Experimental Confirmation of the Modal Filtration in Four- and Five-conductor Microstrip Lines

Anton O. Belousov, Alexander M. Zabolotsky, Timur T. Gazizov
TUSUR University, Tomsk, Russia

***Abstract*— An experimental confirmation of modal filtration based on multiconductor microstrip lines is executed. Authors designed four- and five-conductor prototypes of modal filters (MF), which have the maximum amplitude of the decomposition pulses of 12.6 and 15.3 times less in comparison with the initial signal. The results showed the prospect of research of multiconductor MF because addition of conductors to the initial structure additionally (up 2.3 times) decreases the amplitude of the initial signal at the end of the active conductor.**

***Index Terms* - multiconductor microstrip line, experimental confirmation, protection device, modal filtration, optimization.**

I. Introduction

COUPLED lines have been intensively studied for a long time. Meanwhile, attention to the distortions of a signal in the active line is not sufficient: distortions are shown in real example of three coupled microstrip lines [1]; minor distortions can be seen from the example of two coupled lines in the presence of significant signal reflections; moreover, it is shown that distortions may occur because of the losses in the ground. However, these distortions can bring benefits, in particular, for protection.

A technique of modal filtration [2] was proposed for the protection of electronic equipment against ultrashort pulses [3]. This technique is based on modal decomposition of a pulse signal in multiconductor transmission lines which occurs due to difference between modal delays. Paper [4] represents the results of simulation of a microstrip line (MSL) consisting of two, three, four and five conductors and shows decomposition of an input pulse at the end of a conductor into 2–5 pulses with the maximum amplitudes of 3, 3.6 and 4.5 times (correspondingly) less than a signal in the near end of a line. Optimization showed that equalization of differences of delays of the pulses allows to increase duration of a pulse which is going to be completely decomposed in these structures [5]. In addition, the optimization of multiconductor MF is performed by criteria of minimization of the maximum output amplitude and maximization of a difference of time delays between the first and the last decomposition pulses [6]. Paper [7] introduces an experimental confirmation of the feasibility of modal filtering based on two- and three-conductor MF prototypes with the maximum pulse amplitude 11.5 and 13.7 times less in comparison with the initial signal [7]. Meantime, paper [7] experimentally confirms feasibility of modal filtering only for two - and three- conductor line, therefore it cannot completely confirm the effectiveness of a multiconductor MF with the increased number of conductors. Therefore, an experimental confirmation of modal filtering is appropriate for the multiconductor MSL with four and five conductors. The aim of this paper is to perform such research: make the prototypes of four- and five-conductor MF perform the experiment and compare the results of experiment and simulation.

II. Prototypes of Multiconductor MF

Manufacturing of multiconductor MF prototypes is based on the structures and the results from the papers [4–6]. However, for the manufacture of printed circuit board (PCB), you need to perform simulation and optimization based on the technological parameters: the minimum value of conductor width and conductor spacing (w, s) is 0.2 mm for thickness of a conductor (t) being 18 μm and 0.25 mm for thickness of the conductor t = 35 μm; dielectric thickness h = 0.5; 1; 1.5 mm.

Parameters and forms of a signal were calculated in TALGAT software [8]. It was assumed that a T-wave is propagating along the considered lines. Losses in conductors and dielectrics were considered. A digitized signal of oscilloscope C9-11 was used as an initial pulse, it was measured at 50 Ω load, with an amplitude of 0.657 V. Durations of rise – 27 ps, fall – 29 ps and flat top – 9 ps, so that the overall duration – 65 ps. (Durations were measured by levels of 0.1–0.9).

As a result, there are the following parameters of PCB for manufacture of a multiconductor MF prototype: w = 1000 μm, t = 18 μm and h = 500 μm, relative permittivity is ε_r = 4.5 and dielectric loss tangent tgδ = 0.017, measured at a frequency of f = 1 MHz. The value of w was optimized in order to assure 50 Ω characteristic impedance of a single line and it was unchanged, as well as the values of t, h and ε_r. Values of s_i are different for all lines, as they were optimized by criterion of minimization of the maximum voltage of a waveform at the output of a MF [4]. In the case of four-conductor MSL s = 200, 720 and 550 μm, for five-conductor – 200, 220, 200 and 800 μm, correspondingly. Cross sections of MSL with the specified parameters are shown in Fig. 1.

Prototypes of MSL are presented in Fig. 2 (a prototype of single MSL was also made for comparison). Length of each MSL is equal to 60 cm. At the ends of passive conductors, for N = 4, and 5, resistors of 50 Ω are set. SMA connectors

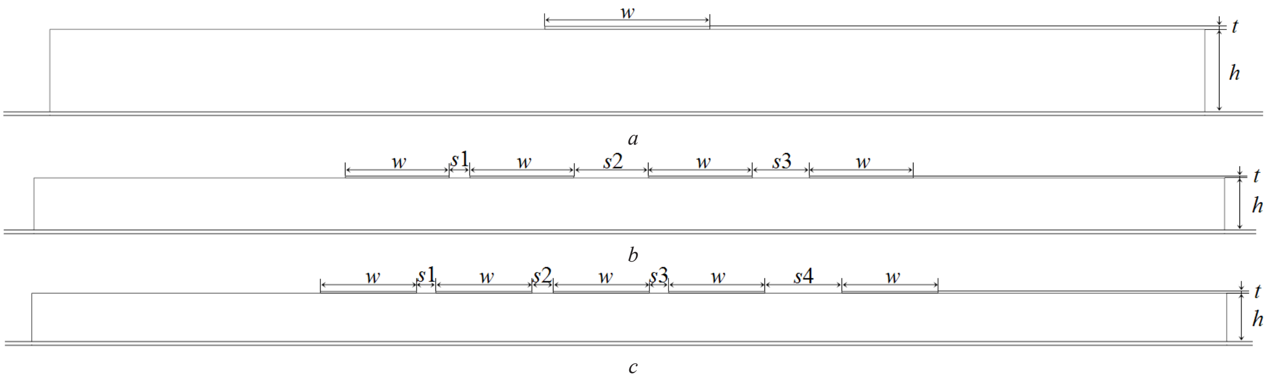

Fig. 1. Cross sections of one- (a), four- (b) and five- (c) conductor MSL

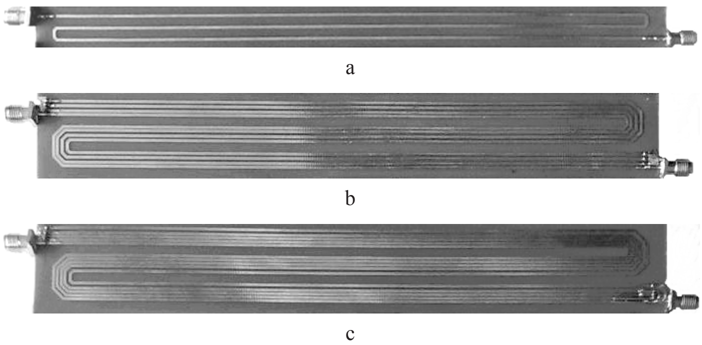

Fig. 2. Prototypes of one- (*a*), four- (*b*) and five-conductor (*c*) MSL

are installed to connect the prototypes to the measuring channel.

III. Description of the Experiment and Results

The scheme from Fig. 3 was used for the experiment. Before the experiment, software calibration of a channel was performed. Therefore, the error of measurement of time is less than ±1% and voltage – ±7%. To connect a prototype to a generator and stroboscopic converter device C9-11, we used two additional coaxial adapters PK2-20-03R-13 and one coaxial adapter 2.236.482, which provide additional delay of about 116 and 104 ps, respectively, so that the total delay is 336 ps.

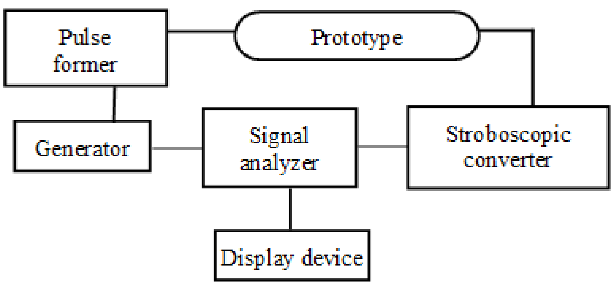

Fig. 3. Experimental scheme

Measured waveforms at the input and output of one-, four- and five-conductor MSL are presented in Fig. 4, *a*–*c*. Values of the maximum pulse amplitude are 6.6; 12.6; 15.3 times less than the initial signal amplitude during the experiment (Tab. I). The simulation (see Fig. 4, a–c) showed that the values of the maximum amplitudes measured without losses are 2; 6; 8 times less than the initial signal amplitude, and the values measured considering losses are 6.4; 18.25; 22 times less (see Tab. I). The discrepancy between the simulation results may be due to inaccurate calculation of loss matrices for conductors and dielectrics, as well as the neglect of influence of frequency dependence of the relative permittivity of the prototype material. Experimental results are close to results of simulation considering losses. Thus, the experimental results confirm the possibility of expansion of the initial pulse at the end of the active conductor of four- and five-wire MSL, that was previously confirmed via simulation only (see Fig. 4, *a*–*c*).

TABLE I
The Maximum Value of Pulse Amplitude

N	max(U), V		
	Simulation without losses	Simulation with losses	Experiment
1	0.33	0.103	0.099
4	0.11	0.036	0.052
5	0.084	0.03	0.043

IV. Conclusion

Three prototypes based on MSL have been developed. It is shown that in the four- and five-conductor structures of MF original signal is decomposed into four or five pulses. The

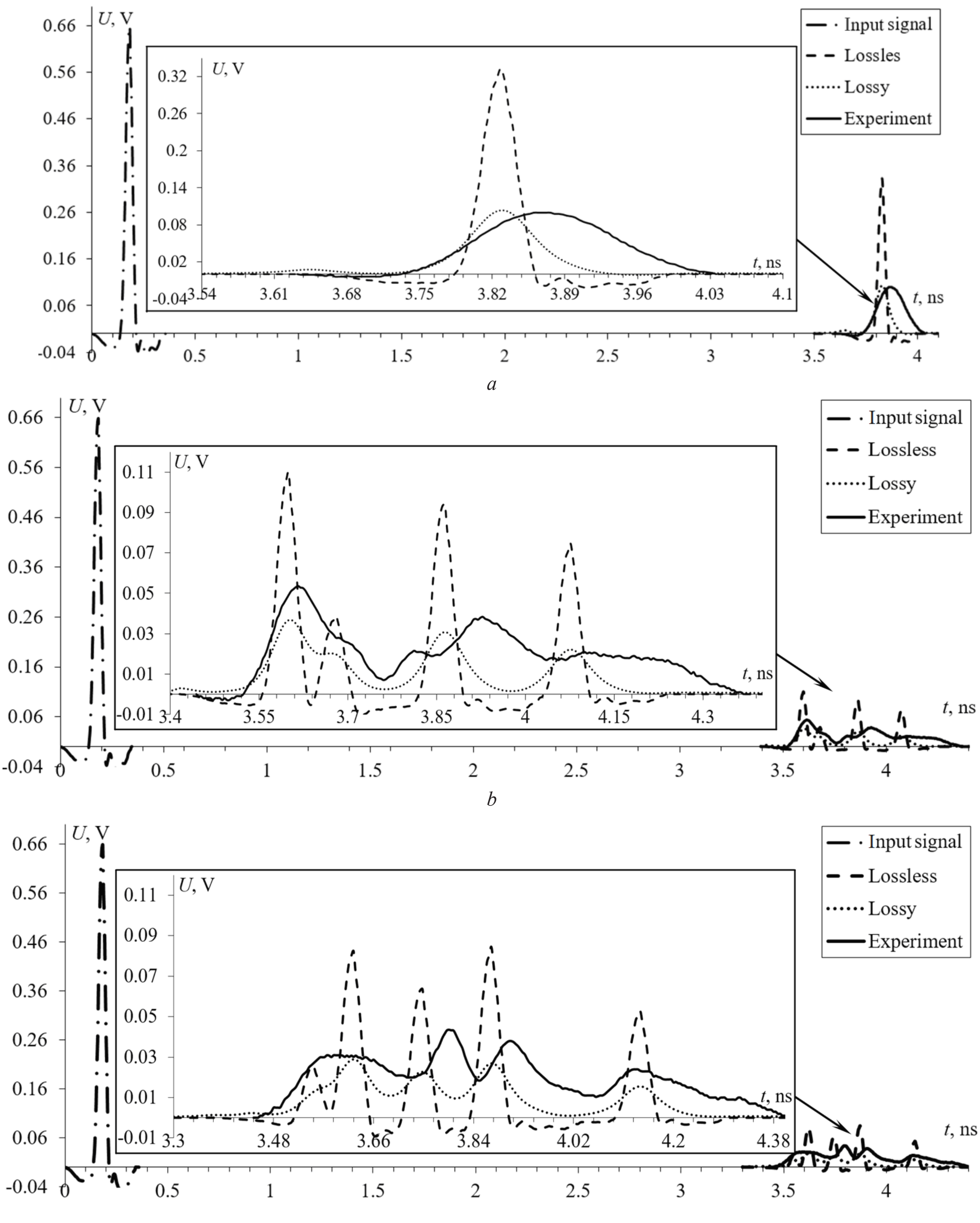

Fig. 4. Waveforms of signal at the input (–·–·–) and output (with their enlarged fragments) single- (a), four- (b) and five-conductor (c) MSL, resulting from the simulation excluding (---) and including (····)losses, via experiment (——)

maximum values of amplitudes are 12.6; 15.3 times less than the initial amplitude. To summarize, the experimental data confirms the results of simulation and the idea of improving the protection of ultrashort pulses by adding to the existing structure additional conductors. (It is assumed that spectrum of a useful signal is not attenuated by MF).

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Belousov Anton Olegovich received the B.E. degree of TUSUR in 2015. Currently, he is a first year master student and is working as an engineer at TUSUR. He is the author of 9 scientific papers.

Alexander Mikhailovich Zabolotsky received an engineering degree in 2004 and the Ph.D. degree of TUSUR in 2010. Currently, he is working as a senior research fellow at the TUSUR. A.M. Zabolotsky is the author of 164 scientific papers including 6 books.

Timur Talgatovich Gazizov received an engineering degree in 2007 and the Ph.D. degree in 2008 at TUSUR. Currently, he is working as a senior research fellow in the TUSUR. T.T. Gazizov is the author of 72 scientific papers including 3 books.