Propagation of Pulse Signals in the Turn of a Meander Microstrip Delay Line

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***Abstract*—The paper describes the results of simulating propagation of information and interference signals in the turn of a meander microstrip line (MSL), performed for the first time in one paper. For this we used quasistatic and electrodynamic approaches. The simulation results obtained by these approaches are in good qualitative agreement, but for short pulses they are poorly quantified. It was revealed that not all useful signals pass through the meander line without significant distortions. The simulation showed attenuation of interference signals by 1.3–2 times. The work presents some assumptions about the causes of such small attenuation and proposes possible ways for increasing it.**

Keywords—meander delay line, ultrashort pulse, pulse decomposition, band pass.

I. Introdution

Radioelectronic equipment (REE) found its application in the life of modern people long ago. However, complemented by the increase of frequencies and a decrease of amplitudes of useful signals, there is an acute need for its protection against electromagnetic interferences, in particular pulses of nanosecond and picosecond ranges. Such ultrashort pulses have a short rise time, high amplitude and a wide spectrum, because of which they are able to penetrate into the REE, bypassing shields and protective equipment, and lead to PCB elements damage. The danger of such impacts to society is caused by the possibility of their use by criminals for terrorist purposes. For example, there is a well-known incident of using an ultrashort pulse generator by Chechen fighters to block communications of the detachment which belonged to Russian Federation Ministry of Internal Affairs [1].

There are many studies of various devices based on using strip lines to protect REE against ultrashort pulses and to filter signals in frequency domain [2–7]. A remarkable approach to protecting REE against ultrashort pulses is based on the use of meander delay lines [8], which allows minimizing the ultrashort pulse amplitude at the output of the line without resorting to additional elements on the PCB. A detailed analysis of one turn of a meander line has been executed in [9]. In their study, the authors obtained time responses to the ultrashort pulse interference and the frequency dependences of $|S_{21}|$, and experimentally proved the possibility of ultrashort pulse decomposition in the turn of the meander line. Meanwhile, apart from the obtained frequency dependences $|S_{21}|$, the other studies of the useful information signal propagation in the turn of the protective meander line have not been performed. Moreover, note that as an acting signal they took the ultrashort pulse with an idealized waveform. Therefore, it is reasonable to investigate the propagation of useful and interference signals in the meander line, and to provide the reliability of the results, simulation should be performed by two different approaches: quasistatic and electrodynamic.

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The aim of this paper is to investigate the pulse signal propagation in the turn of a meander microstrip line (MSL). To achieve this aim it is necessary to solve the following tasks: select information and interference signals as an impact; perform quasistatic and electrodynamic simulation of the response to the selected impacts; perform a comparative analysis of the results.

II. Structure and Diagram for Simulation

In the cross-section, the line under investigation is a coupled MSL without covering layers of mask and varnish (Fig. 1). The parameters of the line cross-section were chosen the same as in paper [3]: w=2500 μm, t=35 μm, h=2000 μm, s=250 μm, l=90 mm, ε_r=5,4. The chosen parameters of the line cross-section ensure its matching with the measuring tract of 50 Ω.

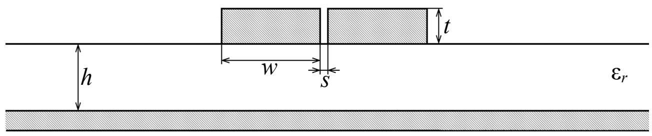

Fig. 1. Cross-section of the meander MSL.

Fig. 2 shows a schematic diagram of the line. It consists of two parallel conductors interconnected at far end. One of the conductors at the near end of the line is connected to a pulse source, which is presented by the ideal e.m.f. source and the internal resistance $R1$. Another conductor is connected to a receiving device, which is shown in the diagram as $R2$. Resistances $R1$ and $R2$ are choosen equal to 50 Ω.

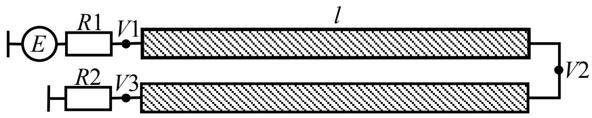

Fig. 2. Schematic diagram of the meander MSL.

III. Choosing the Signals for Simulation

A. Useful signals

REE uses a large number of single or periodic pulse signals for digital data transmission. The sources of such digital signals are integrated circuits (IC). In the civilian REE, the family of 74 ICs are widely used, the simplest of which are the TTL series ICs [10]. Fig. 3 shows the waveforms inherent to the 74-type family of ICs used in the simulation, and Table I summarizes their characteristics: the frequency limit (f_{max}), the duration of the rise (t_r), fall (t_f), and the flat top of the pulse (t_d). Note that in the simulation, only the waveforms of real impacts were taken into account, and all EMF amplitudes were taken at 1 V.

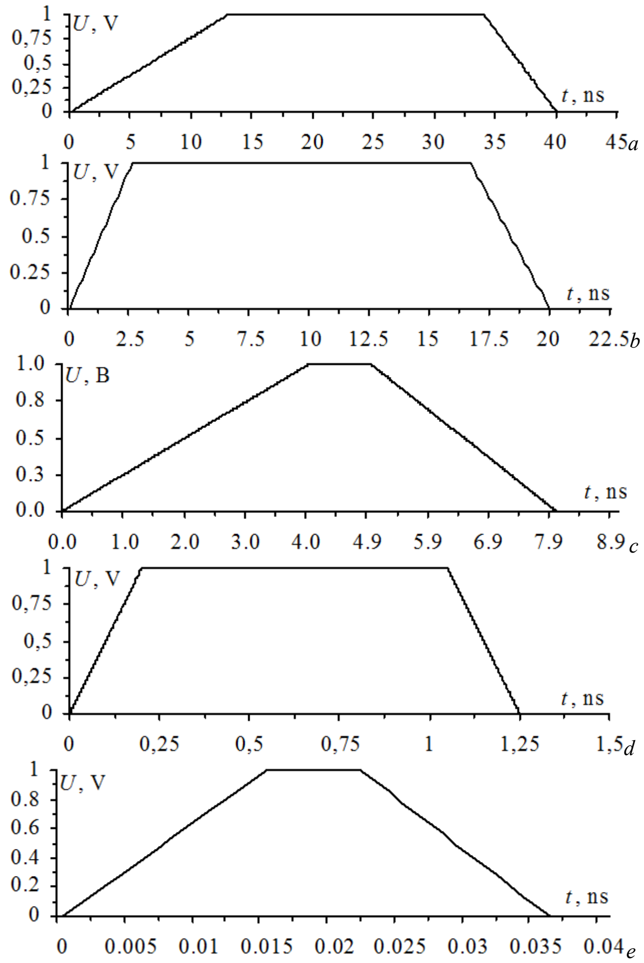

Fig. 3. Signal waveforms of the 74F04 (*a*), 74HCT (*b*), 74F (*c*), LVPECL (*d*), HMC (*e*) ICs.

TABLE I. CHARACTERISTICS OF 74-TYPE IC FAMILY SIGNALS

IC	f_{max}, MHz	t_r, ns	t_f, ns	t_d, ns
74F04	25	13	6	21
74HCT	50	2.6	3.29	14.11
74F	125	3.01	4	0.99
LVPECL	800	0.2	0.2	0.85
HMC	28000	0.014	0.015	0.007

B. *Interference signals*

Currently, ultrashort pulse generators are increasingly used as a means of radioelectronic warfare (REW) [11]. The first attempts to create such generators were made with the aim of creating picosecond locators, but soon there was discovered a potential possibility to increase their power manifold in order to disrupt the onboard REE, which led to further development of ultra-wideband radiation generators as an REW device. The specialists at the Institute of High Current Electronics of the Siberian Branch of Russian Academy of Sciences have tested a generator of the ultra-wideband (UWB) radiation, in which peaking and shearing arresters are used to form a signal fed to the input of the antenna array of 16 elements [12]. However, UWB pulse generators which include a tunable short closed stub that allows forming a bipolar pulse [13] also find their practical application.

Within this study, for simulation we used interference pulses (Fig. 4) from the output of the above mentioned generators with an amplitude of 1 V: an ultrashort pulse generator (*P*1), an antenna array of a UWB radiation generator (*P*2), a UWB pulse generator with a tunable short closed stub (*P*3).

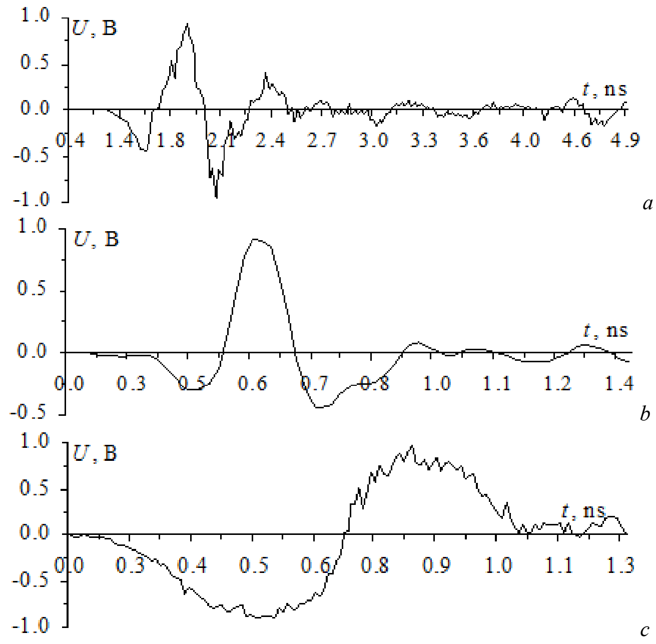

Fig. 4. Waveforms of the interfence signals P_1 (*a*), P_2 (*b*), P_3 (*c*).

IV. SIMULATION RESULTS

A. *Propagation of useful signals in the meanderMSL*

Fig. 5 shows the waveforms of useful signals (Fig. 3) at the end of the meander MSL obtained using quasistatic and electrodynamic approaches.

It can be seen that the waveforms which correspond to 74F04, 74HCT and 74F ICs are practically not distorted. But the waveforms of LVPECL and HMC ICs have marked distortions. For example, Fig. 5d shows that the rise of the main LVPECL IC signal pulse is superposed by the same pulse with smaller amplitude, which appears due to the properties of the turn of the meander MSL and is actually a crosstalk from the main signal at the near end of the line. This phenomenon is described in detail in [9] and occurs because of the selected parameters of the turn that fulfill the conditions for decomposing interference ultrashort pulses with a duration of less than 0.2 ns into three pulses (crosstalk at the near end of the line and odd and even modes). Since the duration of the LVPECL IC signal is somewhat more than 0.2 ns, the signal is incompletely decomposed. Fig. 5e shows that the HMC signal at the end of the meander MSL is represented by a sequence of three main pulses: crosstalk, odd and even modes. Thus, the HMC IC signal is completely decomposed in the turn of the meander MSL, since its duration is only 0.036 ns (which is much less than 0.2 ns).

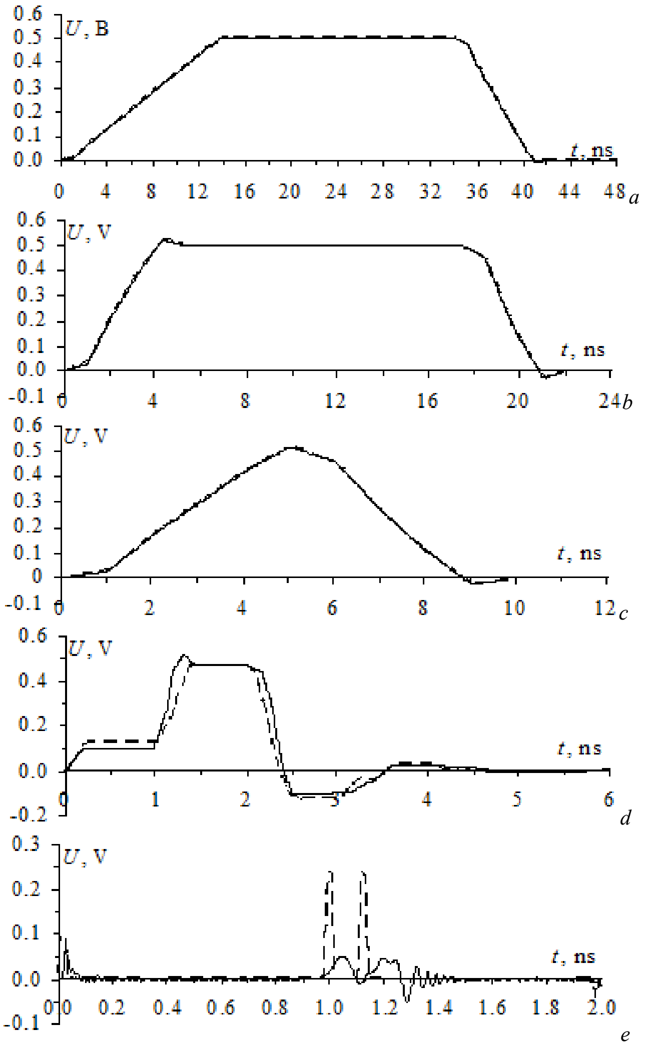

Fig. 5. Useful signal waveforms of 74F04 (*a*), 74HCT (*b*), 74F (*c*), LVPECL (*d*), HMC (*e*) ICs at the end of the meander line, obtained by using quasistatic (—) and electrodynamic (– –) approaches.

As for the consistency of the results of the quasistatic and electrodynamic approaches, the 74F04, 74HCT and 74F signals have the same waveforms at the end of the meander MSL. As can be seen from Fig. 5d, when the electrodynamic approach is used, there are small differences in the waveform and fall of the main pulse. Fig. 5e shows that the signal amplitude and waveform are significantly different when different approaches are used. For example, with the quasistatic approach the maximum signal amplitude at the end of the meander MSL is about 0.25 V, and with the electrodynamic approach it is about 0.07 V. It can be seen from the waveform that the duration of the last two pulses (odd and even modes) for the electrodynamic approach is somewhat longer in comparison with the quasistatic approach. Thus, this meander MSL can only be used with 74F04, 74HCT and 74F signals.

B. Propagation of the interference signals in the meander MSL

Fig.6 shows the interference waveforms (Fig. 4) at the meander MSL output obtained with both quasistatic and electrodynamic approaches. Table II presents their U_{max} and attenuation (in relation to the signal waveform at the line input). It can be seen that the waveforms and amplitudes of interference signals change when they propagate through a meander MSL. In addition, the waveforms and amplitudes of signals P_1 and P_3, calculated with the use of quasistatic and electrodynamic approaches, have hardly any differences, but P_2 signal differs significantly. For example, when the electrodynamic approach is used, pulse P_2 at the end of the meander MSL is completely decomposed into the odd and even mode pulses of the line (second and third pulses), whereas with the quasistatic approach, the pulses of the odd and even modes overlap each other. Moreover, pulse P_2 at the end of the meander MSL has the lowest amplitude among other interference pulses, which is caused by its complete decomposition into three pulses. Thus, when the quasistatic approach was used, the attenuation was 3.14 times, and when electrodynamic approach was used – 3.45 times.

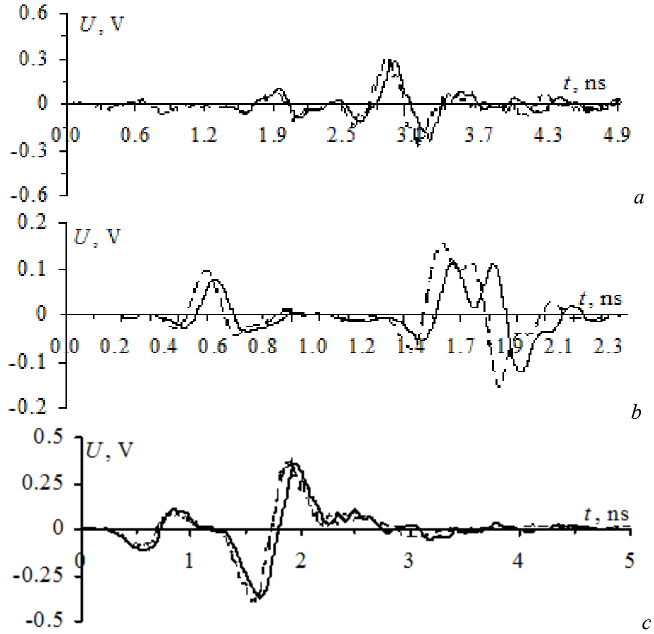

Fig. 6. Interference signal waveforms P_1 (*a*), P_2 (*b*), P_3 (*c*) at the end of the meander line, obtained using quasistatic (– –) and electrodynamic (—) approaches.

TABLE II. MAXIMUM AMPLITUDE (U_{MAX}) AND ATTENUATION OF INTERFERENCE SIGNALS AT THE END OF THE MEANDER MSL

Interference pulse	*Quasistatic approach* U_{max}, V	*Quasistatic approach* *Attenuation, times*	*Electrodynamic approach* U_{max}, V	*Electrodynamic approach* *Attenuation, times*
P_1	0.33	1.51	0.29	1.59
P_2	0.15	3.14	0.11	3.45
P_3	0.39	1.29	0.36	1.33

V. CONCLUSION

For the first time, results of simulation of the information and interference signal propagation in a turn of a meander MSL was performed in one paper. The approaches used were quasistatic and electrodynamic. The simulation results obtained by these approaches are in good qualitative agreement (the expected distortion of the waveform was observed), but for short pulses they are poorly quantified. The differences are caused by taking into account the higher types of waves during the simulation with the electrodynamic approach. This result in the lengthening of the rises and falls of the pulses and lead to significant distortions. It is shown that useful signals from 74F04, 74HCT, and 74F ICs when propagating through the meander MSL are hardly distorted, and from LVPECL and HMC ICs are badly distorted. Therefore, in practical application of protection devices, first it is advisable to analyze the signals on the PCB, and then choose the parameters of the protective lines so as to minimize distortions of useful signals. It is revealed that the interference signals from the output of the ultrashort pulse generator, the antenna array of the UWB radiation generator, and the UWB pulse generator with a tunable short closed stub are badly distorted in the meander MSL, and their amplitude decreases by 1.3–3.4 times. A relatively small attenuation of the interfering signals result from the weak coupling between the conductors of the turn (due to the small thickness of the conductor) and other non-optimal parameters of the cross-section. For example, in a broad-side coupled line, more significant attenuation can be achieved. Thus, in practical implementation of protective devices based on the meander MSL, it is necessary to take into account the parameters of both useful and possible interference signals inherent to specific REE application field. And, if useful signals are distorted or interference signals are insufficiently attenuated in the investigated meander MSL, it is necessary to perform additional optimization of its parameters.

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