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Frequency characteristics of multiconductor microstrip modal filters

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***Abstract*— Modal filters (MFs) based on multiconductor microstrip lines are investigated for the first time in the frequency domain. The frequency dependences of |S_{21}| up to 10 GHz are obtained. Both computational and full-scale experiments are used. A printed circuit board with prototypes of multiconductor MFs are presented. Two-, three-, four- and five-conductor MFs are investigated. The computational experiment with and without accounting for losses both in conductors and dielectrics was carried out. Comparison and consistency of the results of computational and full-scale experiments are obtained. It is revealed that the bandwidth of considered MFs are about 0.55 GHz.**

***Keywords*— protection device, microstrip line, modal filter, frequency characteristic.**

I. Introduction

Contemporary complexes of radio-electronic equipment (REE) have wide functional capabilities but, at the same time, they are susceptible to electromagnetic interference. Conducted interference is considered to be the most harmful one, as it can penetrate into devices directly through conductors [1]. Modern generators of ultrashort pulses have very high capabilities [2]. Such ultrashort pulses are able to penetrate and disturb the electronics and due to the high power output and short duration. Therefore, it is necessary to improve the protection of electronics against ultrashort pulses.

A technique of modal filtration [3] was proposed for the protection of electronic equipment against ultrashort pulses. This technique is based on modal decomposition of a pulse signal which occurs due to a difference between the modal delays in multiconductor transmission lines. A number of studies [4–9] on the use of multiconductor microstrip lines (MSL) as protective devices against ultrashort pulses have been performed. Results of simulation of MSL consisting of N=2, 3, 4, 5 conductors showed the decomposition of an input pulse into 2–5 pulses at the end of a conductor with the maximum amplitudes of 3, 3.6 and 4.5 times (correspondingly) less than a signal in the near end of a line [4]. Optimization showed that the equalization of the differences between delays of decomposition pulses allows increasing duration of a pulse which is going to be completely decomposed in these structures [5]. In addition, the formulation of the main criteria for optimizing a multiconductor modal filter (MF) has been performed and an example of its optimization by criteria of the minimization of the maximum output amplitude and the maximization of a difference of time delays between the first and the last decomposition pulses has been given [6]. Experimental confirmation of the modal filtering based on multiconductor MSL was performed. For two- and three-conductor MSL, the attenuation of 11.5 and 13.7 times was obtained [7], and for four- and five-conductor – 12.6 and 15.3 times [8]. In [4–8], a heuristic search for parameters was used, but it did not provide the best results. This disadvantage is eliminated in [9] based on optimization of the three-conductor MSL MF using a genetic algorithm (GA) providing the output MF amplitude 13% less than after the heuristic search. However, in [4–9] only one criteria was used for the optimization. Thus in [10] a general objective function for the optimization by several criteria was formulated and a basic optimization criteria are detailed.

Meanwhile, in [4–10] the time response on excitation of only dangerous ultrashort pulses was investigated, while the effect of MF on propagation of useful high-frequency signals was not previously investigated. Therefore, it is useful to study the frequency characteristics of multiconductor MF. It is advisable to start it with consideration of |S_{21}| for MF based on multiconductor MSL in the frequency range. The aim of this paper is to perform such study.

II. Structures and Schemes of Consideration MF

As the object of research, a printed circuit board (PCB) consisting of multiconductor MSL layouts was chosen. Multiconductor MSLs of 2–5 conductors are considered, which detailed research, as well as a full-scale experiment in the time domain, was performed in [7–8]. The cross sections of these lines are shown in Fig. 1 where w – width of conductors, s_i – separations between them, t – thickness of conductors and h – thickness of dielectric of PCB. Schematic diagrams of these MF are shown in Fig. 2.

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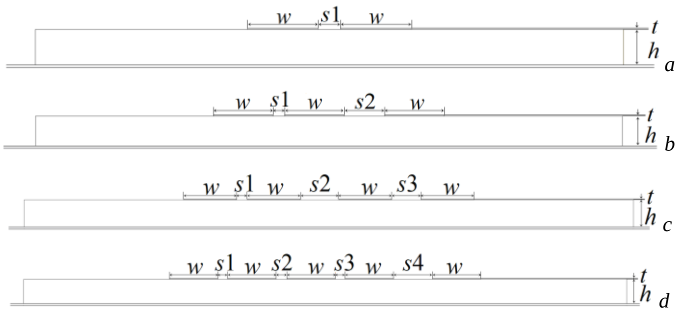


Fig. 1. Cross sections of two- (*a*), three- (*b*), four- (*c*) and five-conductor (*d*) MFs

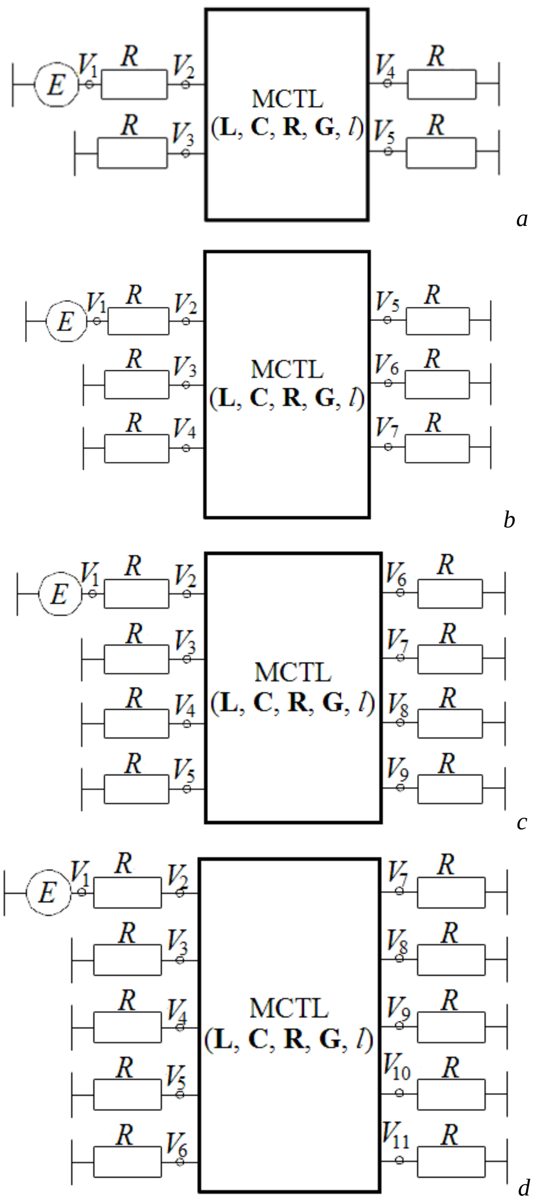


Fig. 2. Schematic diagrams of two- (*a*), three- (*b*), four- (*c*) and five-conductor (*d*) MFs

III. Investigation of Frequency Dependence $|S_{21}|$ of Multiconductor MFs

Simulation of MFs was performed in TALGAT software [11]. It was assumed that a T-wave is propagating along the MF. Losses in conductors and dielectrics were considered. The initial parameters of the cross section are chosen so as to match the impedance of the MF prototypes to the impedance of measuring channel of 50 Ω of the scalar network analyzer R2M-40 when measuring the frequency dependence.

As a result, there are the following parameters of PCB for manufacturing the multiconductor MF prototypes were chosen: w = 1000 μm, t = 18 μm, h = 500 μm, relative permittivity is ε_r = 4.5 and dielectric loss tangent tgδ = 0.017. 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, ε_r and tgδ. 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 two-conductor MF s = 320 μm, for three-conductor – 200 and 685 μm, for four-conductor – 200, 720 и 550 μm, and for five-conductor – 200, 220, 200 и 800 μm, correspondingly. Cross sections of MSL with the specified parameters are shown in Fig. 1.

MF prototypes are presented in Fig. 3. The length of each MF is equal to 60 cm. At the ends of passive conductors of each MF resistors of 50 Ω are connected in parallel. SMA connectors are installed to connect the prototypes to the measuring channel.

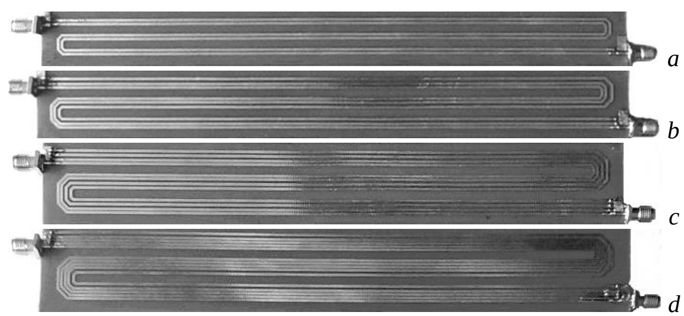


Fig. 3. Prototypes of two- (*a*), three- (*b*), four- (*c*) and five-conductor (*d*) MFs

Calculation of $|S_{21}|$ for each manufactured prototype is carried out. 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. When simulating without losses, matrices of the per-unit-length resistance **R** and conductivity **G** were accepted to be equal to zero. When taking into account the losses for calculating the elements of the matrix **G**, a widely known model of the frequency dependence of the relative permittivity and tangent of the dielectric loss angle of FR-4 material was used [12]. The elements of the matrix **R** were calculated taking into account the skin effect, the proximity effect and losses in the ground plane by the method proposed in [13] and implemented in TALGAT system [14].

Fig. 4 shows calculated frequency dependence of $|S_{21}|$ for each prototype, while Table I summarizes bandwidths of -3 dB for lossless and lossy simulations, as well as those obtained experimentally.

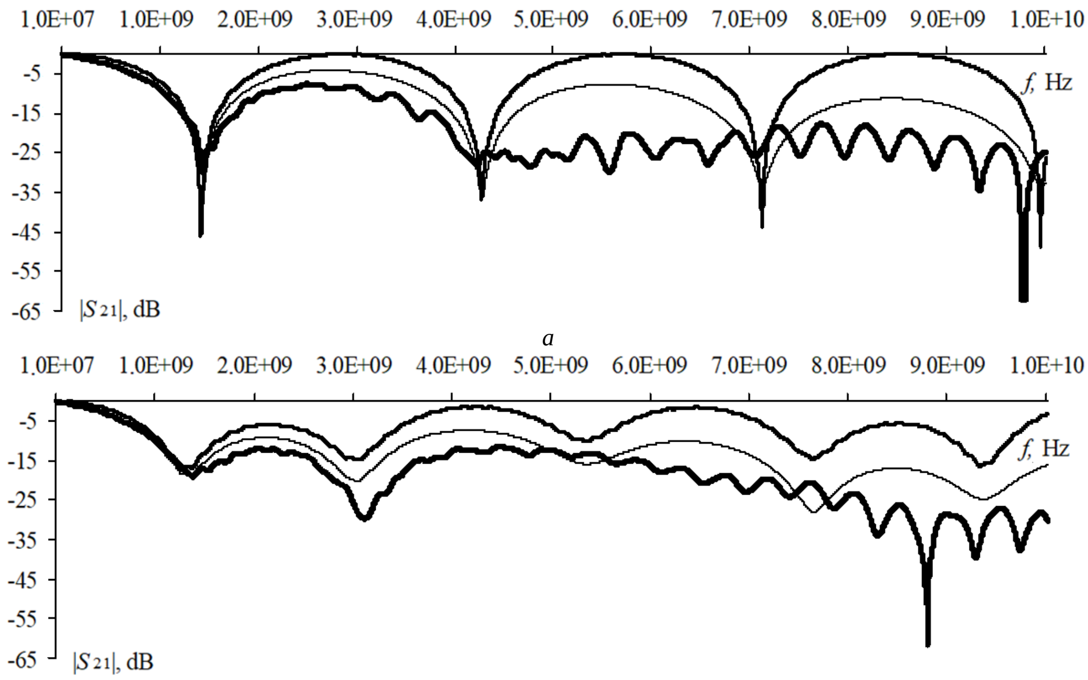
TABLE I. PASSBAND (GHZ) OF MULTICONDUCTOR MF

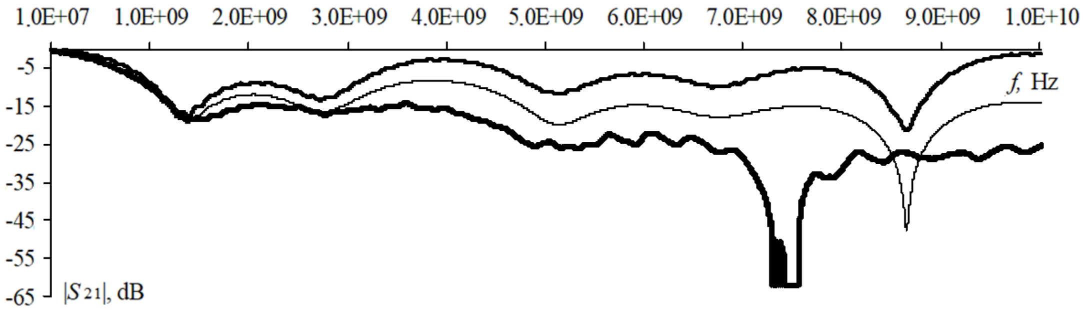
N	**Simulation**		**Experiment**
	Lossless	***Lossy***	
2	0.7	0.55	0.53
3	0.61	0.52	0.48
4	0.64	0.52	0.48
5	0.65	0.53	0.47

From the results, it is seen that the passbands of the MFs are equal to 0.53–0.47 GHz but in the simulation with losses the passband slightly expands up to 0.55–0.52 GHz for all prototypes. At the same time, accounting for losses leads to the decrease of the attenuation at the resonance frequencies. Comparison of the results shows that the measured and calculated dependences are consistent for two-, three-, four- and five-conductor structures up to 4.5, 5.5, 6.5 and 6.0 GHz accordingly. Also, it is seen that the measured dependences have lower passband which does not exceed 0.55 GHz. For a four- conductor MF at the frequency of 7.5 GHz and for the five- conductor MF at 2.4 GHz, a negative extra low level of -62 dB is observed, which is explained by the specificity of the investigated PCB, as well as the error of full-scale experiment. The discrepancy between the results could be explained by the difference between the real and the simulation parameters of the PCB, as well as the presence of discontinuities in the measured structures.

IV. CONCLUSION

Thus, the results of the investigation in the frequency domain for MFs based on multiconductor MSLs were presented. Comparison of results of computational and full-scale experiments for five different structures in frequency range from 10 MHz to 10 GHz was carried out. It was revealed that the manufactured prototypes have lower passband, compared with the simulation, which is about 0.55 GHz. The results in the frequency domain together with the previously obtained results in the time domain allow us to assert, that multi-wire microstrip MF provides protection of REE from ultrashort pulses due to its decomposition into a sequence of pulses of lower amplitude, with a controlled bandwidth of the useful signal.





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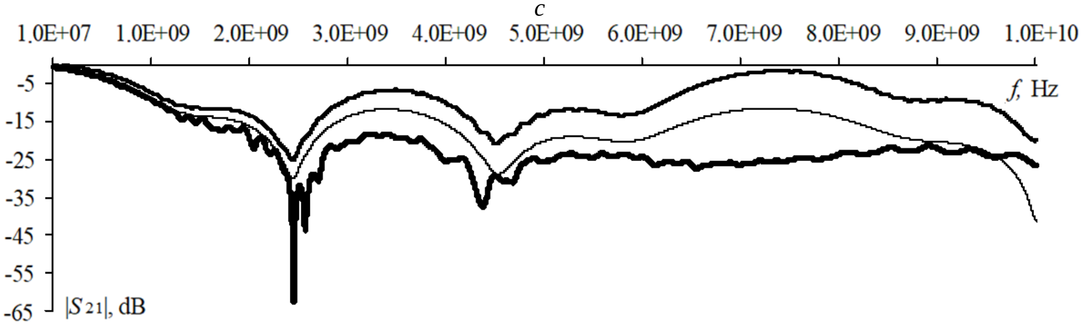

d

Fig. 4. Frequency dependences $|S_{21}|$ of two- (*a*), three- (*b*), four- (*c*) and five-conductor (*d*) MFs, resulting from the simulation without (——) and with (▬▬) losses, and experiment (▬▬)

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