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Transmission Coeficient Frequency Dependence of Protective Meander Line Turn up to 10 GHz

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***Abstract*—Results of the investigations of the turn of meander microstrip delay line in the frequency domain are presented. Computational and full-scale experiments were used as the methods for investigation. Firstly, the results of the preliminary optimization of the geometrical parameters of the turn for the matching with measuring channel are presented. Secondly, the simulation of the frequency dependence of the transmission coefficient module for four turns with the different separations of 300, 250, 200, 150 μm is executed. The simulation is carried out with and without losses in conductors and dielectric. Accounting of losses substantially (of 5–7%) increases the width of passband of the turn and moves all resonances to the higher frequencies. The acceptable consistency of the simulation and experimental results is obtained. It is revealed that the manufactured models have lower passband (equal 1.15 GHz). Possible causes of the difference between full-scale and simulation experiments are determined.**

Keywords*—ultrashort pulse; meander microstrip line; protection

I. INTRODUCTION

Electronic equipment (EE) protection against different interference (both internal and external) is becoming more urgent. The reason for this is the permanently increasing response speed of the modern EE and the increasing density of the printed circuit board interconnects. It seems that the most urgent is the protection of the EE of important objects of infrastructures against intentional interference of pulses with durations inclined to nanosecond range [1]. Such ultrashort pulses are able to penetrate into EE and due to high power and short duration they can cause malfunction of EE. Both circuit and constructive solutions are used for protection purposes; these methods have a number of disadvantages, the main of which is low power and response speed. In this regard, the traditional protection devices often do not provide the protection against strong ultrashort pulses [2]. Therefore it is necessary to conduct the investigation and the search for the new methods of the effective protection.

Approach to protection against ultrashort pulses, based on pulse decomposition into a sequence of pulses with lower amplitudes in the one turn of meander delay line was suggested [3–7]. The choice of the line parameters provides some simple conditions which provide the ultrashort pulse decomposition to the three main pulses with lower amplitudes relatively to initial amplitude. The first pulse is near end crosstalk, which comes to the end of the turn simultaneously with the main signal. The second and the third pulses (for simplicity we will call these pulses as the even and odd mode pulses) are resulting from the decomposition of even and odd mode of the signal in time. The results of the detailed analysis of the pulse signal distortions in one [3] and two [6] turns of meander line and the investigations of possible applications of the results for the design are considered in some papers [4, 5]. Besides the theoretical investigations, the full-scale experiment has been carried out and the possibility of the EE protection against ultrashort pulses based on the turn of meander line with the side [8] and broad-side coupling [9] has been experimentally proved. Despite the significant results obtained in this field, it is difficult to call this investigations comprehensive, because all the results were obtained only in time domain, while the investigations of protective delay lines in the frequency domain were not executed. Besides, on practice, the high-frequency signals with different durations and rise times are used in the equipment. The main deficiency of the mentioned papers is that they investigated propagation in the protective delay lines of only ultrashort pulses which are dangerous for the equipment. At the same time, the influence of the protective delay lines on the useful high-frequency signals has not been studied yet. Consequently, it seems necessary to conduct the investigation of frequency characteristics of the protective delay lines and other electronic devices. It is reasonable to start with the investigation of the transmission coefficient of a protective delay line turn in the frequency range. So the aim of this paper is to study frequency dependences of the transmission coefficient module of the one turn meander delay line. It is required to carry out simulation and full-scale experiments. The structure of the meander line from paper [8] can be suitable for this purpose. At first, we need to estimate the impact of losses in the conductors and dielectrics on the frequency dependences of the transmission coefficient

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module, and then to compare its results with the experimental results.

II. STRUCTURE AND CIRCUIT FOR MODELING

A. Cross-section of meander line turn

A simple structure is chosen for the investigation, it is one turn of meander based on coupled microstrip line. Detailed analysis of this structure in the time domain is carried out in paper [8], where besides the simulation, the full-scale experiment in time domain is executed. For this aim the printed circuit board with models of a turn of meander line with optimal choice of parameters is made.

Fig. 1 shows the cross section of the turn, where *w* and *t* are the width and the thickness of the signal conductors respectively, *s* is the separation of conductors and *h* is the thickness of the printed circuit board dielectric.

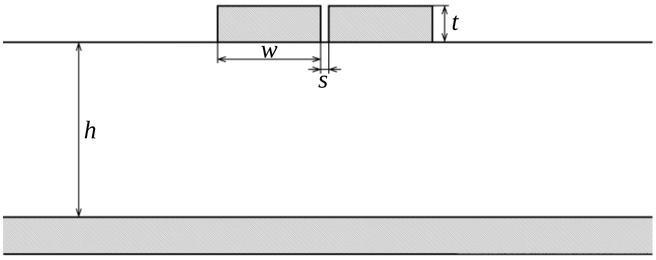

Fig. 1. Cross section of the meander microstrip line

B. Circuit of connections of the turn

Fig. 2 shows the electrical circuit of line connections for simulation. Detailed description of the circuit is given in paper [8].

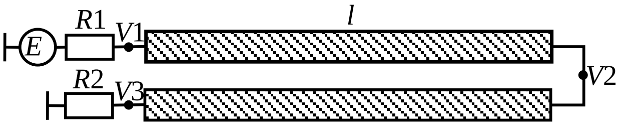

Fig. 2. Circuit of connections of the examined structure

III. SIMULATION AND MEASUREMENT OF FREQUENCY DEPENDENCE OF TRANSMISSION COEFFICIENT MODULE OF TURN

The initial parameters of the cross section are chosen so as to match the impedance of the meander line prototypes to the impedance of measuring channel of 50 Ω of the scalar network analyzer R2M-40 when measuring the transmission coefficient. Detailed description of the process of the cross section parameters optimization in TALGAT software [10], the manufactured printed circuit board view with the meander line turn prototypes and the calculation of the matrices **R** and **G** for the losses accounting (in conductors and dielectric) is given in paper [8].

Calculation of the transmission coefficient module $|S_{21}|$ of each manufactured model using real geometrical parameters is carried out. At first, the influence of losses on $|S_{21}|$ is estimated. For this aim, the simulation without and with losses in conductors and dielectric in frequency range from 10 MHz to 10 GHz is carried out. The internal resistance of the source ($R1$) and resistance of the receiver are accepted to be equal to 50 Ω. When simulating without losses, matrices of the per-unit-length resistance **R** and conductivity **G** were accepted to be equal to zero.

Fig. 4 shows calculated frequency dependence of $|S_{21}|$ for each model (black lines – without losses, red line – with losses) and in Table II summarizes the passbands of all models at level –3 dB over the simulation with and without losses. From the results, it is seen that the passbands of each turn are equal to 1.2–1.3 GHz but in the simulation with losses the passband slightly expands for all models. For example, for turn with s=300 µm, losses give the increasing of passband of 70 MHz, and for s=150 µm of 80 MHz. At the same time, accounting of losses moves the resonances of $|S_{21}|$ to the higher frequencies and decreases the attenuation at the resonance frequencies. For example, with s=300 µm the maximum attenuation with and without losses of –55 and –30.5 dB respectively and with s=150 µm –56.5 and –40 dB.

TABLE I. PASSBAND (GHZ) OF THE MEANDER LINE TURN

s, µm	**Simulation**		**Experiment**
	without losses	***with losses***	
300	1.28	1.35	1.13
250	1.25	1.34	1.13
200	1.24	1.32	1.12
150	1.22	1.30	1.14

Additionally the full-scale experiment to measure the frequency dependence of $|S_{21}|$ of all models by the scalar network analyzer R2M-40 in frequency range of 10 MHz to 10 GHz was carried out. SMA type connectors were soldered to the leads of all turns to connect the models to the measuring channel. For the comparison, Fig. 4 (blue lines) shows measuring frequency dependences of $|S_{21}|$ and Table II summarizes the passbands of all turns at level –3 dB. It is clear from the comparison of the results that the measured and calculated dependences agree qualitatively in range up to 5 GHz. Also, it is seen that the measured dependences have lower passband which does not depend on the separation between the signal conductors of the meander and does not exceed 1.15 GHz. In frequency range higher than 5 GHz there has been observed a number of resonances with the level up to –50 dB. Quantitative discrepancy of the results may occur due to the inexact losses accounting in conductors, particularly radiation losses. At the same time, results mismatching can be explained by the influence of inhomogeneities in connectors and halfturns joint at the end of the turn, which was not accounted in the simulation. The difference of real and simulated values of parameters could also cause discrepancy. Finally, other causes of the differences are errors of the simulation and measuring. Nevertheless, the results in frequency domain together with the results in time domain received previously suggest that the turn of meander delay line allows EE protection against ultrashort pulses by its decomposition into a sequence of pulses with lower amplitudes. At the same time, useful pulse signals with upper frequency limit 1.1 GHz can propagate in a turn of the line with minimal signal waveform distortions.

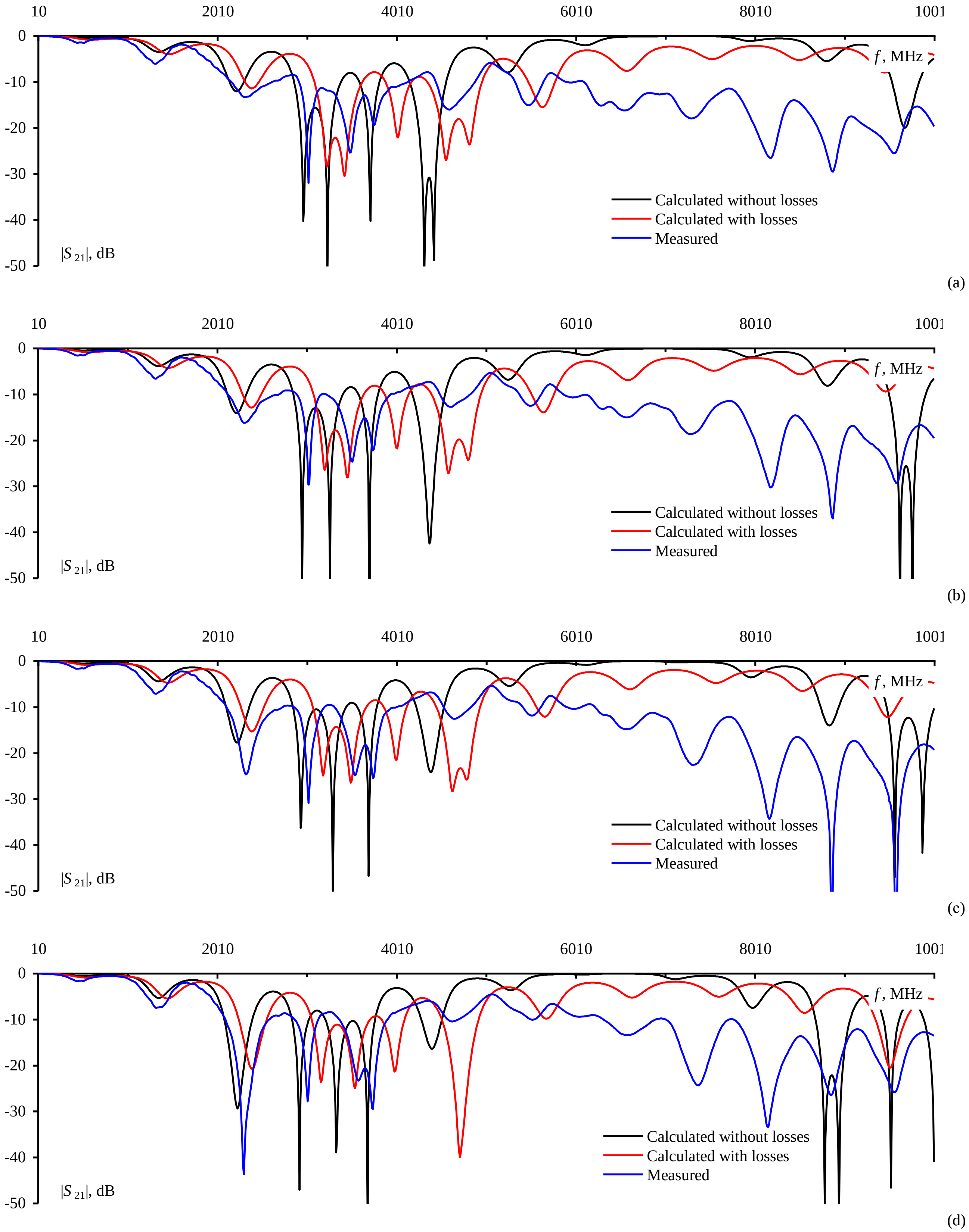

Fig. 3. Calculated (without and with losses in conductors and dielectric) and measured frequency dependences of $|S_{21}|$ for considered meander line turns having various separations s=300 (a), 250 (b), 200 (c), 150 (d) μm

IV. CONCLUSIONS

The paper shows the fist results of the investigations of a turn of meander delay line in frequency domain. At first, for this aim preliminary optimization of the turn parameters have been executed. Then, the printed circuit board with the models has been manufactured and the real geometric parameters have been measured. After that, the computer simulations with those parameters have been executed. The influence of losses in conductors and dielectric on changing of frequency dependence of $|S_{21}|$ have been estimated. It has been revealed that the losses substantially increase the turn passband by 70–80 MHz and move all of the resonances to the higher frequencies and decrease the attenuation on the resonances. Finally, the experimental investigations have been performed and acceptable consistency of the simulation and experiment has been obtained. The estimates about possible reasons for results difference have been made. It is revealed that the manufactured models have lower passband comparably to simulation and the passband does not depend on the separation between the signal conductors and is equal to 1.15 GHz. This suggests that for high-frequency signals with spectrum up to 1.1 GHz propagating in the turn the distortions of waveform in a time domain are minimal. But ultrashort pulses with the duration less than 1 ns will be decomposed into a sequence of pulses.

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