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Influence of the shield on the ultrashort pulse decomposition in a modal filter realized on a double-sided printed circuit board

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Abstract. A modal filter (MF) with four reference conductors (at the edges of the MF on the outer layers) and with the removal of two diagonal reference conductors is simulated. Using the example of two MFs, the influence of connecting the reference conductors with the shield is evaluated. It is shown that connecting the reference conductors with each other with a shield can eliminate their influence, and the shield can be used as reference conductors. The influence of the shield on the decomposition of the ultrashort pulse in two MF is estimated. The increase in the distance from the conductors to the shield is investigated. It is shown that with increasing the distance, the difference in per-unit-length delays becomes smaller for two MFs. In addition, the amplitude of the first pulse decreases and of the second pulse increases. A greater influence of the shield in the MF without two conductors is revealed.

1. Introduction

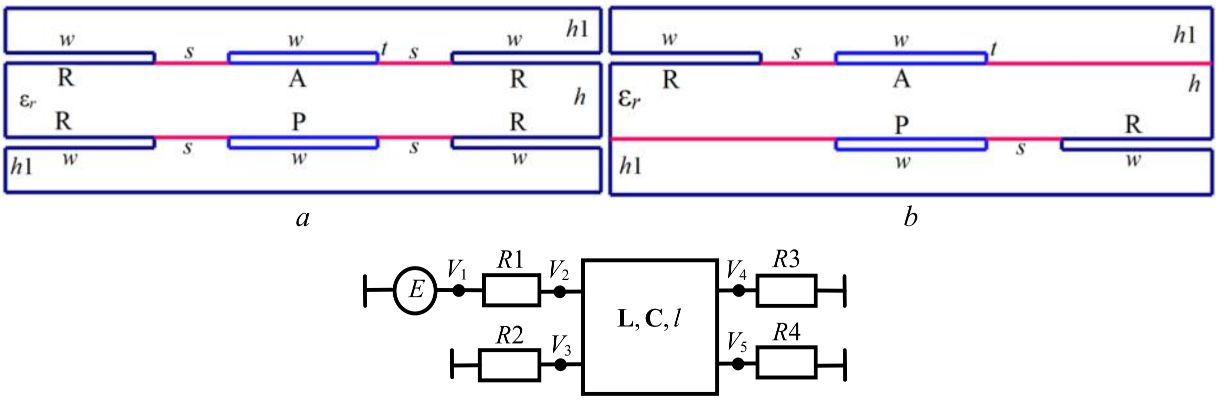
Because of the increasing proliferation of digital devices, the problem of electromagnetic compatibility (EMC) is particularly aggravated: under the influence of interference, electronics can trip falsely and even fail [1]. EMC is violated if the interference level is too high, and the interference immunity of the equipment is insufficient. Particularly dangerous are broadband interference that usually appears as single pulses or a sequence of pulses. A particular case of such interference is ultra-short pulses (USP) [2]. The impact of USP interference in electronic devices causes damage, power dissipation, and destruction of devices [3]. Damage effects usually occur when surge noise enters equipment over power or data lines. This results in system lockups, failures, erroneous data output, lost or corrupted files, and other undesirable effects. The materials used to make electronic components can withstand a certain number of repetitive energy bursts, but not for long. The slow decomposition that occurs will eventually lead to the failure of the components. Destructive effects summarize all cases where high energy pulse noise causes immediate equipment failure. Often it is visible physical damage, such as burned or cracked boards and components of a personal computer, melted electronic components, etc. Therefore, protection against electromagnetic interference is highly relevant.

New protective devices called modal filters (MF) suppress USPs well [4]. The signal suppression is achieved by decomposing it into modes, each of which propagates with its own delay. The number of modes at the MF output is determined by the number of conductors in the line. The technology of modal filtration is being investigated in different directions: MFs on printed circuit boards, meander lines, modal redundancy, MFs in the form of cables. MFs on double-sided printed circuit boards are also being investigated. Such MFs have a number of advantages, for example, ease of implementation, equally good signal suppression of the USP regardless of the number of conductors in the MF [5], the possibility of different connections of the reference conductors. For example, previously investigated is the configuration where the reference conductors were connected only at the ends of the MF. Such a connection makes it possible to observe, with some parameters in the cross-section (for example, a small *s* value), a larger number of mode at the MF output. In such an implementation, the number of reference conductors matters [6]. However, the configuration where all reference conductors are connected along the entire length of the MF has not previously been investigated. In this configuration, the reference conductors can be connected to each other, for example, with a shield or metalized holes. The specificity of such connection is that the decomposition of the USP will also be affected by the shield itself. Thus, in this paper for the first time we propose to investigate the effect of connection of reference conductors using a screen, as well as to evaluate its effect on the decomposition of USP in a modal filter on a double-sided PCB.

2. Structures under investigation

To simulate the structure, we chose an MF with all reference conductors and an MF without two diagonal reference conductors. (The removal of the reference conductors allows you to reduce the weight of the MF.) The cross-sections of the MF and the connection diagram are shown in figure 1. Cross-section parameters are as follows: *s* is the distance between the conductors, *w* is the width of the conductors, *h* is the dielectric thickness, *h*1 is the distance from the conductor to the shield, ε_r is the relative permittivity, *t* is the thickness of the conductors. The foil-clad fiberglass (ε_r=4.5) was chosen as the substrate material because of its low cost.

The active conductor is connected to the pulse signal source, represented in the diagram by the ideal source of e.m.f. *E* and internal resistance *R*1. The other end of the active conductor is connected to the load *R*3. The resistance values *R*1, *R*2, *R*4, and *R*5 were assumed to be the same and equal to 50 Ω. The input excitation was a trapezoidal pulse with the following parameters: the e.m.f. amplitude of 2 V; the rise, flat peak and fall top of 500 ps each. The parameters and waveforms were calculated using the quasistatic approach in the TALGAT software [7]. The losses in the conductors and dielectrics were not taken into account.



a *b*

c

Figure 1. Cross-section of the MF (where the conductors: R – reference, A – active, P – passive) with all reference conductors (*a*), without the two diagonals (*b*) and an MF connection diagram (*c*)

3. Simulation results

Simulations were performed with the same parameters for the two MFs: *t*=35 μm, w_1=1500 μm, w_2=1500 μm, *s*=500 μm, *h*=500 μm, *h*1=500 μm.

3.1. Influence of the shield on the USP decomposition

The values of pulse amplitudes and per-unit-length mode delays obtained are shown in table 1, and the voltage waveforms at the MF input and output are shown in figure 2. You can see that there are two pulses on the MF output. The amplitude of the first («fast») mode, which propagates predominantly in the air, is the same for the two MFs, but the arrival time is different. This is due to the small value of *s*, because of which a different end connection with the reference conductors is formed; in the MF with all reference conductors, it is larger, and without diagonal conductors, it is less. The reference conductors make the first mode propagation more in the dielectric. Therefore, in the MF without two diagonal conductors, the first mode comes faster. The second mode, which propagates mainly in the dielectric, comes at the same time and with the same amplitude.

Table 1. Per-unit-length mode delays (τ_i, ns/m) and pulse amplitudes (U_i, V) for two MFs

MF	τ_1	τ_2	U_1	U_2
with all the reference conductors	4.085	5.932	0.493	0.399
without two diagonal conductors	4.013	5.935	0.490	0.399

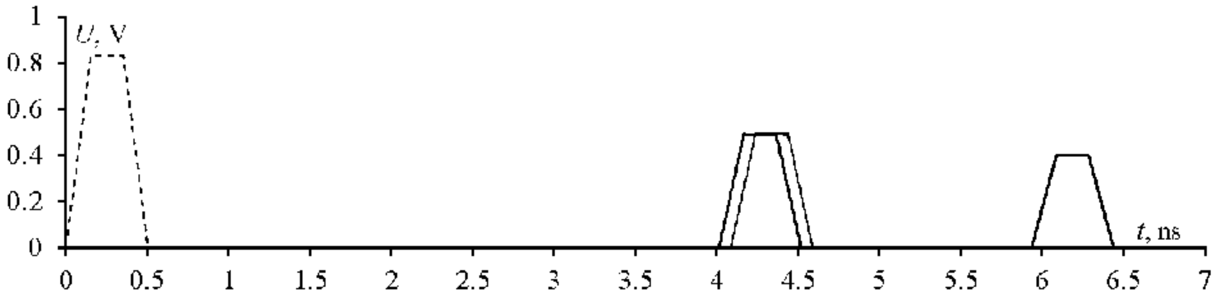


Figure 2. Voltage waveforms at MF input (– –) and MF output with all (–) reference conductors and without diagonal (–)

3.2. Influence of the distance to the reference conductors

The *s* value varied in the range of 600 – 2000 µm in increments of 100 µm. Table 2 shows the obtained values of pulse amplitudes and per-unit-length delays when changing *s* for two MFs. It can be seen that the change in *s* affects the arrival time of the first mode the most. Figure 3 shows the dependence of τ_1 on *s*. The diagram shows that as s increases, the values of τ_1 become smaller and converge. This is due to the fact that with increasing the distance between the reference conductors, the MFs become more symmetrical relative to their center. As a result, at the output of two MFs, the same responses can be observed. The voltage forms at the input and output of two MFs at *s*=600 µm and 2000 µm are shown in figure 4.

Table 2. Per-unit-length mode delays (τ_i, ns/m) and amplitudes (U_i, V) for two MFs at different *s*

***s*, µm**	**With all the reference conductors**				**Without two diagonal conductors**			
	τ_1	τ_2	U_1	U_2	τ_1	τ_2	U_1	U_2
600	4.019	5.934	0.491	0.399	3.961	5.936	0.489	0.399
700	3.966	5.936	0.489	0.399	3.919	5.937	0.488	0.399
800	3.923	5.936	0.488	0.399	3.885	5.937	0.487	0.399
900	3.889	5.937	0.487	0.399	3.858	5.937	0.486	0.399
1000	3.861	5.937	0.486	0.399	3.836	5.937	0.486	0.399
1100	3.838	5.937	0.485	0.399	3.819	5.937	0.484	0.399
1200	3.821	5.937	0.485	0.399	3.805	5.937	0.484	0.399
1300	3.806	5.937	0.484	0.399	3.794	5.937	0.484	0.399
1400	3.795	5.937	0.484	0.399	3.785	5.937	0.483	0.399
1500	3.786	5.937	0.484	0.399	3.779	5.937	0.484	0.399
1600	3.779	5.937	0.484	0.399	3.772	5.937	0.483	0.399

1700	3.773	5.937	0.484	0.399	3.768	5.937	0.483	0.399
1800	3.768	5.937	0.484	0.399	3.764	5.937	0.484	0.399
1900	3.765	5.937	0.484	0.399	3.761	5.937	0.484	0.399
2000	3.762	5.937	0.483	0.399	3.759	5.937	0.483	0.399

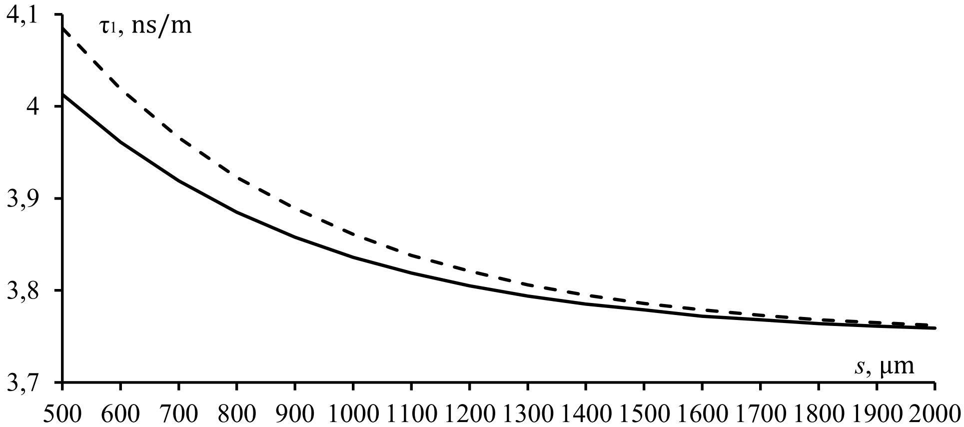


Figure 3. Dependences of τ_1 on s for MFs with all reference conductors (–) and without a diagonal conductor (– –)

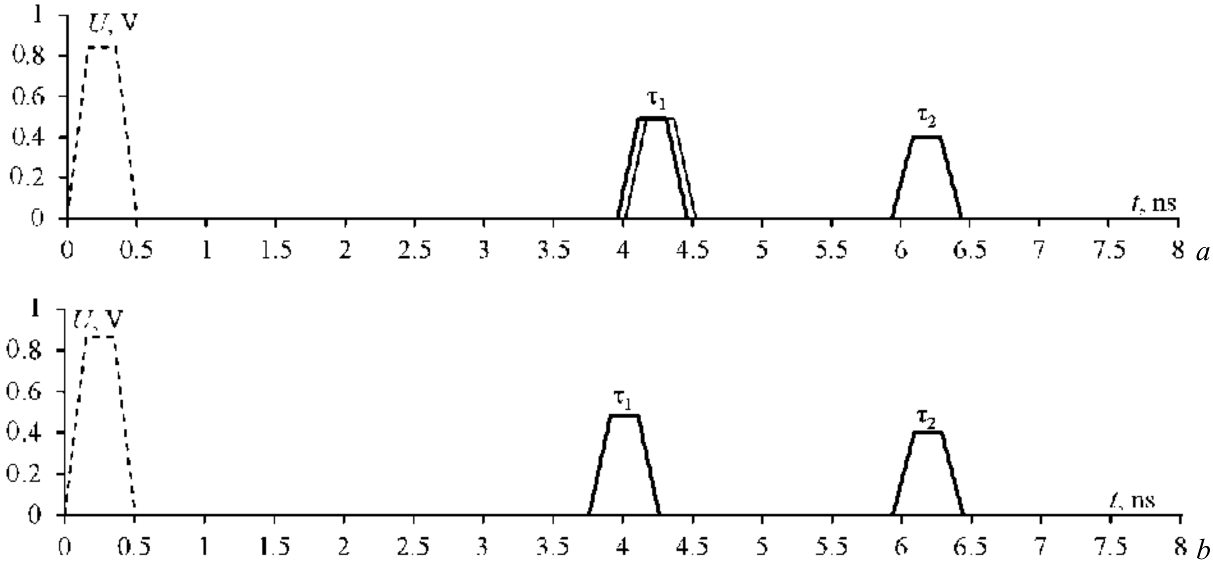


Figure 4. Voltage waveforms at the MF input (– –) and MF output with all reference conductors (–) and without two diagonal conductors (–) at s=600 (a), 2000 (b) μm

3.3. The influence of the distance from the shield to conductors on the USP decomposition

A study of the change in the distance from the conductors to the shield ($h1$) from 0.5 mm to 10 mm, in increments of 0.5 mm at s=500 μm was performed. The corresponding dependences of per-unit-length delays (τ_i) and pulse amplitudes (U_i) at the MF output are shown in figure 2. We can see that as $h1$ increases, the values of τ_1 and τ_2 become greater for the two MFs. However, the difference in per-unit-length delays becomes lower. Thus, for the MF with all conductors, at $h1$=0.5 mm, τ_2–τ_1=1.84 ns/m and, at $h1$=10 mm, τ_2–τ_1=1.77 ns/m; and for the MF without diagonal conductors the difference is 1.92 ns/m and 1.82 ns/m, respectively. When $h1$ starts from 3 mm, τ_i almost ceases to change for both MFs, i.e. the influence of the shield on the decomposition of the USP is almost absent. For two MFs, with increasing $h1$, U_1 decreases and U_2 increases. However, because the first mode propagates mainly in the air, the change of $h1$ has more effect on U_1. A greater effect on U_1 is observed in the MF without two diagonal conductors. When $h1$ is more than 5.5 mm, the pulse amplitudes are almost equal (U_1=0.423 V and U_2=0.421 V). The change in $h1$ has little effect on U_2. For example, starting from 2.5 mm, U_2 does not change (for both MFs U_2=0.421 V). The example of simulation results for voltage waveforms at the MF input and output are shown in figure 4.

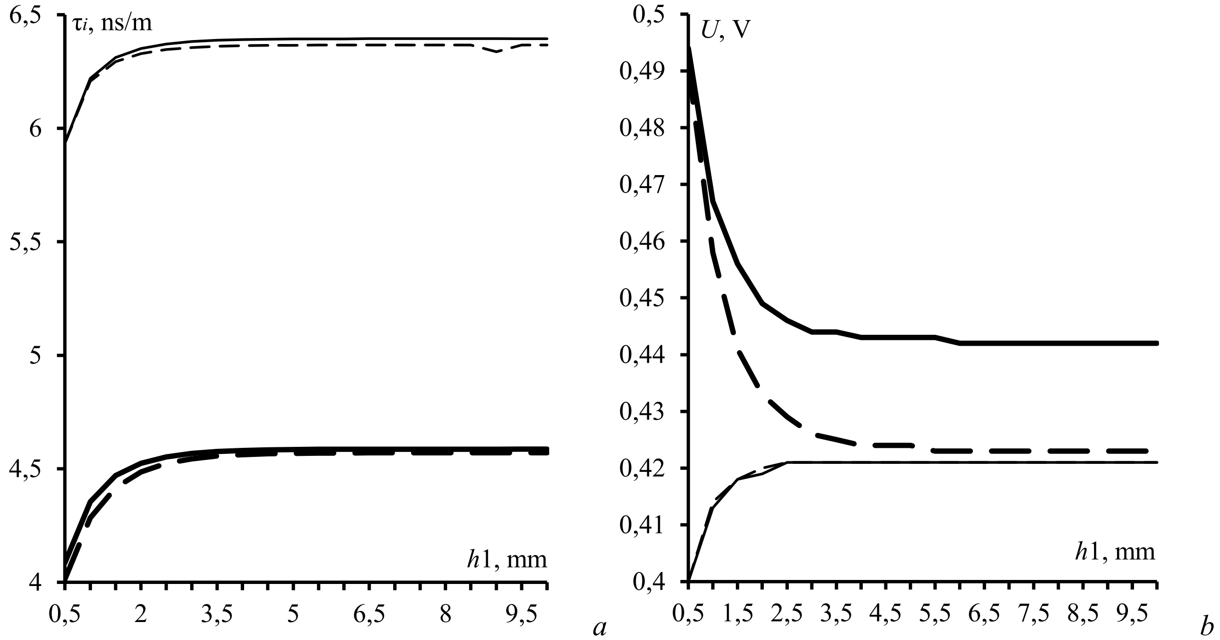


Figure 5. Relationship between τ_1 (–), τ_2 (–) on $h1$ (*a*), and U_1 (–), U_2 (–) on $h1$ (*b*) for the MF with all conductors; and τ_1 (– –), τ_2 (– –) and $h1$ (*a*), and U_1 (– –), U_2 (– –) and h_1 (*b*) for the MF without diagonal conductors

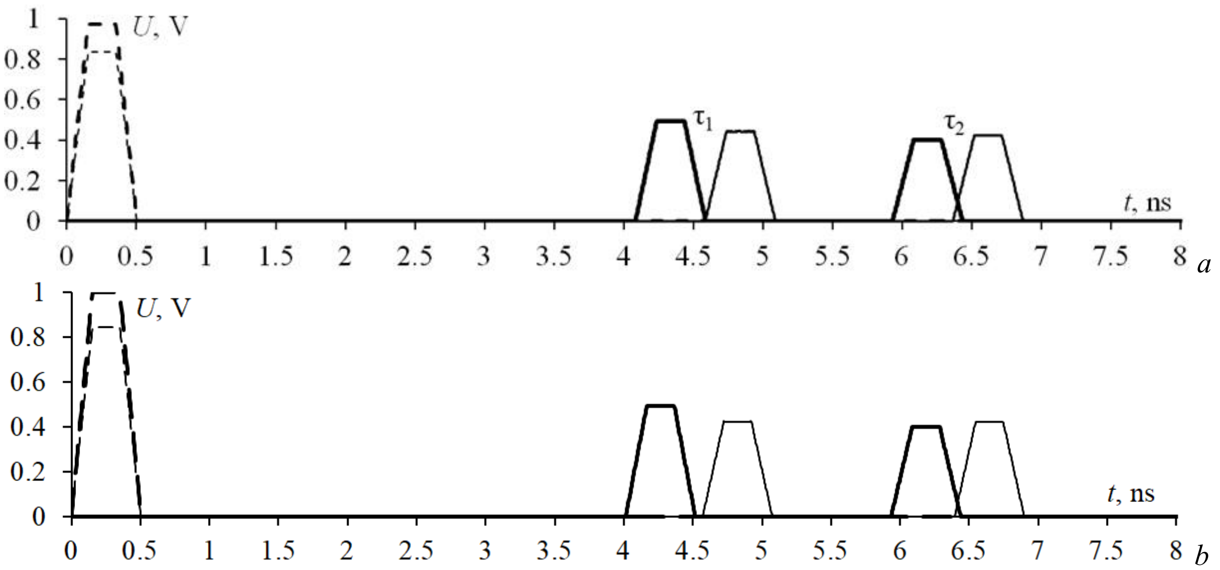


Figure 6. Voltage waveforms at the MF input at $h1$=0.5 mm (– –), $h1$=10 mm (– –) and the MF output at $h1$=0.5 mm (–), $h1$=10 mm (–) for the MFs with all diagonal conductors (*a*) and without them (*b*)

4. Conclusion

Thus, the paper shows that the connection of the reference conductors with a shield realized in the MF on a double-sided printed circuit board allows you to achieve approximately the same decomposition of the USP, regardless of the number of reference conductors. Their influence is reduced and, in fact, replaced by the shield. The influence of the shield on the USP decomposition is shown on the example of two MFs. As $h1$ increases, the values of τ_1 and τ_2 increase, but their difference decreases. When the shield moves away from the conductors, the amplitude of the first pulse decreases, and the second pulse increases. The greatest influence occurs on the amplitude of the first mode. A greater effect on U_1 is observed in the MF without two diagonal conductors. When $h1$ starts from 3 mm, the per-unit-length delays and pulse amplitudes for two MFs cease to change. This implies that the influence of the shield (with such MF parameters) becomes minimal. The revealed results highlight the relevance of more detailed studies of the effect of the shield on the USP decomposition in the MF on a double-sided printed circuit board.

Acknowledgments
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References

[1] Kucera M and Sebok M 2016 *Diagnostic of Electrical Machines and Insulating Systems in Electrical Engineering*. pp 1–6
[2] Gizatullin Z M and Gizatullin R M 2016 *Journal of Communications Technology and Electronics*. **5** 546–550
[3] Arnesen O H, Krogager E, Bäckström M, Bø-Sande S., Godø J. and Härkönen S. *EMC Europe Workshop*, (Rome, September 2005) **5**
[4] Gazizov A T, Zabolotsky A M and Gazizova O A 2015 *Proc. 16th International conference of young specialists on micro/nanotechnologies and electron devices* (Erlagol, Russia) p 120
[5] Samoylichenko M A 2021 *Systems of Control, Communication and Security*. **4** 58–71
[6] Samoylichenko M A and Gazizov T R 2021 *JOP: Conference Series.* **012020**
[7] Gazizov T R Sagiyeva I Ye and Kuksenko S P 2019 *Complexity*. **2019** 11