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Simulation of broad-side coupled modal filter with passive conductor in reference plane cutout

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Abstract. The article presents the simulation of a modal filter with broad-side coupling, having a passive conductor in reference plane cutout. The authors calculate the matrices of per-unit-length parameters **L** and **C** and investigate the influence of end terminations of the passive conductor of the modal filter. As a result, we achieve alignment and minimization of the amplitudes of the decomposed pulses and show the possibility to attenuate the input ultrashort pulse with a duration of 450 ps 4.5 times.

1. Introduction

The problem of ensuring electromagnetic compatibility (EMC) has become especially pressing after a number of accidents that have led to human casualties, loss of wealth and environmental disasters. Safety violations can result from not only failures of elements in microelectronic control systems of equipment, but also from failures caused by electromagnetic interference [1-7]. Conducted interferences penetrating through conductors are particularly dangerous, one of which is an ultrashort pulse (USP). High-voltage USP can lead to failures of electronic equipment, as well as its disabling. Conventional protection devices (filters, decoupling devices, interference suppressors, dischargers, and others) cannot effectively protect against USP. Modern protective devices have large dimensions and high cost, as well as low radiation resistance due to semiconductor elements. Therefore, a search for new protective devices is relevant [8].

A modal filter (MF) is new, miniature and low-cost in realization means of protection against USP, in which the USP is decomposed into pulses of smaller amplitude due to different per-unit-length delays of signal modes in a coupled line with non-uniform dielectric filling. Earlier investigations have focused on MFs with a broad-side coupling [9] and multiconductor MF [10]. However, the passive conductor of an MF takes a lot of space and has a mass, which is undesirable. Therefore, we propose to use a reference plane, which was previously lesser used in printed circuit boards, and investigate it in a new MF design where the passive conductor is located in the cut-out of this reference plane. The purpose of this work is to perform a preliminary simulation to implement the new MF design.

2. The structure of the MF under investigation

As an MF, we chose a simple structure based on the conductors printed on fiberglass laminate. The geometrical model of the MF section is shown in figure 1. Cross section parameters are: ε_r - relative

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permittivity, $w=w_1=w_2$ - conductor width, t - foil thickness, h - dielectric thickness, s - the distance between conductors. As a dielectric we chose fiberglass (ε_r=4.5) because of its cheapness.

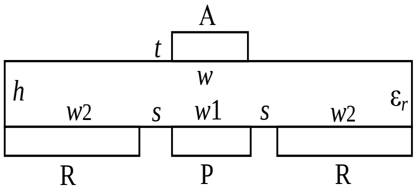

Figure 1. Cross section of MF where the conductors: R – reference, A – active, P – passive.

The connection diagram for the line segment from figure 1 is presented in figure 2*a*. The first conductor is connected to a source of pulsed signals represented in the diagram by an ideal source of e.m.f. E and internal resistance R1. At the other end, the first conductor is connected to R4. The resistance values of R1, R2, R4, R5 are assumed to be the same and equal to 50 Ω, and to interconnect the outermost conductors – R3=R6=0.001 Ω. The input excitation is a trapezoidal pulse shown in figure 2*b*, with the e.m.f. amplitude of 2 V, the rise time of 150 ps, the flat top time of 200 ps, and the fall of 150 ps. Calculation of parameters and waveforms was performed using the quasistatic approach in TALGAT system [11]. Losses in conductors and dielectrics were not taken into account.

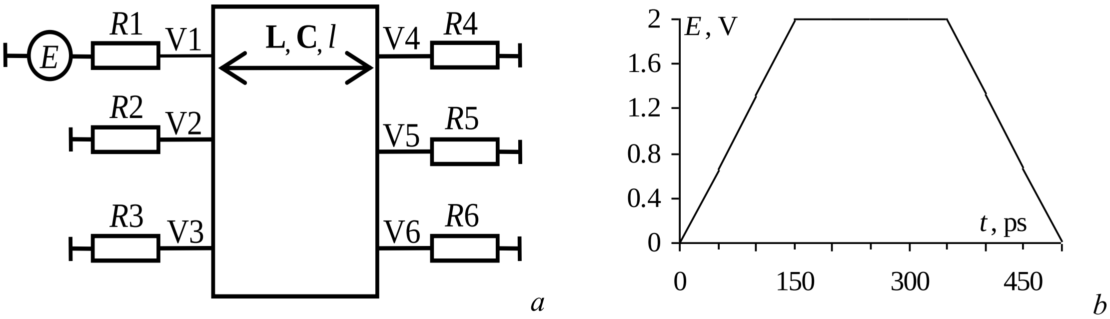

Figure 2. Circuit diagram of the MF connection (*a*) and the waveform of exciting EMF (*b*).

3. Simulation results

Simulation was performed with typical parameters of foil-clad fiberglass: t=35 µm, h=0.18 mm with MF length l=30 cm. The value $w=w1=w2$ changed in the range from 0.8 to 1.5 mm with a step of 0.1 mm for s=0.2; 0.3; 0.4; 0.5 mm. Optimization was performed according to the criteria of minimizing the maximum amplitude and equalizing decomposition pulses. Figure 3 shows the dependences of the amplitudes of the first (U1) and last (U3) decomposition pulses on w, for s=0.2; 0.3; 0.4; 0.5 mm. Alignment of amplitudes and minimization down to 0.34 V are achieved for $w=w1=w2$=1 mm and s=0.5 mm.

For $w=w1=w2$=1 mm, s=0.5 mm the per-unit-length parameters of the matrixes **C** and **L**:

$$\mathbf{C}=\begin{bmatrix} 2.62471e-10 & -2.39025e-10 & -1.32909e-11 \\ -2.39025e-10 & 2.62916e-10 & -1.35979e-11 \\ -1.32909e-11 & -1.35979e-11 & 3.30553e-11 \end{bmatrix}, \text{F/m},$$

$$\mathbf{L}=\begin{bmatrix} 6.16794e-7 & 5.26685e-7 & 4.33424e-7 \\ 5.26685e-7 & 6.09862e-7 & 4.33411e-7 \\ 4.33424e-7 & 4.33411e-7 & 8.66379e-7 \end{bmatrix}, \text{H/m}.$$

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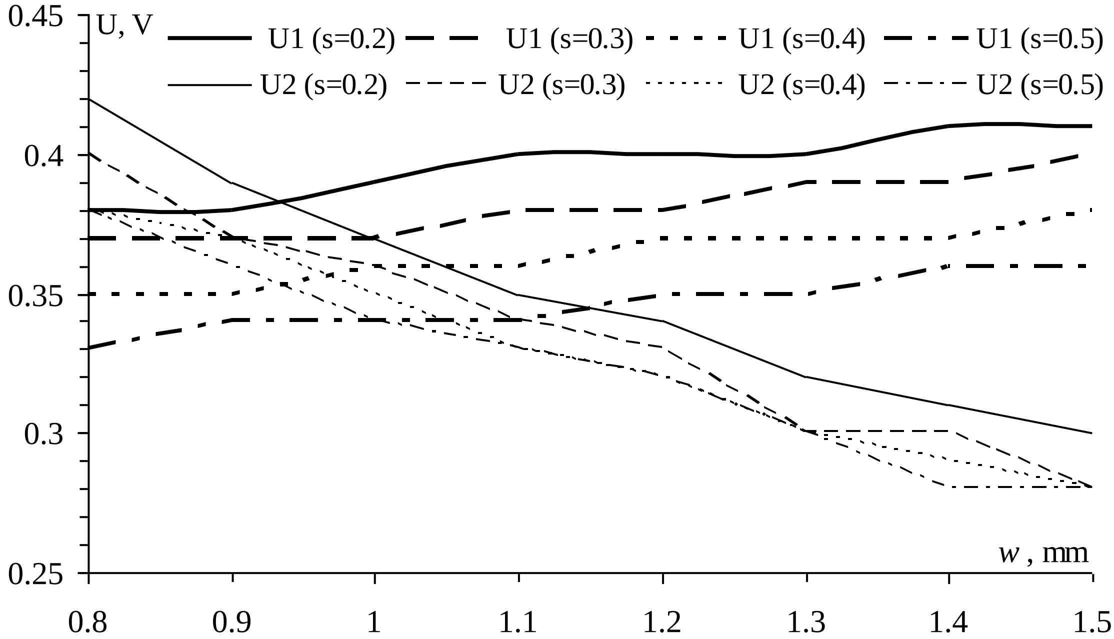

Figure 3. Dependence of amplitudes of the first and last decomposition pulses on the width of the conductors with different distances between the conductors.

The simulation results are shown in figure 4. The amplitude of the output voltage is 0.34 V. It corresponds to attenuation of 2.94 times with respect to half of the e.m.f. (1 V).

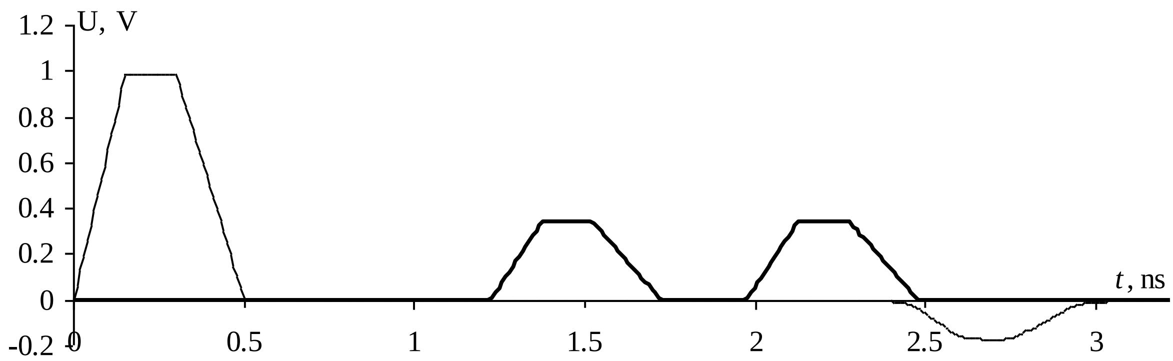

Figure 4. Voltage form at the MF input (-) and output (**-**).

Let us consider an MF with the same parameters, but without resistors. It will increase the service life of the MF and reduce its cost. We simulated the influence of the passive conductor terminations: “short circuit (SC) – open circuit (OC)”, “SC–SC”, “OC–SC”, “OC–OC”. SC was simulated as 10^{-3} Ω, and OC–10^{-5} Ω. The results are presented in figure 5. Attenuation is 4.54 times. The amplitudes of the decomposition pulses in “SC–OC” and “OC–SC” are the same (U1=0.22 V, U2=0.25 V).

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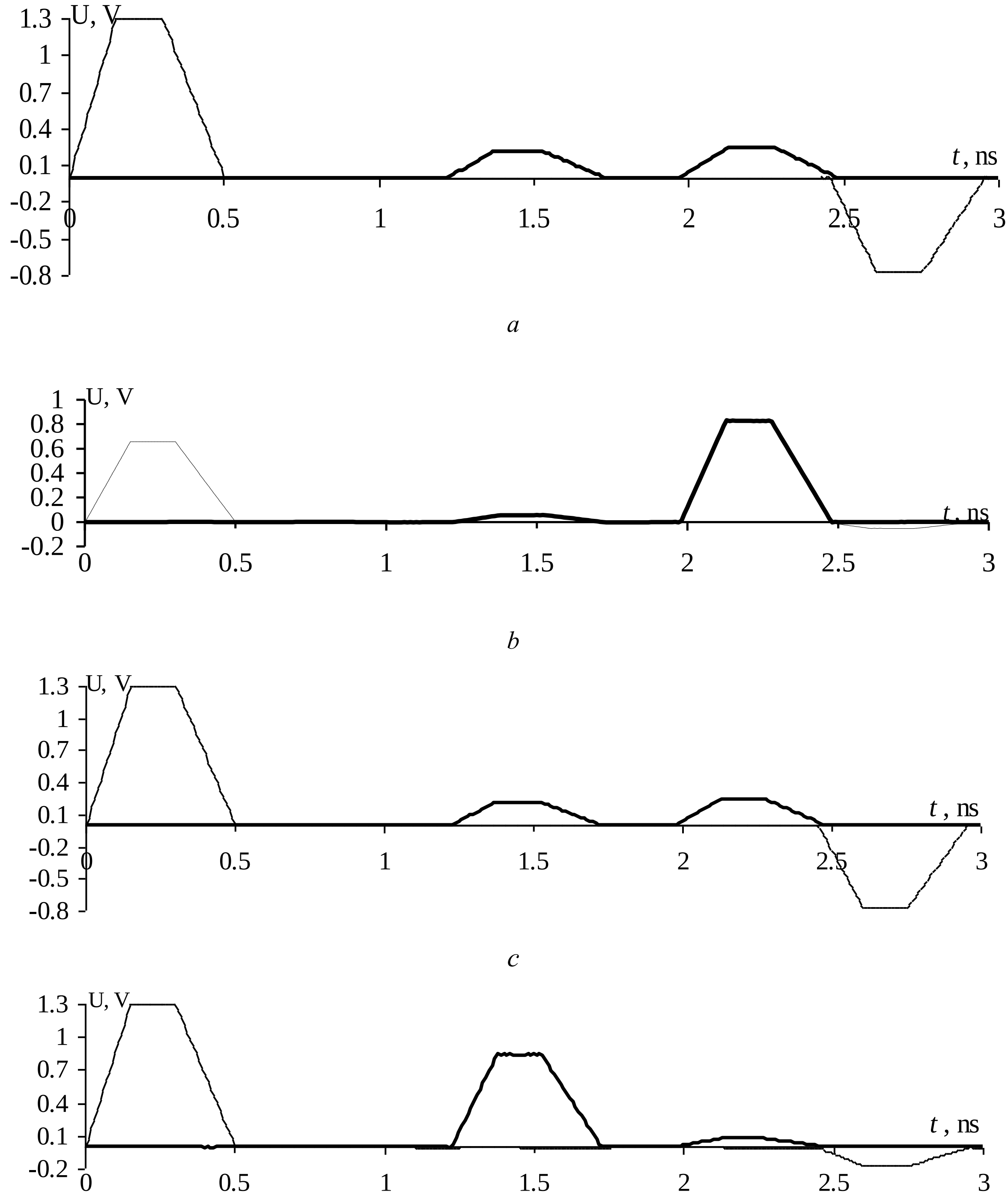

Figure 5. Voltage at the MF input (-) and output (**-**) for different terminations of the passive conductor: SC–OC(*a*), SC–SC (*b*), OC–SC (*c*),OC–OC(*d*).

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4. Conclusion

For typical parameters of the substrate material with terminations at the ends of the passive conductor “SC–OC” and “OC–SC”, it is possible to achieve greater attenuation of the input pulse (4.54 times). This will increase the service life of the MF, and may also be beneficial when implementing the MF in printed circuit boards. This fact makes it relevant to conduct a similar study into increasing the coupling between passive and active conductors.

5. Acknowledgments

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