# Influence of boundary conditions and coupling enhancement on the attenuation of a modal filter with a passive conductor in the reference plane cutout

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*Abstract*— **Ensuring the stable operation of radio-electronic equipment under the influence of electromagnetic interference is relevant due to the fact that radio systems are becoming more complex, the scope of radio- electronic equipment is expanding, and the density of circuit boards is increasing. There is a large selection of protection devices, but they have complex design features that lead to inadequate performance and spurious parameters, making it difficult to protect against a powerful ultrashort pulse. The development of modern protection devices requires simplification and cheapening of their implementation, therefore, their improvement is relevant. The article considers the improvement of protection against an ultrashort pulse using a modal filter with the passive conductor implemented in the reference plane cutout and investigates the influence of boundary conditions of the passive conductor of the modal filter. The simulation showed the possibility to minimize and align the pulse amplitudes and to increase ultrashort pulse attenuation up to 10 times for a given dielectric.**

***Keywords*** *– modal filter, ultrashort impulse, electronic equipment.*

## I. Introduction

Due to the accelerated pace of development of electronic equipment, and as a result, the transition of modern radio-electronic equipment (REE) to an increasingly high-frequency range, the issue of ensuring electromagnetic compatibility (EMC) of radio engineering systems is becoming increasingly relevant.

The active process of miniaturizing of the modern element base leads to a decrease in the thickness of the insulating dielectric layers and increases the risk of breakdown under the influence of powerful electromagnetic interference. One of these threats is a powerful ultrashort pulse (USP), which leads to equipment failure, accidents and malfunctions [1].

To increase the protection of the REE from the USP, such protection devices such as jammers, filters, etc. are offered. The main disadvantages of such devices are: design complexity, small life time, not always acceptable de-energization of the device, complicated circuitry [2–5]. For example, in the onboard REE of spacecraft, it is desirable to minimize the mass and have an almost unlimited life time. Therefore, the search for new protection devices is relevant.

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A new means for protecting equipment against USPs is a modal filter (MF) [6–10]. The main idea of the MF is to decompose the USP into pulses of lower amplitude due to different per-unit-length delays of the modes in a coupled line with a nonhomogeneous dielectric filling. Simple design and circuitry allow the introduction of an MF at different structural levels. In the previous studies, MFs have been realized with a passive conductor, which takes up additional space and complicates the implementation of modal filtering in printed circuit boards. Therefore, it is important to explore new approaches to MF morphology.

Thus, it was proposed to place the passive conductor in the cutout of a reference plane. The paper [11] shows the input pulse attenuation of 5 times and it is believed that additional attenuation can be achieved by changing the boundary conditions at the ends of the passive conductor. The purpose of the work is to carry out such study.

## II. Description of MF

The MF structure is based on a microstrip line. In the reference plane of the line there are two cutouts that form a passive conductor. Fig. 1 shows the MF cross section, where $\varepsilon_r$ is the relative permittivity of the substrate, $w_1$, $w_2$, $w_3$ are the widths of the conductors, $t$ is the thickness of the conductors, $h$ is the substrate thickness, $s$ is the separation of the conductors. Foil-clad fiberglass ($\varepsilon_r$=4.5) was chosen as the substrate material because of its low cost, availability and widespread use.

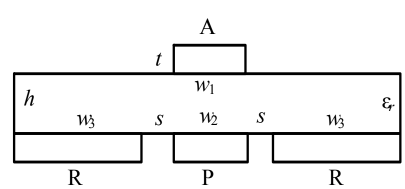


Fig. 1. MF cross section where the conductors: R – reference, A – active, P – passive

The MF connection diagram is shown in Fig. 2*a*. The active conductor is connected to a pulse signal source, represented in the circuit as an ideal EMF source $E$ and internal resistance $R1$. The other end of the active conductor is connected to load $R4$. The resistance values $R1$, $R2$, $R4$, $R5$ are assumed to be the same and equal to 50 Ω, and $R3$=$R6$=0.001 Ω for connecting the side conductors. The input excitation is a trapezoidal pulse, shown in Fig. 2*b*, with the following parameters: an EMF amplitude is 2 V, rise time is 150 ps, flat peak time is 200 ps, fall time is 150 ps. The calculation of parameters and waveforms has been performed using the quasistatic approach in the TALGAT system [12]. Losses in conductors and dielectrics were not taken into account.

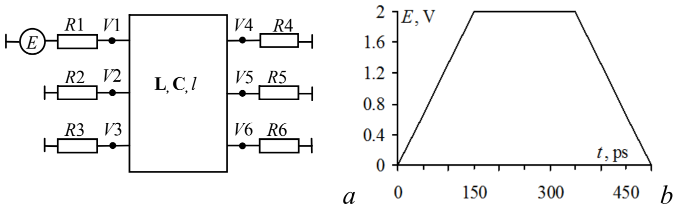


Fig. 2. MF connection diagram (*a*) and exciting EMF waveform (*b*)

## III. Simulation Results

The simulation was performed with typical parameters of foil-clad fiberglass: $t$=35 µm, $h$=0.18 mm with an MF length ($l$) of 30 cm. Since the material parameters are fixed, to increase the coupling we simultaneously increased only the width of the active ($w_1$) and passive ($w_2$) conductors ($w_1$=$w_2$) from 1 to 3.5 mm and gaps ($s$) from 0.5 to 3.5 mm in 0.2 mm increments. The width of the side conductors did not change ($w_3$=0.5 mm). The optimization was performed according to the criteria of minimizing the output voltage amplitude. The obtained voltage waveforms for $w_1$=$w_2$=2.1 mm and $s$=3.3 mm are presented in Fig. 3. The alignment of the amplitudes of the decomposition pulses (0.21 V) has been achieved.

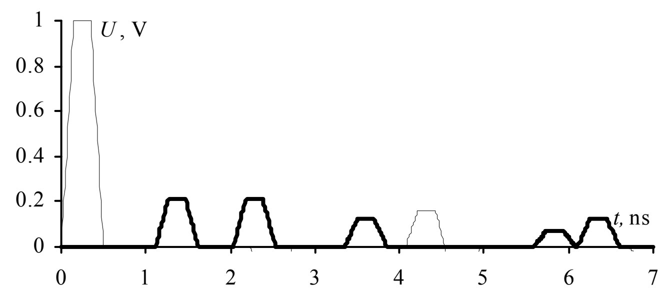


Fig. 3. Voltage waveforms at the MF input (-) and output (-)

The influence of the "beginning–end" boundary conditions of the passive conductor was simulated: "short circuit (SC) – open circuit (OC)", "SC–SC", "OC–SC", "OC–OC". An SC was modeled as $10^{-3}$ Ω, and an OC – $10^5$ Ω.

Fig. 4 shows the simulation results at the input and output of the MF for $w_1$=3.3 mm and $s$=3.3 mm, where the strongest coupling was achieved. The amplitudes of the decomposition pulses for "OC–SC" and "SC–OC" the same and equal to 0.1 V. For "OC–OC" $U_2$=0.69 V and $U_3$=0.01 V, and for "SC–SC" $U_2$=0.01 V and $U_3$=0.51 V.

For all values of $w_1$ and $s$, the voltage waveforms were calculated (Fig. 5). The simulation showed that the main attenuation occurs in the "SC–OC" mode; therefore, to save space, the graphs are presented only for this mode. In Fig. 5, $U_2$ represents the amplitudes of the first two fast modes, which arrive approximately simultaneously, i.e. with a difference of about 0.01 ns [11], and $U_3$ is the amplitude of the third mode. The analysis of Fig. 5 shows a monotonic decrease in $U_2$ and $U_3$ with an increase in $w_1$. However, for some values, this decrease is nonmonotonic. Fig. 5*a* shows that when $w_1$ increases, $U_2$ decreases from 0.24 V to 0.12 V and $U_3$ decreases from 0.21 to 0.12 V. When $s$ increases, the amplitude also becomes smaller: $U_2$ – from 0.24 V (Fig. 5*a*) to 0.18 V (Fig. 5*h*), and $U_3$ – from 0.21 V (Fig. 5*a*) to 0.15 V (Fig. 5*h*). The minimum amplitude of 0.10 V was achieved at $w_1$=3.3 mm and $s$ =3.3 mm.

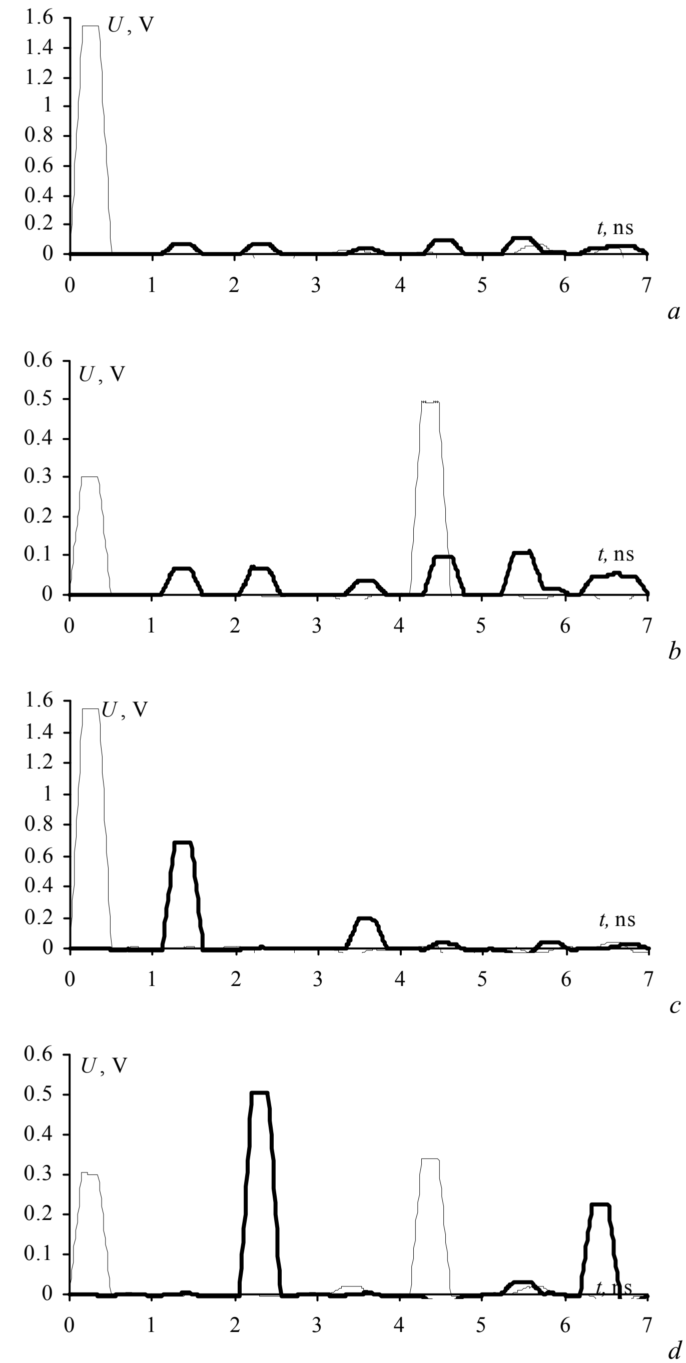


Fig. 4. Voltage waveforms at the MF input (-) and output (-) for different boundary conditions of the passive conductor: OC–SC (*a*), SC–OC (*b*), OC–OC (*c*), SC–SC (*d*)

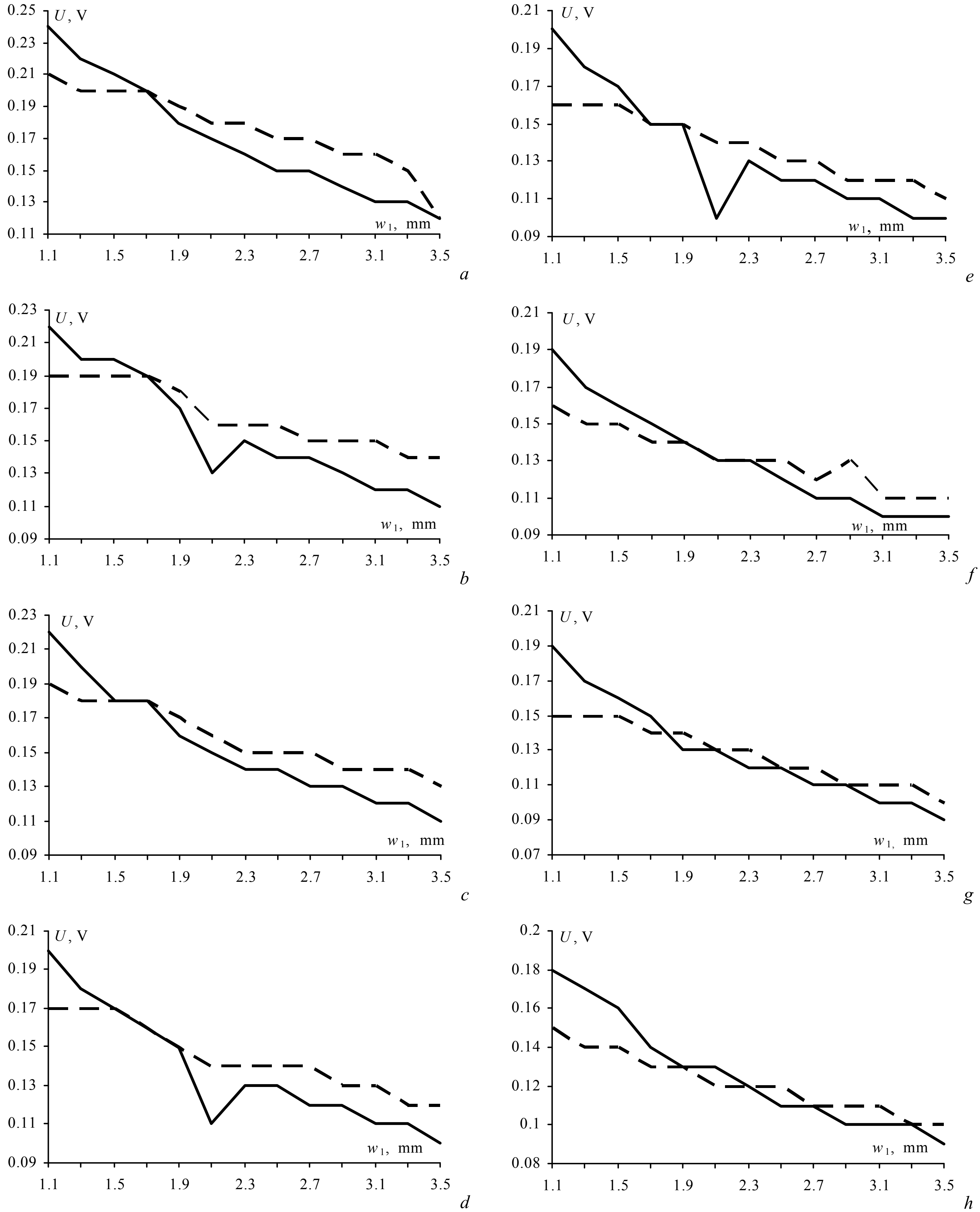


Fig. 5. Dependences of $U_2$ (–) and $U_3$ (- -) on $w_1$, for $s$=0.5 (*a*), 0.9 (*b*), 1.3 (*c*), 1.7 (*d*), 2.1 (*e*), 2.5 (*f*), 2.9 (*g*), 3.3 (*h*)

## IV. Conclusion

Thus, it is shown that for typical parameters of the substrate material and an increase in the coupling between the active and passive conductors under the "OC–SC" boundary conditions, it is possible to achieve a greater attenuation of the USP (about 10 times with respect to half the EMF). In this case, several parameter values may exist for which the amplitudes of the main pulses are equal In the future, it is supposed to investigate the effect of the symmetry of an MF.

## References

[1] 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.

[2] V. I. Grischuk and V. V Chernousov, "Device for protection of radio engineering equipment from impulse overvoltages", Patent Rassian, no. SU 1840225 A1. Publ. 20.08.2006, bul. №23.

[3] A. P Borisov, V. A. Gurlev, G. K. Karpov and V. N. Pavlov, "Device for protecting consumers against overvoltage in the power supply network", Patent Rassian, no. H02H3/20. Publ. 20.10.1995.

[4] D. A. Veselov, V. Ye. Ponimatkin, V. A. Sychugov, A. A. Vikhlyantsev and P. A Shakirov, "Device for protecting the input of a radio receiver from an electromagnetic pulse of a nuclear explosion". Patent Rassian, no. 96106554 Publ. 07.27.1998.

[5] S. V. Khanevich, Yu. N. Skachkov, A. E. Severin and V. S Khanevich, "Device for protection of electrical receivers from the effects of lightning discharges and electromagnetic pulses of induced discharges in the main cable transmission lines". Patent Rassian, no. 2001126011 Publ. 07.10.2003.

[6] R. Khazhibekov and A.M. Zabolotsky, "Modal filter with interdigital structure of conductors for 100 Mbit/s Ethernet equipment protection," International Siberian Conference on Control and Communications (SIBCON 2019), Tomsk, Russia, April 18–20, pp. 1–4, 2019.

[7] E. Chernikova, A. Belousov and A. M. Zabolotsky, "Comparative analysis of microstrip and reflection symmetric four-conductor modal filters," International Siberian Conference on Control and Communications (SIBCON 2019), Tomsk, Russia, April 18–20, pp. 1–4, 2019.

[8] A. Belousov, A. M. Zabolotsky and T. T. Gazizov, "Experimental confirmation of the modal filtration in four- and five-conductor microstrip lines," 18th International Conference of Young Specialists on Micro/Nanotechnologies and Electron Devices EDM, Erlagol, Altai, June 29–July 3, pp. 46–49, 2017.

[9] R. Khazhibekov, A. M. Zabolotsky and M. V. Khramtsov, "Study of the characteristics of a modal filter with different periodic profiles of the coupling region," Proc. of IEEE 2017 International multi-conference on engineering, computer and information sciences, – Novosibirsk, Akademgorodok, Russia, September 18–24, pp. 506–509, 2017.

[10] A. T. Gazizov, A.M. Zabolotsky and T.T. Gazizov, "Time-domain response of asymmetrical modal filter without resistors to ultrashort pulse excitation," 17th International Conference of Young Specialists on Micro/Nanotechnologies and Electron Devices, Erlagol, Altai, 30 June–4 July, pp. 85–88, 2016.

[11] M. A. Samoylichenko and T. R. Gazizov, "Effect of close coupling on performance of a modal filter with the passive conductor in the reference plane cutout," Journal of physics: conference series [Electronic resources], P. 1–6, 2019, in press.

[12] S. P. Kuksenko, T. R. Gazizov, A. M. Zabolotsky, R. R. Ahunov, R. S. Surovtsev, V. K. Salov and Eg. V. Lezhnin, "New developments for improved simulation of interconnects based on method of moments," Advances in Intelligent Systems Research (ISSN 1951-6851). Proc. of the 2015 Int. Conf. on Modelling, Simulation and Applied Mathematics (MSAM2015), August 23–24, Phuket, Thailand, pp. 293–301, 2015.