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UDC 621.391.825

# ADDITIONAL PULSES IN THE TIME RESPONSE OF A MODAL FILTER ON A DOUBLE-SIDED PRINTED CIRCUIT BOARD WITH TWO DIAGONAL REFERENCE CONDUCTORS

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In this paper, we consider additional pulses that appear in a modal filter (MF) realized on a double-sided printed circuit board when two of four reference conductors are diagonally removed. For the MF under consideration, the additional pulse delays are determined by a linear combination of per-unit-length delays multiplied by the line length. The authors found that with the removal of two diagonal reference conductors, there occur fewer additional pulses than with all reference conductors or with the removal of one reference conductor (upper left, lower left, or upper right). The amplitudes of the additional pulses are smaller than the amplitudes of the main mode pulses.
**Keywords:** modal filter, additional pulses, reference conductor.

Ensuring electromagnetic compatibility is relevant because the variety and number of modern electronic equipment is constantly growing. In real operating conditions, the performance of electronic equipment is frequently reduced under the influence of electromagnetic interference (EMI). Nanosecond and subnanosecond pulses (or ultrashort pulses (USP)) are especially dangerous because they can penetrate electronic equipment bypassing protection devices, and impair the operation of electrical circuits [1]. The current protection devices are not able to adequately protect against USPs. New protection devices called modal filters (MFs) have been proposed [2].

In [2] the appearance of additional pulses in various MFs is considered. It was theoretically and experimentally established that extra pulses are a new resource for improving MF efficiency. The study in [3] that examined the effect of removing one or two reference conductors in an MF on a double-sided PCB to reduce mass unexpectedly revealed the presence of additional pulses. In [4], the authors investigated the occurrence of additional pulses in the MF realized on a double-sided printed circuit board with one reference conductor removed. But the additional pulses appearing when two reference conductors were removed have not been investigated. Therefore, the purpose of this work is to study additional pulses in the MF on a double-sided PCB, which occur with the removal of two diagonal reference conductors.

The cross section of the MF under consideration is shown in Fig. 1, *a* and its connection diagram is shown in Figure 1*b*. The simulation was performed with $t$ = 70 μm, $h$ = 0.5 mm, $w$ = 1 mm, $s$ = 0.5 mm, $R1 = R2 = R3 = R4$ = 50 Ω, and the MF length ($l$) of 7 m.

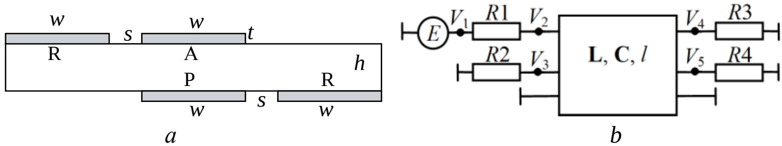
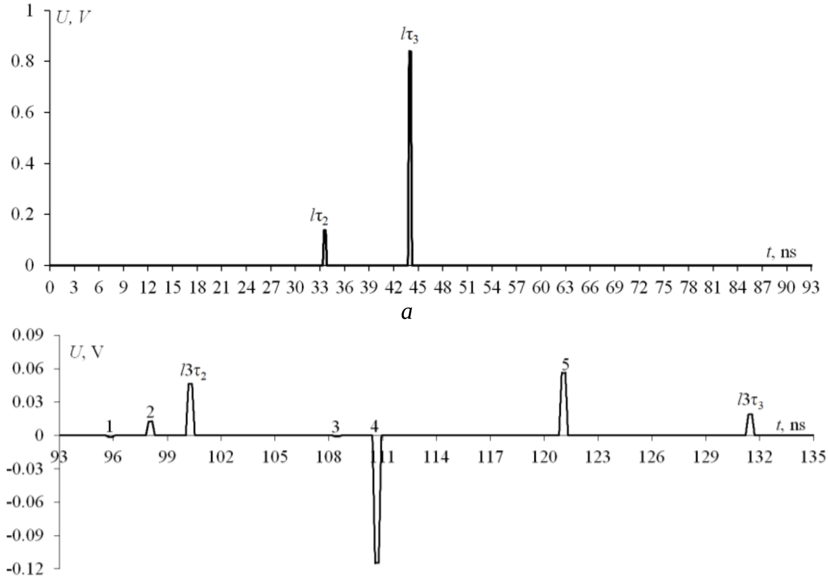



Fig. 1. MF cross section (*a*), where the conductors:
*R* – reference, *A* – active, *P* – passive; and MF connection diagram (*b*)

Figure 2, *a* shows the simulation results at the MF output with a single pass of the mode pulses over the line and Fig. 2, *b* with a triple pass. As can be seen in the figure, there are no additional pulses between the pulses of modes in the case with a single pass, while in the case with three passes they appear. The additional pulses have both negative and positive polarity. The amplitudes of the additional pulses are less than the amplitudes of the main mode pulses. Thus, when two reference conductors are removed, only 5 additional pulses are observed. However, when all reference conductors are present, their number is 29, and when one is removed (upper left, lower left, or upper right), there are 16 of them [4]. Table 1 shows the values of the per-unit-length modal delays and arrival times of the mode pulses. Table 2 shows the resulting combinations and the arrival times for additional pulses. Thus, from Table 1 it can be seen that the additional pulse delays are determined by a linear combination of per-unit-length delays multiplied by the line length.

Thus, the results show that with the removal of two diagonal reference conductors there are fewer additional pulses than with all reference conductors or with the removal of one reference conductor. It is relevant to study the additional pulses for situations when the boundary conditions at the ends of the passive conductor in all the proposed MF structures change. This is important because in some MFs with the change of boundary conditions at the ends of the passive conductor, the amplitudes of the additional pulses are greater than the amplitudes of the main modes. For example, it is observed in the MF with a passive conductor in the cutout of the reference plane.




*b*

Fig. 2. Voltage waveforms at the MF output with a single pass of the mode pulses over the line (*a*) and with a triple pass (*b*)

Table 1

**Per-unit-length mode delays (ns/m) and mode pulse arrival times (ns)**

| $\tau_1$ | $\tau_2$ | $\tau_3$ | $l\tau_1$ | $l\tau_2$ | $l\tau_3$ | $l3\tau_1$ | $l3\tau_2$ | $l3\tau_3$ |
|---|---|---|---|---|---|---|---|---|
| 4.446 | 4.763 | 6.248 | 31.122 | 33.34 | 43.74 | 93.36 | 100.02 | 131.22 |

Table 2

**Arrival times for additional pulses (ns)**

| $l(2\tau_1+\tau_2)$ | $l(\tau_1+2\tau_2)$ | $l(\tau_1+\tau_2+\tau_3)$ | $l(2\tau_2+\tau_3)$ | $l(2\tau_3+\tau_2)$ |
|---|---|---|---|---|
| 95.584 | 97.802 | 108.202 | 110.42 | 120.821 |

The reported study was funded by RFBR according to the research project №20-37-90033.

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UDC 521.315.82.2

# RESISTIVE-CAPACITIVE PROFILING OF HETEROSTRUCTURES WITH QUANTUM WELLS

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The equivalent circuit of a heterostructure with quantum wells (QWs) is constructed. The circuit takes into account the p-n junction differential capacitance and its resistance, the capacitive and resistive properties of the capture-emission processes of free charges and their radiative recombination in QWs.

**Keywords:** equivalent circuits, series-parallel chains, quantum wells, heterostructure.

A possible method for analyzing a heterostructure (HS) with QWs have been the equivalent circuit (EC) method. This method is implemented by representing the structure in a resistor-capacitor (RC) circuit form, which allows using the theory and physical properties of the RC circuit. This technology has been widely used in the development of devices based on bulk semiconductors, as well as in studying the properties of «metal-dielectric-semiconductor» heterostructures [1, 2]. The advantage of the method is the simplicity of analyzing complex processes occurring in a semiconductor. That is, an RC circuit is introduced instead of the complex physical processes of the electron flow in a semiconductor, which is equivalent to these physical processes. The EC parameters are selected so that their active and reactive properties are similar to the dispersion and inertial HS properties.