IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Development of modal filter prototype for spacecraft busbar protection against ultrashort pulses

To cite this article: R R Khazhibekov *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **560** 012145

View the article online for updates and enhancements.

IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

This content was downloaded from IP address 212.192.120.168 on 15/07/2019 at 02:47

Development of modal filter prototype for spacecraft busbar protection against ultrashort pulses

R R Khazhibekov, A M Zabolotsky, Y S Zhechev, V P Kosteletskii and T R Gazizov

Tomsk State University of Control Systems and Radioelectronics, 40, Lenina Avenue, Tomsk, 634050, Russia

E-mail: r300994@mail.com, zabolotsky_am@mail.ru

Abstract. The protection of the onboard equipment of the spacecraft from an ultrashort pulse (USP) based on modal filtering is proposed. The paper presents the results of the development of a modal filter (MF) prototype with a broad-side coupling. When choosing a structure, the maximum bus current, insulation breakdown voltage, wave impedance of line and the duration of the interfering USP are taken into account. To substantiate the choice of structure, quasi-static and electrodynamic simulations are performed. The simulation showed that the MF with resistance of 50 Ω at both ends of the passive conductor effectively weakens the 0.45-ns USP by 4 and with non-resistance connection on the passive conductor by 7. The MF prototype without resistors is made. Frequency dependence of $|S_{21}|$ is measured. An experiment showed that the MF weakens the USP by 5.61. The bandwidth of the MF is 60 MHz.

1. Introduction

Intentional electromagnetic influence applied to electronic and radioelectronic equipment is aimed at achieving its failure or malfunction. Inadequate operation or failure of equipment can lead to significant consequences. One of the most dangerous intentional impacts is an ultrashort pulse (USP) [1].

USP can affect equipment through information transmission lines, the grounding system and power supply networks. Special attention should be paid to the USP distribution on a busbar [2] of a spacecraft. This is due to the fact that all spacecraft equipment consumes electrical power through busbar, and, thus, can undergo USP impact.

The dangers of USP are extensive researched [3]. However, increasing the spacecraft lifetime to 15 years, leading to the degradation of the properties of the used materials, and also difficulties to predict changes in the properties of new materials, used in prospective spacecrafts, can create conditions for increasing the dangerous effects. The use of known protection devices to solve this problem is hampered by a number of conflicting requirements, for example, the protection of as many chains as possible, the small mass of a protective device, the ability to function effectively for 15 years in space. Therefore, the creation of new elements and devices for protection against USP is very important. Protection against USP based on modal filtering is proposed. 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 [4], it was shown that an asymmetric MF with a broad-side coupling has amplitude of decomposition pulses less than a structure with an edge coupling. In addition, the per-unit-length difference in mode delays of this structure reaches 3 ns/m, while in structures with edge coupling it does not exceed 1 ns/m. Therefore, the use of MF with broad-side coupling is advisable,

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

and the purpose of the work is to develop such MF prototype for protection of spacecraft busbar against USP.

2. Choosing and substantiation of the MF structure

When developing the MF for busbar protection against USP, the following requirements were taken into account: the maximum current of 10 A, the maximum allowable voltage of 600 V, the wave impedance of 50 Ω, the interference USP duration of 0.45 ns. According to these requirements and IPC-2221B [5], 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 [6] and GOST 23751-86 [7]). As the material of the dielectric the fiberglass is used. According to GOST 12652-74, the guaranteed value of breakdown voltage for 1 mm thick fiberglass is 28 kV [8]. The relative dielectric constant of fiberglass (ε_r) 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 [9], optimal geometrical parameters were found, at which the geometric mean of wave impedance of even and odd modes was 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 Figure 1, and the connection scheme in Figure 2.

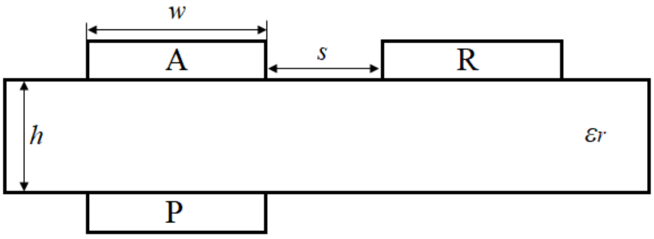


Figure 1. Cross-section of the MF with broad-side coupling for the protection of spacecraft busbar, where the conductors: A is active, P is passive, and R is the reference.

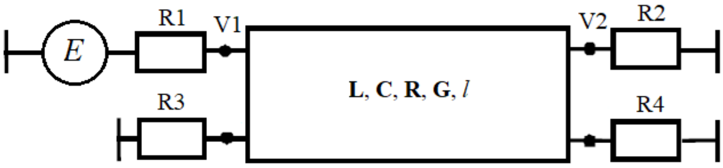


Figure 2. Connection scheme of the MF.

Using quasi-static analysis, the voltage waveforms at the input and output of the MF were calculated under excitation of the USP with a rise, hold and a fall times of 0.15 ns and an EMF amplitude of 1 V. For a preliminary assessment, the length of the conductors is chosen equal to 1 m. The simulation results for $R3$=$R4$=50 Ω are shown in Figure 3. From the diagram it can be seen that the amplitude of the USP has attenuated from 0.5 kV to 0.12 kV or 4.17 times. In addition, the difference in delays of the MF modes is 2.8 ns. Thus, for the full decomposition of a pulse with a duration of 0.45 ns, a length of conductors of 0.17 m is sufficient. However, it is recommended to have a reserve of length for pulse decomposition with a longer duration.

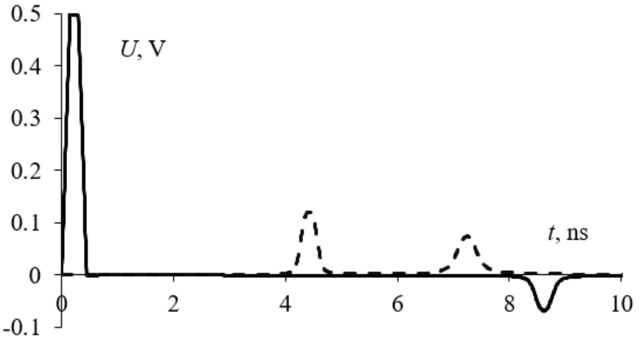


Figure 3. Voltage waveforms at the input (——) and output (- - -) of the MF under excitation of USP with EMF amplitude of 1 V.

3. Development of the MF layout

In the given operating conditions of the busbar, the sizes of the MF printed circuit board of should not exceed 110×50 mm. Based on these requirements and the simulation results, the construction of the MF layout is proposed. To reduce the PCB sizes, the conductors are made in the form of meander. The length of the conductors is 0.276 m and the sizes of the PCB are 105×45 mm. A top and a bottom views of the MF layout are shown in Figure 4.


(a) (b)

Figure 4. MF layout: top (a), and bottom (b) views.

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 MF output were calculated under the excitation of the USP. Resistances at the ends of the active conductor were assumed to be 50 Ω. In [4], it was shown that it is possible to achieve a greater reducing of the USP in the MF using at the beginning and end of the passive conductor in open-circuit (OC) and short-circuit (SC) modes. The passive conductor of MF was connected in three different modes: 50 Ω at both ends, short circuit SC-OC and OC-SC. The simulation results are shown in Figure 5. From the diagrams, the attenuation of the amplitude of the USP at the output of the MF is determined as 0,5E/V2. When $R3$=$R4$=50 Ω, the attenuation was 3.65, while SC-OC and OC-SC modes the attenuation was 6.41. The results of electrodynamic simulation of the same structure, taking into account the effect of the turns (forms of conductors as in Figure 4) are also shown in Figure 5. When $R3$=$R4$=50 Ω, the attenuation 4 was obtained, and in the SC-OC and OC-SC modes – 7.14 times. Thus, in the SC-OC and OC-SC modes of the passive conductor connection, a greater attenuation of the USP than for $R3$=$R4$=50 Ω was obtained. The difference in the results of quasi-static and electrodynamic analysis is due to the folding the structure into the meander.

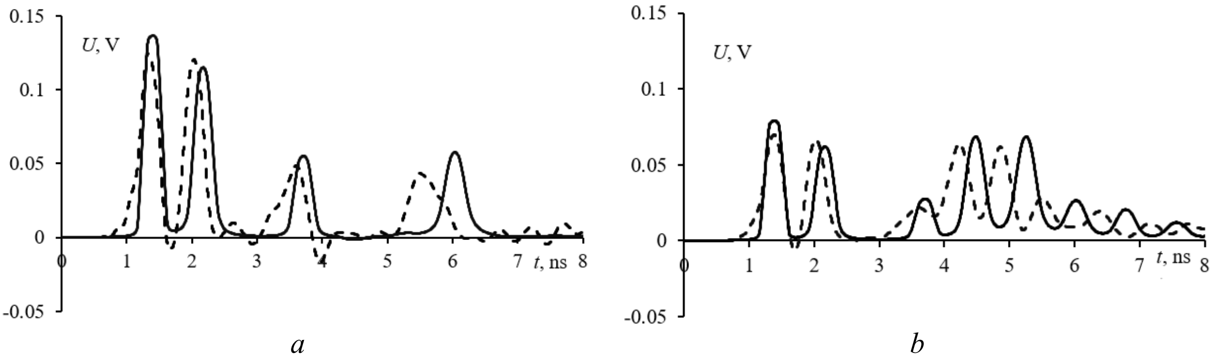


Figure 5. Output MF Voltage waveforms calculated by quasi-static (—) and electrodynamic (---) analyses for different connection modes of the passive conductor: $R3=R4=50\ \Omega$ (a), SC-OC and OC-SC (coincide) (b).

The $|S_{21}|$ frequency dependences of the MF for SC-OC and OC-SC at the passive conductor ends are calculated using electrodynamic analysis (Figure 6). These dependencies are the same. The graph shows that the MF bandwidth is 63 MHz, and the first resonance frequency is 172 MHz.

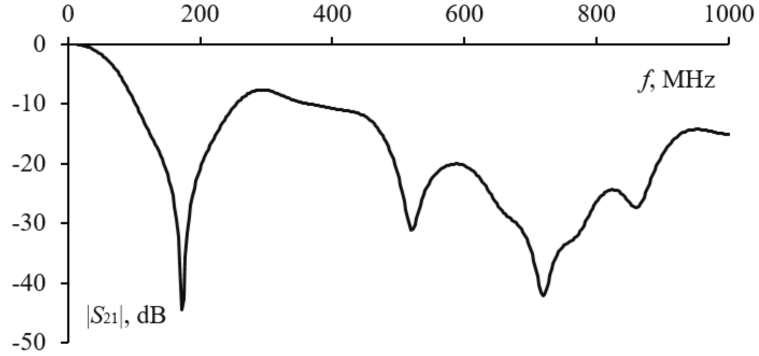
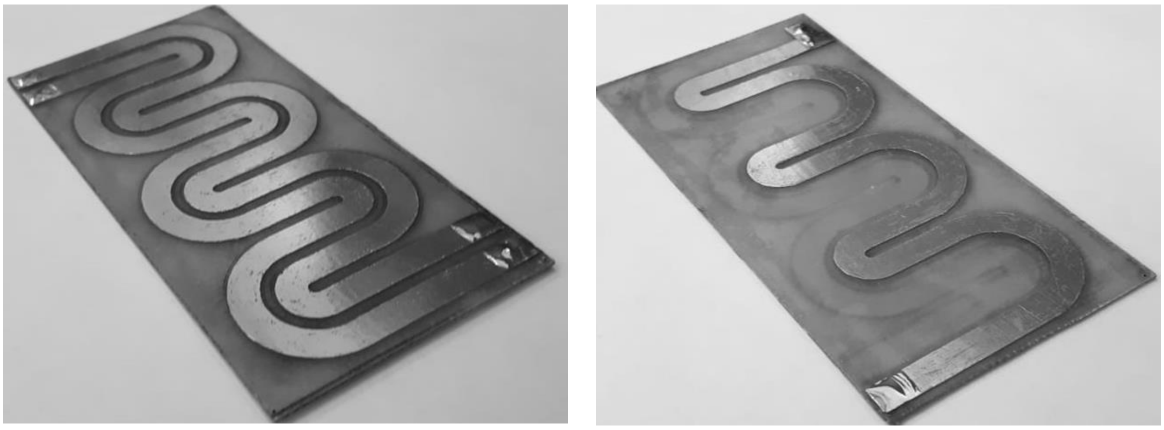


Figure 6. The $|S_{21}|$ frequency dependences of the MF (electrodynamic analysis) for SC-OC and OC-SC (coincide) at the passive conductor ends.

4. Experimental studies

Based on the obtained results, the prototype of the PCB was implemented. Figure 7 shows a photo of the PCB with a top and a bottom views.



а б

Figure 7. The prototype of the MF PCB: top (a) and bottom (b) views.

The $|S_{21}|$ frequency dependence of the MF was measured using the R2M-40 device for measuring the magnitude of the coefficients of transmission and reflection. The measurement set connection is shown in Figure 8, and the results are shown in Figure 9 with the results of electrodynamic analysis from Figure 6. According to the measurements, the bandwidth is 60 MHz, and the frequency of the first resonance is 144 MHz. The deviation from the simulation results is caused by the difference in ε_r values and losses accounting.

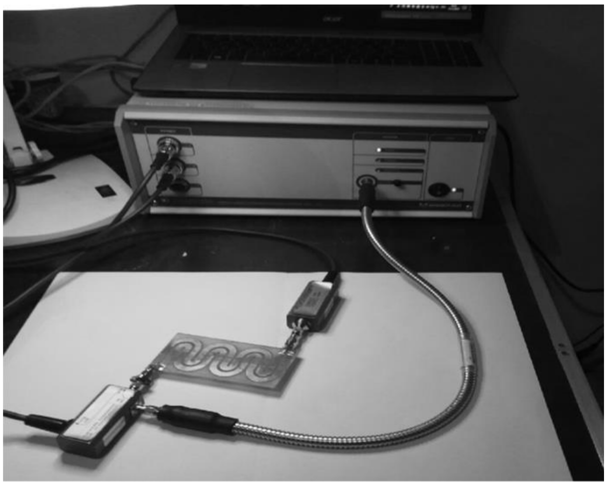


Figure 8. Connection of the MF with the measuring set.

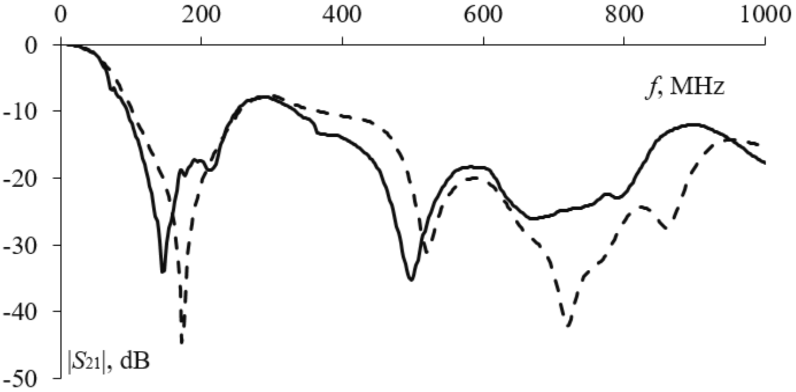


Figure 9. The $|S_{21}|$ frequency dependences: measured (—) and calculated (---).

The voltage waveforms at the S9-11 oscilloscope input are measured when an USP with an amplitude of 0.713 V and a duration of 0.3 ns at level of 0.5 was excited. Measurements are performed without MF and when MF was connected between the generator and the oscilloscope. The results are presented in Figure 10. The voltage amplitude at the oscilloscope input with MF connection is 0.127 V. Thus, an attenuation of 5.61 was obtained.

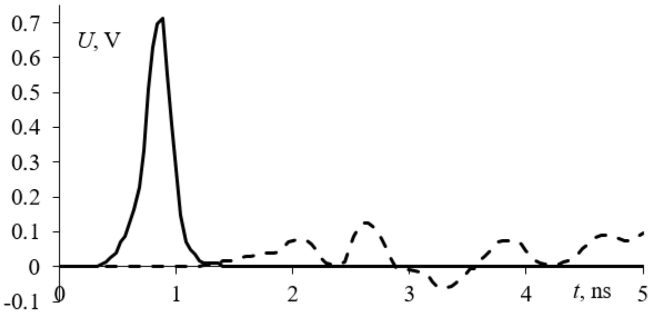


Figure 10. Voltage waveforms at the input of the S9-11 oscilloscope under the excitation of USP without (—) and with (---) MF.

5. Conclusion

Thus, a MF prototype for the spacecraft busbar protection against USP is developed. The device has a small weight (7 g) and small dimensions (105×45×1 mm), which is important during the designing of a spacecraft. In addition, the MF is implemented without resistors, which allows for a required service life. The simulation results showed that the MF effectively attenuates the USP with the required parameters. So, the quasi-static analysis shows that the MF attenuate the USP 6.41 times, and electrodynamic – 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 made. Measuring the $|S_{21}|$ frequency dependence and of voltage waveforms at the output of the MF under the influence of USP is performed. The experiment shows that the MF weakens the USP by 5.5 with a bandwidth of 60 MHz.

Acknowledgments

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

References

[1] Vass S 2004 *Aarms* 443–457
[2] Jodoin R C 1993 *Electron. Packaging Prod.* **33 (2)** 46–7
[3] Mora N, Vega F, Lugrin G, Rachidi F, Rubinstein M 2014 *Syst. and assessment notes* Note 41
[4] Gazizov A T and Zabolotsky A M 2015 *International Siberian Conference on Control and Communications* 1–3
[5] IPC-2221B 2012 *Generic standard on printed board design* 138
[6] GOST R 55490-2013 2013 *General technical requirements for the construction and acceptance* 24
[7] GOST 23751-86 1986 *General technical requirements for the construction and acceptance* 7
[8] GOST 12652-74 2008 *Electrotechnical glass-cloth-base laminate. Specifications* 14
[9] Kuksenko S P, Gazizov T R, Zabolotsky A M, Ahunov R R, Surovtsev R S, Salov V K, Lezhnin Eg V 2015 *MSAM*, 293-301