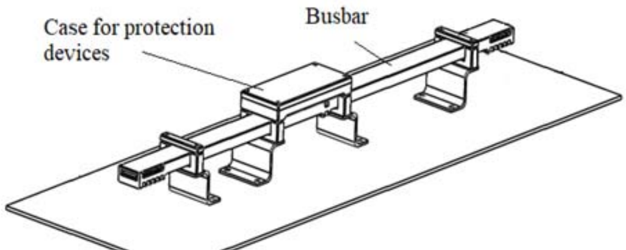

Fig. 1. Isometric view of the busbar installed on a panel (without wire bends).

An important factor in the design is the weight and size characteristics of the protection device in the case. In [9], it was shown that an asymmetric MF with broadside coupling has lower amplitude of decomposition pulses and larger difference in mode delays than a MF with edge coupling. Therefore, to reduce the mass-dimensional characteristics of the device, such construction was chosen. In [10], a MF with broadside coupling was proposed to protect the spacecraft equipment from USP. The justified selection of the MF construction is made. The proposed construction is capable of transmitting direct current up to 16 A [11-13]. At the same time, it provides a small value of the geometric mean characteristic impedance for the even and odd modes

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($(Z_eZ_o)^{1/2}$=19,4 Ω), large value of the coupling coefficient (k=0,97) and per-unit-length difference of the mode delays (Δτ=3,7 ns/m). However, this design does not provide protection against USP in two excitation modes.

II. Measurement Of Characteristics Of The Device In Common And Differential Modes

In order to provide protection as in two excitation modes against USP, it is not enough to use one MF printed circuit board. A layout of a device for USP decomposition in common and differential excitation modes was developed. The layout consists of two MFs with broadside coupling of 75 mm in length on substrates of fiberglass (Fig. 2). The values of the geometric parameters are as follows: w=17 mm, s=2 mm, t=0.105 mm, h_1=0.79 mm, d=2 mm. With these geometric parameters, the capacitance between the conductors is quite large. This is confirmed by the matrix of per-unit-length coefficients of electrostatic induction:

$$\mathbf{C} = \begin{bmatrix} 995.9 & -976.8 \\ -976.8 & 995.6 \end{bmatrix}, \text{ pF/m.}$$

The large capacitive component favorably affects the suppression of USP. Another advantage is the relatively low inductance. This is confirmed by the matrix of per-unit-length coefficients of electromagnetic induction:

$$\mathbf{L} = \begin{bmatrix} 434.5 & 408.7 \\ 408.7 & 436.3 \end{bmatrix}, \text{ nH/m.}$$

From the above matrices it can be seen that $C_{12} \approx C_{21}$ and $L_{12} \approx L_{21}$. Thus, the asymmetry is very small, which gives advantages for the analysis and practical application of such structure.

During the experiment, one MF was located above the other at a distance of h_2. 2 cases were considered: h_2=10 mm and h_2=20 mm. The reference conductors of the first and second MF are interconnected at the beginning and at the end. The switching schemes of the device in common and differential modes are shown in Fig. 3. The resistance at the output of the oscillator R_1 is equal to the resistance at the input of the oscilloscope R_2 and is 50 Ω. The passive conductor was switched on in the short circuit mode with the reference conductor at the beginning and open circuit at the end (SC-OC). Using the SC-OC mode on a passive conductor allows achieving a greater attenuation of the USP due to reflections. The photo of the device is shown in Fig. 4. Fig. 5 shows the appearance of one MF, and Fig. 6 – three-dimensional model of the arrangement of two MFs.

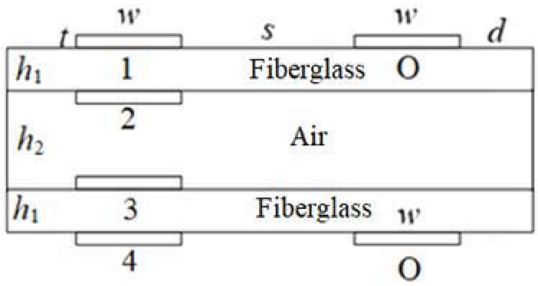

Fig. 2. Cross section of the device for the USP decomposition in common and differential excitation modes.

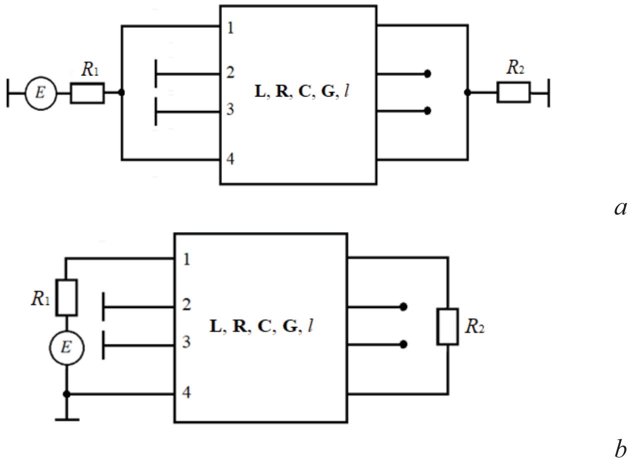

Fig. 3. Switching schemes of the device in common (*a*) and differential (*b*) modes.

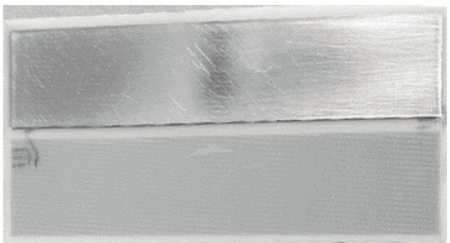

Fig. 4. Photo of one MF.

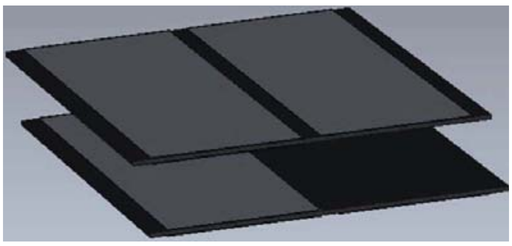

Fig. 5. Three-dimensional model of the arrangement of two MFs.

Using a S9-11 oscilloscope, the voltage waveforms at the device output were measured under the influence of an USP with amplitude of 0.74 V and duration of 0.3 ns at a level of 0.5. The obtained voltage waveforms at h_2=10 mm are shown in Fig. 8, and with h_2 =20 mm – in Fig. 9. The figures showed that in common mode the amplitude of the USP at the output of the device does not exceed 0.03 V (attenuation by 24.7 times) with h_2=10 mm and h_2 = 20 mm. The distance between the MFs affects insignificantly the voltage waveforms. In the differential mode, when the distance between the MFs changes, the differences in the voltage forms are larger than in the common mode. However, the output voltage amplitude at h_2=10 mm and h_2=20 mm does not exceed 0.06 V (attenuation by 12.3 times).

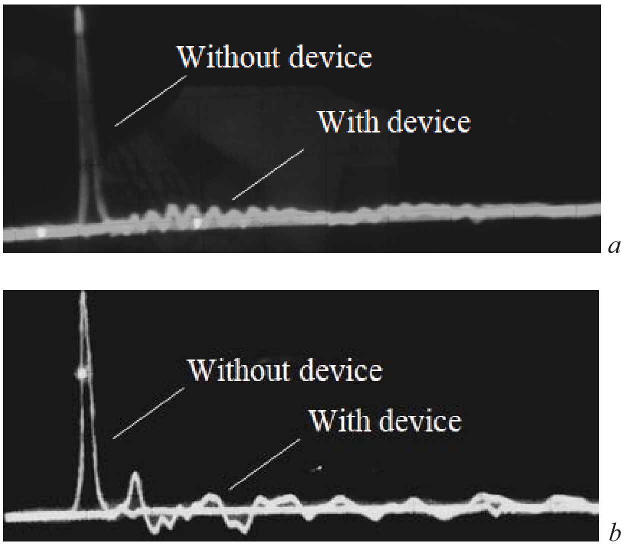

Fig. 6. Voltage waveforms at the output of the device for USP decomposition in common (*a*) and diferential (*b*) excitation modes at *h*2=10 mm.

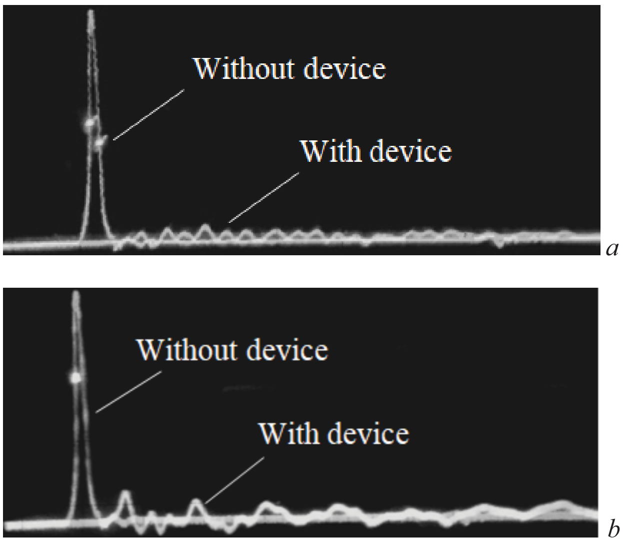

Fig. 7. Voltage waveforms at the output of the device for USP decomposition in common (*a*) and diferential (*b*) excitation modes at *h*2=20 mm

Using the R4M-18, the frequency dependencies of $|S_{21}|$ was measured (Fig. 8). The graphs show that in common mode the bandwidth is 27 MHz when h_2=10 mm и h_2=20 mm. The maximum attenuation (observed at 380 MHz) is 17 dB at h_2=10 mm and 23 dB at h_2=20 mm. At frequencies from 200 MHz to 1500 MHz with h_2=20 mm, more attenuation is observed than when h_2=10 mm. The bandwidth in differential mode is 27 MHz with h_2=10 mm and h_2=20 mm. In this case, the maximum attenuation (about 60 dB) is observed at frequencies of about 250, 1500 and 2000 MHz with h_2=10 mm and h_2=20 mm.

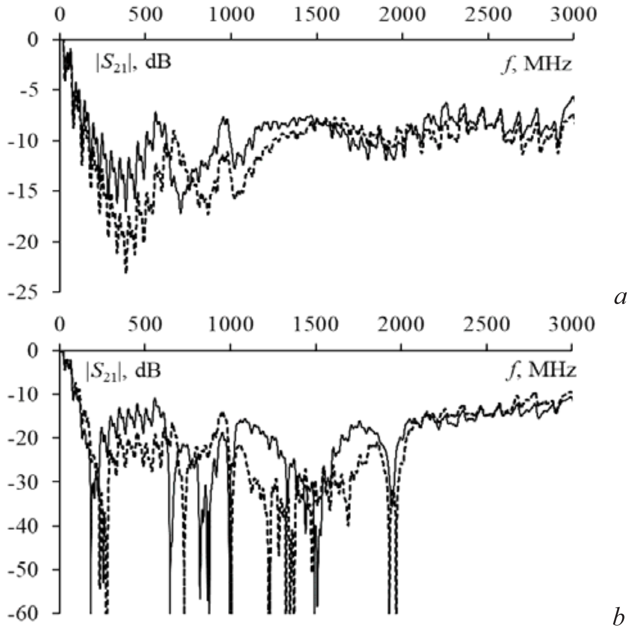

Fig. 8. Frequency dependences $|S_{21}|$ for USP decomposition device in common (*a*) and diferential (*b*) excitation modes when h_2=10 (—), 20 (- -) mm.

III. Conclusion

The results of the development of a device for USP decomposing in high-voltage power supply circuits of the spacecraft are presented. The device uses the modal filtering phenomenon and is based on two MFs with broadside coupling. With this design, the device has a low weight and a long service life, which is important for spacecraft. Measurements showed that in common mode the amplitude of the USP at the output of the device is attenuated by 24.7 times, and in differential – by 12.3 times.

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